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Toray End-board Loading Station

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Team #1

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Abstract

As part of the University of Rhode Island's senior capstone design program, Toray Plastics (America) Inc. has proposed a design challenge which involves creating an end-board loading station to be used in conjunction with their new automated packaging facility. This report details the design challenges, objectives, and processes which were used to arrive at final design for the end-board loading mechanism for Toray Plastics (America) Inc. This report also analyzes and proves the validity of the solution from all perspectives.

Toray Plastics located in North Kingstown, RI, is a producer of plastics prominently used in the food industry for packaging. The plastic packing materials are shipped out on large rolls and recently Toray has been building a fully automated packaging facility to expedite the shipping process. Toray ships these rolls of material on a large coil with end-boards on the sides to support the coil. The new packaging facility has robots which will remove the end-boards from a designated cart and place them onto the ends of the rolls. The challenge which Toray has presented is to design something to assist operators remove the end-boards from the shipping pallets and place them onto the designated carts in the correct orientation. The solution that has been developed by Team 1 is device which will help an operator move 15 of the end-boards at once. The proposed solution uses an internal gripping mechanism which will be lowered into the center of the end-boards and expand outwards gripping the inner diameter. The device will be lifted by an electric hoist and attached to a trolley system to lift and maneuver the end-boards. The internal gripping mechanism will require no external force and it relies on gravity and the weight of the end-boards to secure and grip the end-boards. Only when the end-boards are placed on the ground and no longer being lifted is it possible for the gripping device to be detached.

The proposed solution satisfies all design requirements and removes the lifting requirements from the operators which dramatically improves ergonomics and safety. This solution also has the potential to significantly increase the rate of production by allowing for the handling of many end-boards instead of one end-board at a time. This solution was the final result of months of discussion and deliberation and this report details the process taken to arrive at this final design. With guidance from Toray Plastics the design team has arrived at this solution and proved the concept's strength through thorough cost, safety, ergonomic, and engineering analysis.

Table of Contents

Nomenclature

$F_{friction}$	Frictional Force	Newton (N)
F_{normal}	Frictional Force in the Normal Direction	Newton (N)
μ_{static}	Coefficient of Static Friction	Dimensionless
$F_{vertical}$	Force applied in the Vertical Direction	Newton (N)
$W_{15\ endboards}$	Weight of 15 End-Boards	lbs
σ	Stress	psi
h	Clamp Height	in
r	Radius	in
$\sigma_{tension}$	Tensile Stress	psi
d	Diameter	in
M_{weight}	Moment of the Weight	lbf-ft
$M_{fapplied}$	Moment of the Applied Force	lbf-ft
$M_{ffriction}$	Moment of the Force of Friction	lbf-ft
$M_{fnormal}$	Moment of the Normal Force	lbf-ft
$MArm_{ffriction}$	Normal Force Moment Arm	Newton (N)
α	Strain	Dimensionless
$MArm_{weight}$	Moment due to Weight	lbf-ft
$\sigma_{compression}$	Compressional Stress	psi
FOS	Factor of Safety	Dimensionless
σ_{shear}	Shear Stress	psi
$Enmax$	Max Pitch Diameter of the Internal Threads	in
n	Thread per inch	
L_e	Length of Thread Engagement	in
D_{min}	Min Major Diameter of the External Threads	in
S_{sy}	Yield Strength	psi
$A_{bearing}$	Area of the Bearing	in^2

F_{max}	Maximum Force	Newton (N)
$\sigma_{Weld\ Allowable\ Stress}$	Stress Allowed in Weld	psi

List of Tables

List of Figures

1 Introduction

Toray Plastics is a company located in North Kingstown, RI, which manufactures rolls of plastic packaging materials. Recently Toray has begun constructing a brand new automated packaging facility to expedite the shipping of these products. To ship these rolls of material Toray attaches large end-boards to the ends of the coils for support and then places the coils on pallets for shipping. To attach the end-boards onto the rolls of material, Toray has purchased robots which will grab the end-boards from a designated location on a mobile cart and place them on the end of the coils. This robotic picking station and the mobile end-board cart are shown below in Figure 1 and Figure 2.

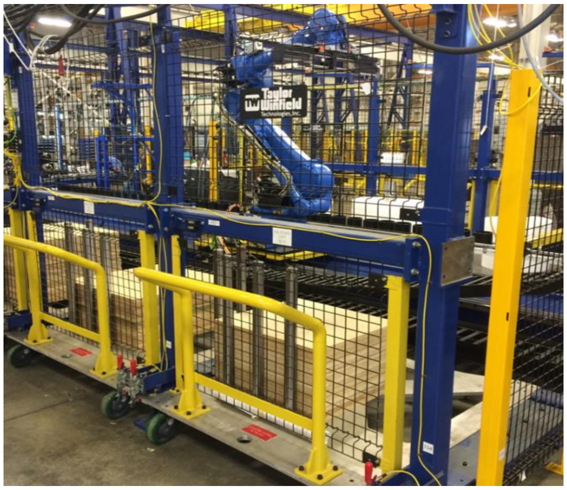

FIGURE 1: Robotic Picking Station

FIGURE 2: Mobile End-Board Cart

Currently Toray is relying on their workforce to transfer end-boards from shipping pallets to the carts one by one. This one process has a bottleneck effect on the new packaging facility and it is slowing down the production rate considerably. This process is also an extremely un-ergonomic practice and is unsafe for the operators. Recently Toray Plastics has proposed a design challenge which involves creating an end-board lifting device to transfer end-boards from shipping pallets to the designated location on the carts for the robots. The device must be a cost effective and safe solution for the operators to use in conjunction with the new automated packaging facility to maximize efficiency.

The moving of the end-boards contains many difficult design challenges, most of which are derived from the variability in the condition and dimensions the end-boards. Toray uses four different sizes of end-boards: 24" x 26", 30" x 30", 32" x 32", and 42" x 42" boards all with a thickness of 1" and a center hole 6.5" in diameter. The end-boards which are currently used are constructed from recycled particleboards which weigh 14lbs for the largest and 44lbs for the smallest. Figure 3 shows a pallet of end-boards, often they are received as shown in stacks of four on one shipping pallet.

FIGURE 3: End-Boards on Shipping Pallet

Often when the end-boards are shipped to the customer, the end-boards will be removed and sent back for recycling and reuse. When the end-boards are recycled they are crudely constructed which lead to high tolerances in the dimensions of each board. The only dimension which is constant is the diameter of the center hole, however in some cases the hole is not centered. When Toray initially constructed this new packaging facility they were completely unaware of this. The original plan was for the robots to pick up the boards with the origin as the center-hole but when

Toray discovered the hole was not always centered, the plans were scrapped and the corner of the cart was designated as the origin.

Throughout this year long project, Team 1 came up with a variety of solutions but after extensive analysis it was decided that an internal gripping mechanism was most aptly suited for solving this challenge. The center-hole diameter is one of the only constant dimensions on the end-board so it was decided that this must be the means for securing and lifting the end-boards. To take advantage of this, Team 1 designed an internal gripping mechanism which is lowered into the end-boards and when lifted, it grips the internal diameter of the end-boards. This design requires no external force and it relies solely on gravity and the weight of the end-boards to make a strong and secure connection to the end-boards. The end-boards are secured with the internal gripping mechanism and lifted with an industrial hoist and trolley system, when the boards are moved to the end-board cart and lowered, only then will the design detach from the end-boards. For this end-board gripping mechanism to be effective the end-boards need to be moved safely, quickly and the design must be able to accommodate all sizes of the end-boards. The design which Team 1 has derived satisfies all of these design requirements and is currently ready for use in production. The objective of this design report is to prove the effectiveness of Team 1's proposed solution through comprehensive cost, engineering, and safety analysis.

2 Project Planning

The initial stages of the process planning process began with a site visit to Toray Plastics of America in North Kingstown. During this brief two-hour meeting, we discussed the specifics of the project definition and the current problems with in the facility. The sponsor also gave us a tour of the facility to give us an idea of how much space is provided for the possible solution. The tour also provided an idea of the current process of lifting individual end-boards and placing them onto each roll. Following the site visit at Toray Plastics, the group brainstormed upcoming deadlines and the preliminary work involved in designing a solution which included but not limited to the patent search, QFD and design specifications. The group used Microsoft Project to divide up tasks and document all deadlines throughout the semester. The group members met each week to discuss the changes in the project plan and rearrange tasks accordingly. Weekly meetings, mostly on Sundays were conducted to progress the project completion and keep team members informed on upcoming deadlines. If there was anything that needed to be assessed or looked at, if materials needed to be collected for prototyping, or research needed to be conducted for analysis, the weekly meetings provided time to analyze it. These meetings were productive and meaningful to keep the group on task. Through email conversation the group stayed in constant contact with the sponsors of Toray Plastics. By doing so, the group could pitch new ideas and receive constructive feedback on the best direction for the upcoming solution. Both sides agreed communication is essential in reaching the end goal and meeting deadlines. After the group generated 30 concepts individually, we met at the Toray Plastics facility to review the concepts and pinpoint the best 3 to continue to research. These three designs were the pallet inverter, the internal clamping, and the external clamping mechanism. The group researched each design in depth and prepared for the fall semester final presentation. In order to visually demonstrate the mechanism that was chosen, the group build an internal mechanism prototype. The sponsor, fellow classmates and the professor offered feedback to our final presentations that was used to improve our design.

The second semester began with selecting the final design to research, build, test and present to the sponsors of Toray Plastics. The design that offered the highest level of quality, manufacturability, cost and probability of completion before the spring semester ended was the internal clamping mechanism. The group met weekly to discuss the specifications of the design through Solidworks. To monitor the design mechanisms, a 3D prototype was designed and built. Additionally, the group purchased materials from McMaster that offered manufacturability and cost savings. Working closely with the URI machinists, the group milled, sanded, the drilled each piece to a high tolerance. During the spring semester the group met with Toray Plastics and sent design changes and drawings as they arose. As the final touches on the design were added, the group brainstormed how to test the material and if additives could increase the weight capacity of the design. With the aid of URI faculty, the group could test the weight capacity of the design with a crane mechanism in the first floor room of Kirk. The group began to prepare for the design showcase by writing a detailed brochure and posture board. Microsoft Project offered a useful tool to manage each individual's progression on the required tasks. The design showcase was a period of reflection. The group could professionally present the hard work of the yearlong project and answer questions that visitors had.

The following Project plan was in place throughout the semester. Microsoft Project offered a quick tool to monitor deadlines and the cross functional development of the project.

		Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1			**End Board Loading Station Research**	**61 days**	**Tue 9/20/16**	**Tue 12/13/16**		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
2			Create Tentative Project Plan	9 days	Tue 9/20/16	Fri 9/30/16		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
3			Sponsor Orientation	3 hrs	Thu 9/22/16	Thu 9/22/16		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
4			**Project Documents**	**33.63 days**	**Thu 9/22/16**	**Tue 11/8/16**		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
5			Problem Definition	6 days	Thu 9/22/16	Fri 9/30/16		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
6			Design Specifications	9 days	Thu 9/22/16	Wed 10/5/16		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
7			Patent Search	4 days	Mon 10/3/16	Thu 10/6/16		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
8			QFD analysis	4 days	Thu 10/13/16	Tue 10/18/16		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
9			Updated Design Specifications	19 days	Thu 10/13/16	Tue 11/8/16		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
10			**Design of Concept**	**12 days**	**Mon 10/3/16**	**Tue 10/18/16**		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
11			30 Concept Ideas	12 days	Mon 10/3/16	Tue 10/18/16		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
12			**Proof of Concept Report**	**24 days**	**Thu 10/27/16**	**Tue 11/29/16**		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
13			Financial Analysis	18 days	Thu 10/27/16	Mon 11/21/16		Griffin Walsh,John O'Shea,Michael Yorio
14			Time Study of Current Process	2 days	Mon 11/21/16	Tue 11/22/16		Garrett Wolf
15			Future Location Designation with flow chart	2 days	Mon 11/21/16	Tue 11/22/16		Garrett Wolf
16			Evaluation of Competition	2 days	Mon 11/21/16	Tue 11/22/16		Griffin Walsh,Garrett Wolf,John O'Shea,Michael Yorio
17			Specifications Definition	2 days	Mon 11/21/16	Tue 11/22/16		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
18			Conceptual Design	2 days	Mon 11/21/16	Tue 11/22/16		John O'Shea,Michael Yorio
19			QFD	2 days	Tue 11/22/16	Wed 11/23/16		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
20			Design for X	2 days	Tue 11/22/16	Wed 11/23/16		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
21			**Product Design**	**24 days**	**Thu 10/27/16**	**Tue 11/29/16**	**18**	Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
22			Drawings	4 days	Wed 11/23/16	Mon 11/28/16	18	Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
23			Engineering Analysis	4 days	Wed 11/23/16	Mon 11/28/16	18	Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
24			Bill of Materials	4 days	Wed 11/23/16	Mon 11/28/16	18	Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
25			Prototype (simulation)	5 days	Wed 11/23/16	Tue 11/29/16	18	Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
26			Report Closure	2 days	Wed 11/23/16	Thu 11/24/16	18	Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
27			**Presentations**	**31 days**	**Tue 10/18/16**	**Tue 11/29/16**		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
28			Presentation 1	8 days	Tue 10/18/16	Thu 10/27/16		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
29			Presentation 2	24 days	Thu 10/27/16	Tue 11/29/16		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
30			Final Report Due	11 days	Tue 11/29/16	Tue 12/13/16		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
31			**Design Solution**	**106 days**	**Tue 12/13/16**	**Tue 5/9/17**		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio

FIGURE 4:The Project Plan for the Fall Semester Deadlines

32	Select Design Method	8 days	Mon 1/23/17	Wed 2/1/17		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
33	**Solidworks Drawing**	**4 days**	**Wed 2/1/17**	**Mon 2/6/17**		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
34	Dimension Design	3 days	Mon 2/6/17	Wed 2/8/17		Garrett Wolf,John O'Shea
35	**Research Materials**	**4 days**	**Wed 2/8/17**	**Sun 2/12/17**		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
36	Order Materials	9 days	Sun 2/12/17	Wed 2/22/17		Griffin Walsh,Michael Yorio
37	**Build Prototype**	**7 days**	**Thu 2/23/17**	**Fri 3/3/17**		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
38	Machine	5 days	Mon 2/27/17	Fri 3/3/17		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
39	**Test Design 1**	**6 days**	**Fri 3/3/17**	**Fri 3/10/17**		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
40	Tensile	2 days	Fri 3/3/17	Mon 3/6/17		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
41	Force Exertion	5 days	Mon 3/6/17	Fri 3/10/17		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
42	**Redesign**	**33 days**	**Fri 3/10/17**	**Tue 4/25/17**		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
43	Test Design 2	5 days	Wed 4/19/17	Tue 4/25/17		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
44	**Presentations**	**35 days**	**Wed 3/22/17**	**Tue 5/9/17**		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
45	Presentation 3	6 days	Wed 3/22/17	Wed 3/29/17		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
46	Design Showcase	3 days	Wed 4/26/17	Fri 4/28/17		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio
47	Final Report	8 days	Fri 4/28/17	Tue 5/9/17		Garrett Wolf,Griffin Walsh,John O'Shea,Michael Yorio

FIGURE 5: The project plan for the Spring semester deadlines

3 Financial Analysis

There are many factors which come into play when analyzing the effectiveness of a solution. When this design was built here were two components which factored into the total cost of production; the actual cost of the materials, and the human resources cost which Team 1 utilized to build and machine the gripping mechanism. In this section all components of cost will be factored in to determine the effectiveness of this solutions from a financial analysis standpoint.

3.1 Materials Cost

The first cost which should be factored into the analysis of a solution is the cost of the materials which were purchased and used to build the product. To account for these costs, a bill of materials for the design was recorded which gives a detailed report of all components which were used as well as the cost and supplier. In this build all materials were purchased from McMaster-Carr because of the good prices and quick delivery times. Table 1 below shows the bill of materials for the design which totaled $264.66. The most expensive part of this design was the raw materials from McMaster-Car which was mostly 1018 stainless steel. This material was chosen for its great cost-strength ratio. All materials were built and machined in the University of Rhode Island engineering machine shop so fortunately there were no associated costs for machinery however if this was not the case, the price would have been drastically increased.

TABLE 1: Cost Analysis – Bill of Materials

Cost Analysis - Bill of Materials					
Item	**P/N**	**Manufacturer**	**Cost/Unit**	**Quantity**	**Total Cost**
High Strength Neoprene Rubber	8599K31	McMaster-Carr	17.56	1	17.56
6ft x .5" Diameter 1018 Steel Rod	8920K155	McMaster-Carr	14.04	1	14.04
3" Diameter 3" Length Steel Rod	7786T36	McMaster-Carr	23.34	1	23.34
1.5"x2"x2ft Steel Rectangular Bar	8910K83	McMaster-Carr	77.35	1	77.35
3ft Steel Tube	7767T62	McMaster-Carr	25	1	25
Steel Clevis Pin W/Retaining Ring	92735A220	McMaster-Carr	7.05	1	7.05
Steel Clevis Pin W/Retaining Ring	92735A260	McMaster-Carr	7.9	2	15.8
Foam Grip Handle	9445K21	McMaster-Carr	10.48	1	10.48
Foam Grip Handle	9445K22	McMaster-Carr	10.48	1	10.48
Hoist Ring	2994T41	McMaster-Carr	55.19	1	55.19
Steel Coupling Nut	90268A125	McMaster-Carr	8.37	1	8.37
				Total Cost	264.66

3.2 Human Resources Cost

The next factor which must be considered in a cost analysis are human resource costs which were accumulated by Team 1 while machining the design in the machine room. In total it took Team 1 11 hours to machine the design which took over two weeks. The following pie chart shows the distribution of hours among the different machines in the shop.

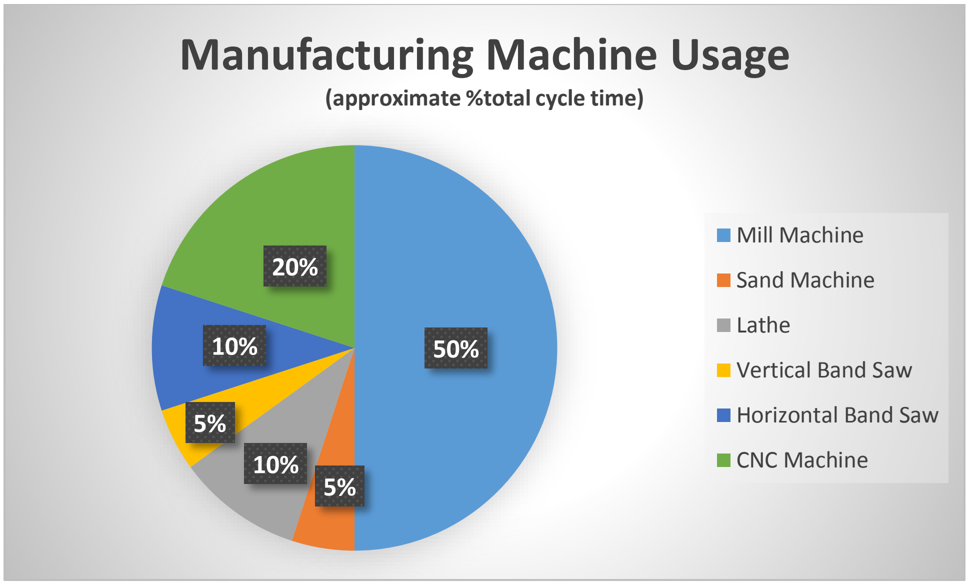

FIGURE 6: Machining Hours

Every hour that is spent working on the design of the mechanism has an associated cost with it as well. There are many ways to account for this but Toray has a personnel cost of $22.00/hour which is to be used to account for this time spent. With 11 hours of machining spent on this design at $22.00/hour the total human resources cost for this design would be $242. This is the cost which will be incorporated into the cost analysis for this design.

3.3 Total Cost

Now that the materials cost and the human resources costs have been defined, the two can be added to obtain a total cost of $506.66. This was a relatively low cost and in the future it could be reduced even further by potentially selecting different materials or using different machines.

3.4 Cost Analysis – IRR

Once the bill of materials and the human resources costs were accounted for and totaled, a cost analysis can be performed to assist in analyzing whether or not this solution is a worthy investment. When performing a cost analysis, the potential savings on a year's basis change according to how much time is saved by incorporating the new design. In Toray's new automated packaging system, it is demanded that the system be able to handle a production output of 1 end-board a minute. If this production rate is not upheld, then the system would be losing money the longer it takes. To accurately determine the cost saving and preform a cost analysis, an accurate time study needed to be performed to assess how much time is being saved. After performing this time study, the following production rates in Table 2 were gathered from measured cycle times.

TABLE 2: Production Rates Time Study

End-Board Loading Mechanism	Number of Operators	End-Boards/Minute
Current Production Method	1	7
Center Gripping Mechanism	1	15

The current production method shown is achieved by using operators to manually load one end-board at a time onto the cart and adjust it with their hands. This method is obviously the longest of the methods and the most labor intensive. The new design which Team 1 has presented will be able to load up to 15 end-boards in a minute and would be operated by only one person and also be able to hit the production goal of 1 end-board a minute. Because of this higher production rate and the associated cost savings in operator work time, the internal gripping mechanism was determined to be an extremely cost solution and worth the investment. This decision was mostly validated from using Toray Plastics' custom Internal Rate of Return model which it uses to determine the legitimacy of a potential investment. This takes many factors into account including project initial capital investment, yearly savings, investment tax credits, depreciation, and income taxes. After inputting these values, the calculator returns an Internal Rate of Return (IRR) percentage. Generally, Toray uses 15% as the benchmark of a good investment, anything over 15% is a good potential investment which will pay off in the long run but anything under 15% is not worth the time or money. Because of the proprietary nature of this calculator these calculations or the program used to calculate them were not permitted to be shown in this report however the IRR values for the Team 1's design was 253% which was extremely higher than the standard of 15%. The high IRR value from the center gripping mechanism was a result of the extremely low initial capital investment of $506.66 and the relatively high saving per year. The savings/year which was input into this IRR calculator was calculated to be around $2,000/year which came from the operator work time savings from quicker production rates.

3.5 Cost Analysis – Cash Flow

Another tool which was used to analyze the cost and effectiveness of this solution was a cash flow analysis. When Toray performs this analysis the time period and cost is spread over a 10-year span. The cash flow analysis takes into account a 10% investment tax credit which Toray receives. It also uses the Modified Accelerated Cost Recovery System (MACRS) which is one of the accounting depreciation standards, in this system the capital cost is recovered by annual deductions over 5 years of 40%. The following table shows the cash flow for the center gripping mechanism.

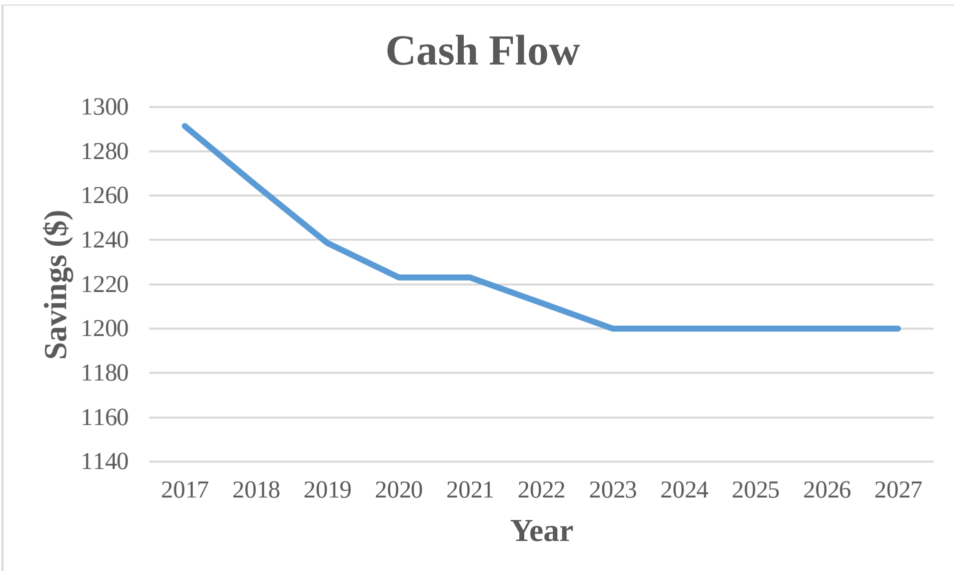

FIGURE 7: Cash Flow

3.6 Cost Analysis – Incremental Profits and Losses

The final tool which was used for a cost analysis was the incremental profits and losses analysis. This tool which Toray often uses was similar to the cash flow analysis except a different model was used. In the incremental profits and losses, depreciation is accounted for with the Generally Accepted Accounting Principles (GAAP) which account for depreciation and yearly taxes in a different differently. Similar to the previous model, the cash flow is spread out over a 10-year period in which the investment will be paid off. The following table shows the cash flow of the profits and losses on a 10-year basis for the center gripping mechanism.

FIGURE 8: Incremental Profits

As shown in both models the center gripping mechanism will more than pay for itself over its lifetime. The IRR value is high enough for Toray to welcome the investment and know for sure that it will pay off in the long run. Both the cash flow model and the incremental profits/losses model justify the initial investment over a 10-year period. The cash flow model predicts that over 10 years there will be a net profit of $14,147 and the incremental profits/losses predicts a net profit of $14,094. After a thorough analysis both models show that the investment in the center gripping mechanism is clearly justified.

4 Patent Search

One of the first steps in researching a design challenge to understand what is currently out in the market or being used in similar situations. The design challenge which was presented by Toray was an extremely unique challenge yet there were still many similar applications which could be looked at as examples and guidance. When first presented with the end-board loading station Team 1 immediately went to the internet to discover existing solutions. One of the most useful tools for this process was the United States Patent and Trademark Office. By using this website much was able to be learned about different approaches people have taken to tackle this problem. Some of the most significant information which was learned in this process was the different approaches which are being used to lift and manipulate coils of material. Despite coils not being the same as an end-board, the issue of manipulating coils from the inner diameter of the coil is a frequent challenge throughout industry. The solution which Team 1 is proving in this design report was not the same of any of the pre-existing patents which were found in the patent search. However, this process certainly helped to identify different solutions and inspire new ideas which have not yet been patented. After narrowing the patent searches the following were some of the most applicable USPTO classes:

- Class 414
- Class 294
- Class 198
- Class 212
- Class 901
- Class 271
- Class 242

Within these patent classes there were a few patents which stood out as similar and useful solutions. The following patents are some of which were similar to this design challenge and were investigated and applied in this concept:

1. Device for mechanically gripping and loading cylindrical objects

Patent #: 6,371,717

April 16, 2002

Abstract: “A device for mechanically gripping, transporting, loading and unloading cylindrical containers of various sizes for attachment to a robotic arm. The containers may be bottles including drinking water bottles. The device includes a plurality of gripping mechanisms for gripping the containers. Support pins are also provided for supporting the rotational motion of full bottles. A system for efficiently removing empty containers from racks and simultaneously loading full containers is also disclosed.”

This patent by Robert Grams and Scott Haddix was a unique patent because it dealt exclusively with the gripping of cylindrical objects from their inner diameter. This patent was mostly aimed towards applications such as gripping smaller and lighter object however this could easily be applied to larger items like the end-boards we are focusing on.

2. Crane hoist apparatus

   Patent #:7,048,491

   May 23, 2006

Abstract: “A crane hoist apparatus and method of use for moving items within, into, out of, or adjacent to an interior of a containerized cargo enclosure causing minimal loss of interior enclosure volume from the crane. The crane includes a first frame with a plurality of beams each having a span, a width, and a depth, the first frame is supported by the enclosure, also a second frame having a beam with a span, a width, and a depth, that is slidably supported by the first frame in a transverse span orientation, with the second frame depth not extending below the first frame depth, the second frame moves in a direction parallel to the first frame span. A winch carriage is slidably supported by the second frame wherein the winch does not extend below the second frame depth, the winch moving in a direction parallel to the second frame span.”

This patent by Werner Windbergs was a useful patent when we were investigating different ways to lift and move the end-boards. The solution which was decided upon was similar to this because the workstation which will be built will have a traversing crane system with a hoist sliding on the frame. This solution allows for the load of the end-boards to be supported and lifted with the hoist and allows for the operator to move the end-boards around the workstation.

3. Quadruple gripper

   Patent #:4,682,806

   July 28, 1987

Abstract: "A central base of a gripper is adapted to be attached to a robot wrist flange. Carriage rods and stabilizing bars extend outwardly, on both sides of the central base. Sliding carriages, which move along the carriage rods on linear bearings, each carry two flexible urethane grippers which are capable of expanding and gripping a part from the inside when the flexible grippers are pressurized. Each carriage when slid from a first position to a second position by an air cylinder, causes the second flexible gripper of a carriage to occupy the same position in space that the first flexible gripper of the same carriage, previously occupied." This patent by Bradley Thomas was similar to the first patent in that it deals with the securing of cylindrical objects from the inner diameter. This patents attacks this problem in a different way however. To secure a load from the inner diameter, this patent is for pneumatically controlled gripping arms which expand when pressurized. This was a different but still extremely useful patent for Team 1 and was considered during the design stage.

5 Evaluation of The Competition

Research into current designs available on the market for similar mechanisms caused the team to analyze a pallet inverter. One company that offers a mobile pallet inverter with the specifications of our project was Vestil. This company is a massive distributor of material handling equipment with over 1,000 different product lines. One product line that closely relates to our project is the Vestil PPI-90 Fully Powered 2000 lb Low Profile Portable Pallet Inverter. This forklift attachment has a load capacity of 2000lbs, and a clearance of 31.5''. The mobility of the forklift will allow the operator to combine two processes and speed up the loading of carts. The operator can remove incoming pallets directly and transport the pallet with 30, 1 inch thick end-boards to the automated system without downtime or inefficiencies. The cost for the product is in the range of $13,000 (Vestil PPI-90 Fully Powered 2000 lb Low Profile Portable Pallet Inverter).

The closet the team came to finding a solution similar to the project was from a company called R on I. This company was based out of Charlotte, NC. This was a company that specialized in making aluminum rails to suspend a mechanical lifting device. They also are distributors of automated lifting devices for long rolls and expandable shafts. Initially, this is the direction the team was heading in, and wanted to seek more information. After talking to their engineers and explaining the problem at hand, R on I had a similar solution to what was needed. An expandable steel shaft went into the inner diameter and when the handle was release, spring loaded metal gripping teeth bit into the sides of the material in contact. This method was capable of picking up 640 lbs. Which was about half of the thirty end boards needed. The one problem was the expandable spring loaded teeth were not located at the bottom. This would mean the bottom end board could not be grabbed to load onto the carts. The engineers at R on I are working with their machinist's to see if it is possible to move the teeth to the bottom of the shaft. By doing so, this would ensure every board would be grabbed, and the top end boards would be held up by the bottom five boards in tension from the expandable shaft.

6 Specifications Definition

The general design specifications for this design challenge came from multiple sources. The three main and most important aspects were as follows; the design needed to conform to all safety codes, the design needed to allow for higher production rates by lifting up to 15 end-boards at once and the design needed to be flexible enough to secure all sizes of end-boards and needs to be accurate enough allow the end-boards to be lifted by the robots. All of these customer requirements were understood and transcribed into engineering parameters which are outlined in each section. Each design specification was rated 1-10 for priority and importance, 10 being the most important.

6.1 Safety Code Specifications

After meeting with the sponsor, Toray Plastics, the specifications for the design were defined and the sponsor made it very clear, OSHA (Occupational Safety and Health Administration) and NIOSH (National Institute for Occupational Safety and Health) requirements were to be met. Currently the system in place has operators violating parts of OSHA's code which states that no person should be lifting over 50 lbs. By forcing the operators to lift the end-boards one at a time, they were often attempting to pick up multiple end-boards at a time which was much heavier ta 50 lbs. To fix this issue, Team 1 began working on a station with an assisted lifting mechanism which would be essential to worker safety. This was found true by NIOSH through a mathematical model that helps predict the risk of injury. The model is based on research into compressive forces needed to cause damage to bones and ligaments of the back. Due to the lifting duration, recovery time, twisting motions, repetitiveness, and load weight manually lifting each end board had a poor classification. This design specification of being up to code by regulating standards was very important to Team 1 to provide a safe work environment for the operators using this design. Below, Table 3 outlines the safety design specifications which Team 1 derived from the desires of Toray Industries in order to conform to all safety agencies.

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TABLE 3: Safety Design Specifications

Design Specification		
Parameter	Value	Priority
Operator Lifting Limit	< 50lbs	9
Cycle Time	< 7/end-boards/minute	7
Hoist Lifting Speed (fpm)	8	3

6.2 Production Rate Specifications

After meeting with the sponsor several times, the design specifications were clearly laid out. The pickup rate of the end boards had to be greater than their current method, which when timed, averaged around 7 end-boards a minute. The new automated packaging system would keep up with that demand and it was the team's task to beat that. As long as Toray can load end-boards into the system faster than the machine packages and uses them, Toray was satisfied. Below, Table 4 outlines the production rate design specifications which Team 1 derived from the desires of Toray Industries.

TABLE 4: Production Design Specifications

Production Design Specification		
Parameter	Value	Priority
Workers Required to Operate	1	7
Lifting Capacity	15 End-Boards	5
Cycle Time	< 7/end-boards/minute	7

6.3 Accuracy and Flexibility Specifications

The other aspect of our design which was also constrained by design specifications was the placement of the end-boards onto the cart. Because the new automated packaging system uses a robotic arm to pick up the end boards, the end-boards needed to be in a very specific location for the robot to successfully pick it up with its robotic arm which originally only had a tolerance of +/- 0.25”. The drawing for the robotic arm is shown below in Figure 9

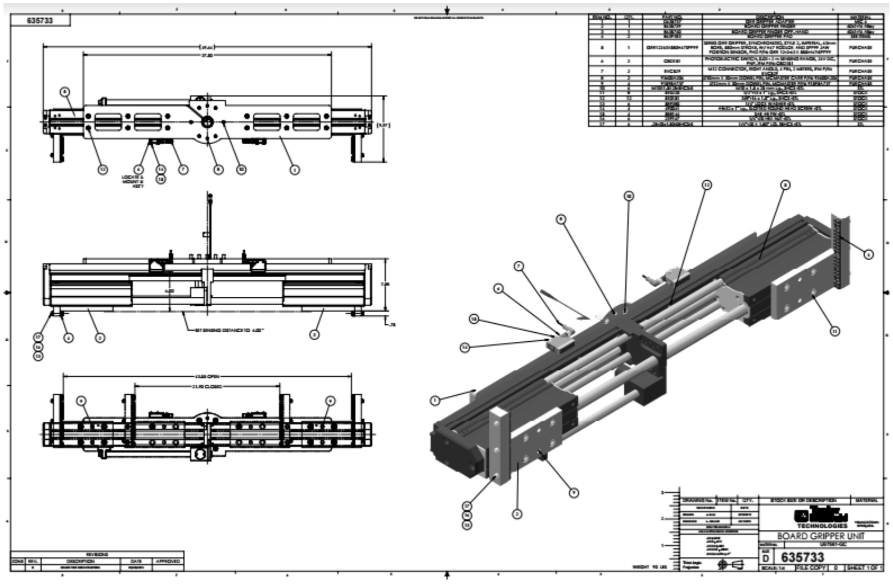

FIGURE 9: Robotic Clamping Mechanism

This tolerance was initially very low so Team 1 was certainly concerned at first however after Toray's engineers ran some tests, it was realized that the tolerance was much greater and realistically allowed for the end-boards to be misaligned by a couple of inches for the robot to successfully pick it up. In the end Team 1 decided on a tolerance of +/- 2 inches to be safe.

In addition to the above specification our design was also constrained by the fact that it needed to be able to lift all sizes of end-boards. In total there were four different sizes of end-board all of which had different weights. The design specification which we were given demands that the design be able to accommodate all sizes. For this reason, Team 1 decided to design a device which secures the end-boards on the internal diameter which is the same on all end-boards regardless of size or weight. Table 5 outlines the accuracy and flexibility design specifications which Team 1 derived from the desires of Toray Industries.

TABLE 5: Flexibility/Accuracy Design Specifications

Flexibility/Accuracy Design Specifications		
Parameter	Value	Priority
Accuracy of End-Board Placement	+/- 2 Inches from Corner of End-Board	8
Min Bottom Clamp Distance	5 Inches	5
Max Bottom Clamp Distance	6.5 Inches	5

6.4 Engineering Requirements and Specifications

The table below displays every parameter and specification which were defined by Team 1 to successfully accomplish the design challenge which Toray industries had presented.

TABLE 6: Engineering Design Requirements and Specifications

Engineering Design Requirements and Specifications		
Parameter	Value	Priority
Operator Lifting Limit	< 50lbs	9
Cycle Time	< 7/end-boards/minute	7
Hoist Lifting Speed (fpm)	8	3
Workers Required to Operate	1	7
Lifting Capacity	15 End-Boards	5
Cycle Time	< 7/end-boards/minute	7
Accuracy of End-Board Placement	+/- 2 Inches from Corner of End-Board	8
Min Bottom Clamp Distance	5 Inches	5
Max Bottom Clamp Distance	6.5 Inches	5
Vertical Lifting Force	>500 lbs.	5
Mount Type	Trolley	6

6.5 Other Specifications

Another aspect that was explained later, was finding the most logistic location for the entire end-board loading stations. A few meetings and walkthroughs were needed to get a better understanding of the facility workflow, and usage of each individual component. A 20 ft by 20 ft section needed to be assigned for this station. Factors such as distance traveled were taken into consideration. It was inefficient if a worker had to travel with a loaded or unloaded cart 90 seconds, when the station could have been positioned closer. The best solution was a station fifty feet from where the carts are plugged into the automated packaging system. This was the safest option, without multiple workers constantly traveling under suspended beams and hoists. This area is out of the way from where the final packaged product is unloaded, and the assembly lines were the packages are inserted onto the trucks via forklifts. The assigned work space will be the most time efficient solution, as it is the closest possible location to load the carts.

7 Conceptual Design

The brainstorming phase was essential in creating and developing a solution that satisfied all of the needs of Toray Plastics of America. Some of the concepts are ideas and portions of an entire assembly process, with certain key essential aspects to make the production flow work properly. The below section are there concepts generated by team one.

7.1.0 List of Concepts Generated

7.1.1 Mike Yorio's Concepts:

1. The first stage of these designs concepts will consist of a wide feed conveyor holding a line of pallets as they are originally received. The pallets will be placed onto the conveyor by the forklift operator; the additional length of the conveyor makes room for multiple pallets. The idea behind this is to give the operator time to transport the stacks from the racks and bring them over to the system. The pallets of end boards will move down the conveyor until it is their turn to move into positioning onto a platform.

2. The loading platform will be equipped with sensors. They will be able to tell the computers when the end boards are finished unloading and tell the system that another pallet is needed to move forward onto the platform.

3. When the system is done unloading the end boards there will need to be an operation to discard the empty pallet. A second conveyor can be used to carry the pallet off of the platform and out of the system.

4. In a similar way to cut down on designs costs, the conveyor could be replaced by a set of rollers. Instead of spending money on an automatic conveyor system with a sensor setup, to oversee the process, the rollers would be man operated. This is beneficial due to machine errors that take place in the workplace. Dust accumulates on sensors that could throw off the timing while loading the pallets onto the platform. Having a human operator would eliminate the chance of buildup early on in our design.

5. After the system is finished unloading the end boards the operator will be able to pick up the empty pallet and remove it from the system

6. In each of these designs the end board carting system, already developed by Toray, will need to be secured and locked into place. This will assure that there is no movement in the wheels of the cart when the mechanical devices are loading the heavy sheets of end boards onto the cart. Wheel locks will be used to assure no movement during loading process.

7. Another method of locking the cart in place is having two locking brackets. The cart will be able to be pushed into locking mechanism with a release switch.

8. The suction cup method starts when the pallet gets positioned onto the platform. From there, a hanging arm consisting of four suction cups will drop down to pick up individual end boards. Toray uses a variety of end board sizes ranging from 24''x24" to 42''x42''. In order to eliminate time consuming changeovers the suction cups extensions will be positioned within the 24'' range but still need enough force behind them to lift the heavier sizes. When the boards are picked up the hanging mounts will move down a track of about 5 ft. and hang above the loading cart. When in position it will lower them down onto the rack close to the positioning needed.

9. To assure a 1/4'' maximum displacement on the cart there will be two hydraulic push-arms located at the front and side of the cart. After each board is lowered a sensor will signal the arms to initiate and push the boards back against the side supports. This method is a good cost efficient way to secure the boards and get them into the automated system.

10. One of the main concerns the team had was getting the boards into the right positioning so the mechanical arms being developed in the automated system will have the correct distance to grab the end board and put them onto the spindle. Team 1 believes the hydraulic arm system will be sufficient but another approach would be to use a lowering rack. This rack would sit between the hanging suction-cups and the locked loading cars sitting on the floor. Instead of the cups coming all the way down to the cart it will only have to drop a foot or two to deliver it the

loading rack. The frame will consist of four edge supports with lowering clamps. The suction cups will place the end boards onto these clamps, using a variety of sensors, it will lower the boards down onto the carts in an organized manner that will be within the play of the automatic arms.

11. Making sure the end boards are in specific alignment of the cart is a vital part of the problem statement. Toray has attached three metal bars in the back and side of the loading cart to help the mechanics align the sheets. Other then two sets of mechanical arms to positing the boards one corner bracket can be used. A hydraulic extension attached to a square bracket with the length of 30" (length of 30 end boards on a full cart) will be used to pull the stack of boards vertically into the corner of the loading carts pushing up against the metal supports.

Hydraulic Raising Methods

12. The pallets of end boards will move down the conveyor until it is their turn to move into position on the platform, where the hydraulic raising system will start. Above the platform will be an opening that will allow end boards to pass through as they are raised. A sensor located above the opening will state when the end boards are in position. After they are raised a mechanical arm will initiate and push the top board off of the stack and onto the cart, which will be locked in place, until it hits the back metal supports. To the right of the cart there will be an additional arm that pushes each board to the left support of the cart to assure correct positioning for Toray's new automated system. Another sensor located at the opening will keep a number count and will stop when it hits the desired number of thirty.

13. Another altercation of the hydraulic raising method would be to raise multiple end boards at a time. Due to the static friction and overall weight of the material moving thirty at a time is not applicable. With the use of various sensors the team could format them to be able to read when five end boards crossed the platform plane. After the five are in position the hydraulic arm will come and push the boards off the stack and onto the cart. The arm to the right could then come and get the boards into place.

Center Hole Method

14. For this method the initial steps will continue to be in effect. The pallets well be admitted into the system with multiple stacks lined up on the conveyor/roller assembly. When the pallet gets situated in position there will be a mechanical arm that comes down sliding into the center hole of the end board. There will be a circular expandable device split up into four quarter circles that will expand and grip onto each individual end board. From there the device will lift the sheets and transport them along the horizontal path of the rollers above only moving a few feet until it positions itself above the locked loading cart.

15. The individual aspect of this method is in effect because the center holes are not perfectly aligned on the end board. This means that when they are brought into Toray in stacks there is not a perfect circular hole going through the whole assembly. Using a thinner hydraulic pipe to insert into the middle will work, by doing further testing to expand and align the holes if the devices pass through two-three boards at a time. When the apparatus transports the sheets over to the carts and lowers them into place they will not be in a neat stack. Two mechanical arms will be needed at the front and side of the cart to align them in a way such that the automated system will be able to grab them off of the cart.

16. The hydraulic arm that is used to pickup the end boards from the center of the boards will need to be on a track above of the assembly. It will need to be able to move down a horizontal track from the stack of the end boards to the cart.

Automated Arm Method

17. The first stage of Toray's automated system incorporates a mechanical arm that is used for taking the end-board off of the loading cart and installing them into a racking system for shipment. These same arms can be incorporated into the stacking process with less function. When the pallets are set on the platform the arm can be located in-between the conveyor belt and the loading cart that is locked into place. The precise movement of the arm will assure that the

end boards will be loaded up to organize specification. With the accuracy of these arms there will be no need for any other mechanical devices to center the sheets.

Hoist Method

18. A hoist method could be another way to transport end boards off of the pallets and onto the carts. Hoists are very common in manufacturing facilities. A four sided corner clamp will be able to lock multiple end boards and lift them onto the cart.

19. The hoist could also incorporate some aspects of the center hole method in the design. The hoist cable can be lowered into the center of the end boards. From there, the operator would need to reach in and secure four flat metal posts in-between the sheets of wood. Similar to a treble hook setup, the hoist could be used to raise the end boards and place them on the cart. The two mechanical arms on the front and side will be used to position them into the corner of the cart.

20. The simplest hoist method would be to use a hoist system for bulk bag material referenced above. Rope supports can latch down on each side of the end boards. From there they can be lifted.

Second Initial Loading System

21. The next following concepts will use a different initial staging to load the end boards. It calls for a horizontal loading method where the sheets will be placed on their sides so they can be developed into the system. This will be beneficial because the smallest size end boards are brought into Toray in stacks of four per pallet. Having the boards be received this way makes it very difficult to unload in a mechanical way.

22. This concept will work by having a staging station with slots that the boards will fit into. The slots will be connected to a rotary chain-like device that will circulate as the boards are

being unloaded. It will have enough space to fit multiple pallets of end boards and allow the loading system to be placed into positioning without having to stop the line.

23. Create a hydraulic clamping system that will be used to unload the end boards from the horizontal loading system. A mechanical arm with a 90 degree rotation will be used to transfer the boards onto the cart.

24. A suction cup method could also be applied with the horizontal loading method. Similar to the hydraulic clamping system when the suction cups are in place there will be a 90 degree rotation ball joint. The mechanism will rotate down and release the end board onto the cart.

25. Another means of unloading the end boards is having a mechanical arm extension that can expand rotate and release the board onto the car in one horizontal motion.

26. From the horizontal loading system a mechanical arm can be used to push the end boards into thirty vertical slots. Once the thirty channels are filled a massive clamp can be used to squeeze the stack and place them onto the loading cart.

Alternate Methods

27. The end boards can be brought to the loading cart using a means of a mechanical incline conveyor. The operator will remove each end boards off of the pallets and onto the conveyor. Sensors will need to be used to see where the sheets are located. When the system is ready to unload the end board it was transfer it onto the cart and then adjust the height to discard the next board on top.

28. The end boards can be loaded directly onto the cart by an operator with a similar concept to a car scissor jack. This is a method that would use mechanical advantage and be implemented in Toray’s facility. It is efficient because there will be minimal mechanical failure that would slow down the automated process.

29. A pallet jack could be used to move the end boards into position. From there a mechanical clamping device can be used to assist the operator to lift and move the end board onto the cart into position.

30. The suction cup method could also be used in this respect. The pallets can be brought over to the workstation using a pallet jack. From there a mechanical suction cup lifting device can be used to lift and transfer the end boards off of the pallet and onto the loading cart.

7.1.2 Griffin Walsh's Concepts:

1. Gravity fed: adjustable slide composed of rollers that can be extended and moves vertically, push cart up onto raised platform, slide end boards from the top down (therefore, human inspection of each end-board can ensure condition prior to manually sliding the end boards onto conveyor-like slide)

2. This is a concept that adds an attachment to lift truck- pinchers at an angle that won't interfere with the current end board cart design.

3. Incorporate a rotating crane, with adjustable claw like attachment that can fit the 4 end boards in use, fits on the outside of the end board.

4. Another aspect of a rotating crane, with suction cups oriented on a flat platform that when near the top end board will pick up the end-board and can rotate 180 degrees with the end result releasing on the automated cart.

5. This concept still incorporates a rotating crane, with adjustable claw like attachment that can fit the 4 end boards in use, it fits on the inside face of the end board and outside face.

6. Incorporate two traverse hoists in a straight line (each with one suction cup) running from the end board delivery site to the automated cart that can vacuum one end board triggered by a human that will first inspect the top end board of the rack and if conditions are met it will initiate

the vacuum process and allow transportation to the end board cart (only permits one end-board at a time).

7. Involve multiple groups of two hoists mounted from the ceiling that will run on a track in an oval fashion and will pick up the appropriate end boards and drop them off at the automated site (run continuously, involves 2 people, 1 to attach the vacuum cups to the proper end board, and 2 release of end boards to the cart).

    a. Add flexible hoists that have a range of motion in the vertical direction so the hoist can be lowered to the appropriate cart height.

    b. Add foot pedals to the automated cart site that will allow the cart to travel up/down to the appropriate height of the incoming end board.

8. Traversing a hoist to a conveyor with rollers, having end boards slide to the cart on rotating bands with incremental markings for each end board, using minimal speed, which would allow time for human inspection of the end boards.

9. Implementing an automated traversing hoist to a conveyor with rollers, the end boards slide to the cart on a rotating band with incremental markings for each end board. Again using minimal speed, and add a camera that will take digital images of each end board for inspection of the conditions.

10. Another concept would be change the cart design by adding a sliding drawer on the top face (closest to the lowest incoming end board). Next, unload end boards onto the drawer or tray (that is in the open position) and then manually push the tray into place.

    a. Add a lock safe device, to ensure that the end boards are secured when the tray is in closed position.

11. A different potential option would be to unload the end boards onto a pusher that slides the end boards into the corner of the cart.

    a. Example: arcade coin machine game.

b. This solution requires that the end boards are received in stacks of 30.

12. Another option would be to add a machine that can push the top end board and is adjustable to slide vertically; a support must be included on the backside of the exiting end boards to allow travel only for the top end board that has been inspected.

a. The end boards that have been pushed can travel on a conveyor of rollers.

b. The end boards that have been pushed travel onto cart that is maneuvered by foot pedal (or spring).

c. Requires knowledge of the frictional coefficient of the end boards

i. This coefficient must stay relatively constant

ii. The end boards conditions, in terms of surface finish and material composition must be held constant.

13. An ergonomic solution would be a fork lift attachment known as a pallet inverter, that has two flat sides and an adjustable fork. This design is currently used in industry, the process is simple and is as follows. Pick up the skid with the fork (two tongs on the fork lift), use automated system correlated the pallet inverter that will rotate the tongs of the fork lift 360 degrees. At the end of 180 degrees when the skid is now the topmost face, remove the skid and permit the final 180 degrees of motion to complete the rotation.

a. There are many current videos which implement a pallet inverter for a D45 forklift.

14. Another concept that should be considered would be to add pegs to the end board final loading cart that will permit stability and provide an additional mean of reference, as opposed to the current design in which case the end boards have to be positioned and oriented with only the right corner as a reference.

15. Similar to the concept above, the fork lift attachment should have a carton clamp and impedes the stack of end boards similar to pinchers.

a. One method would be to have flat face of pinchers.

b. Another method would be using “L” shaped pinchers that slide under the lowest end-board.

16. A different possibility would be to add a belt to the cart that can be pinned down to ensure that the end boards are securely fastened.

a. Example- pressurizing cylinder in fire suppression.

b. One could manually drop a pin into a slot and allow the four end boards to have appropriate slots, each being measured.

17. One concept that would help ease the inspection process would be use of good/bad end boards with a sensor to filter out whether appropriate conditions are met.

a. One question that remains is if there is a specific area on end board that is of failure (i.e.: chipping in right corner, fracturing of the concentric hole).

18. Adding a workstation that is comprised of multiple components, a conveyor belt that is dimensioned with incremental dividers of the maximum thickness of the end boards that can move vertically and release one end board onto a conveyor, in which case digital images are taken, and an operator presses a good/bad button that will signal a swing to open or close and the end board will travel down one of two paths.

19. Another concept that can be incorporated is the end board cart locks into a track, instead of free motion that travels to and from the automated site and requires human force.

20. As mentioned above, the end board cart locks into a track that is automated, with lock safe technology (a green light will illuminate if and only if the cart is in the closed position inside of the gated automated cage, completes a circuit). A handheld device for operators can be used to allow motion into and out of the cage.

21. Another aspect is dividing the process into two steps, one being preliminary of transferring end boards to automated system. An operator inspection of the entire delivered end board set would be helpful in the full process. Good condition end boards will go to a marked area, and bad condition end boards to another marked area. The next step would be to move each good condition set to the automated system.

22. Another concept is to have a “roller coaster “like track that runs in an oval shape on the floor, transfer stacks of 30 end boards onto the track.

a. Multiple tracks run to/from cages from the delivery site to the cage.

23. One can also add a pivoted arm to the end board loading cart that will ensure all the safety precautions are met, the arm will have the capability to swing up-open and swing down-closed.

24. Alternative to the above solution, place a low friction, low static material between skid and lowest end-board in stack.

25. A different potential option would be to drill additional holes into the end boards to allow the cable of a hoist to be passed through and a fasten to be attached on the underside, lifting the stack of end boards and push with the traversing hoist to the end board cart.

26. The group has been in contact with the end board suppliers. They control the quantity and condition in which the end boards are received. Having each supplier receive end board stacks in multiples of 30 and to add an additional step, having the distributer place a divider (sheet between stacks).

27. Another alternative solution would be to add adhesion to pallets, use crane with flat face to pick up the end-board (i.e.: Velcro).

28. Flip the stack of 30 end boards to pallet in rotation method.

29. This concept would use air pressure (i.e.: air hockey table) to lubricate the end boards (in contrast to the conveyor with rollers) decreasing the static friction coefficient making each end board easier to slide.

30. The last concept is to use high air pressure to extract the end boards to the cart (blow boards onto cart). Exerting an equally distributive force to ensure no damage is done to each end board.

7.1.3 Garrett Wolf's Concepts:

1. Team 1 is envisioning an automated system with an assisted personal station for most of the concepts generated. At this station the person will quickly select what size end board will be picked up and if it is defected. The system has the potential to be fully automated with a person only pausing the system if they encounter a problem. The user would select a button for defected parts on the display as that board is separated into a different pile.

2. This concept is the layout and estimated space needed for the end board loading station. After reviewing drawings and layout plans the team decided a space of 20 feet by 20 feet will be necessary, to include all aspects such as three additional loading carts, room for pallets to be positioned after being received off the trucks. This space would optimize efficiency.

3. One concept that is very possible is a central pick up method powered by hydraulics. Each particle board is one inch thick, with a central hole diameter of 6 ½ inches. This method can either pick up one or multiple end boards at a time.

4. Similar to the last concept, a pinching arm can come down and grab the outside edges of each end board. Again, these arms will be long enough to pick up any requested amount of end boards, from one to thirty. This arm would come down vertically and travel in the y-axis plane.

5. Another aspect that needs to be taken into consideration would be using a robotic arm to pick up the end boards from one of the two selected pallets on the floor. The concept of two pallets is to increase the flow and efficiency of incoming pallets. This also allows the workers to load up and plan ahead for different pallet sizes and allows time for someone to load/unload a pallet while the robot arm is unloading from the adjacent pallet.

6. After the arm has successfully picked up the particle board from the pallet, it has two options. The first option is bringing the end board to the cart. This is a critical aspect, making sure the board is placed in the zero-origin point for the automated packaging system robotic arm to successfully locate each end board.

7. In order for the robotic arm to off-load the end boards in the same location every time, the loading cart has to be stationary. The moving cart with four wheels has to be locked into place. This will reassure the same spot of origin for every board. This loading dock will be similar to parking a car in a garage with much tighter tolerances. Sensors will be used to inform the robotic arm when a cart is locked into place. Levers on the back end will push the cart to the most upfront position. Toray has a similar system in place to secure the carts on the other end of the operation, when the cart is engaged in the automated packaging system.

8. Another concept that needs to be taken into consideration for the design is if the particle board is a defect, the robotic arm will bring the end board to a scrap pallet instead of on the loading cart. Hitting the defect button will allow this action to take place.

9. A different method is to pick up the end boards by the center cut out hole in the boards. This method is slightly more labor intensive, having to move and reposition the robotic arm every time.

10. Alternative to the concept described above, the internal shaft would lift multiple end boards at a time. The designed hydraulics would have to be redesigned to lift heavier loads, increasing the spring force. A design constraint would be that not all the 6 ½ inch hole diameters are centered on each particle board. One option is to talk to the vendors to tighten up their tolerances to ensure the hole locations are more central. Another option is to decrease the shaft diameter that enters the center holes, to allow room for the overlapping boards. Having a small insert diameter that expands upon request to firmly grasp multiple end boards is a very practical solution.

11. To detect defects, a concept has to be thought of to examine each board. A vision system that automatically inspects end boards to a pass/fail requirement. It would be very time consuming for a worker to individually inspect each particle board prior to moving it to either the moveable loading cart or a scrap pile on a separate pallet. After visiting Toray it is clear that most of the defected boards are due to miss handled end boards resulting in chipped corners. There would be an automated sensing system to ensure sharp corners and no chips, which would ultimately increase production time. There are many current solutions in the field using this technology. Researching one that would fit this specific application would be crucial.

12. This concept is a different method than the ones described above. This would be a flat insert piece that would slide under the 30th end board on the pallet. This allows space for previous concepts to operate. A pile of thirty end boards will be heavy with a high static friction coefficient. This device would have to withstand upwards of 1,000 pounds of end boards. This insert device would angle up the boards allowing for a fork lift method to pick up all thirty boards at one time. It would consist of very thin, non-sharp material to ensure no board was damaged. The extension would be hydraulically powered.

13. After the design of the concept listed above was implemented, and the expanded shaft is in place, it allows for a two arm fork lift to pick up the thirty end boards at a time. This is critical because the end boards come in on pallets of fifty, however the cart can only hold thirty end boards. This insert will be placed in the correct location to ensure the forklift picks up only the required number of end boards. This is a very efficient way for a two prong system to move thirty end boards off the pallet. This arm would be manually controlled, because the load size alternated per pallet.

14. Another design concept is a different insert piece to separate the thirtieth end board from the thirty first board. This is a clip on attachment that is inserted on the exterior. The clips would expand and contract from each other in a vertical position. The clips would be made out of high grade metal, to withstand the weight of the boards. This separation allows for the design above to move and relocate the boards.

15. Another alternative method of picking up the end boards is a suction method. There would be strategically placed suction cups to lift each board up, distributing the weight evenly. There are multiple existing methods similar to the one described above. This method would work well, after looking into the surface friction properties.

16. This concept would be a rigid body to move the end boards from one location to another. A moving track would reposition each board from the pallet to the final destination. Team 1 is picturing a non-moving frame with internal tracks to move in three dimensions. This overhead beam system will support the robotic arm.

17. An alternative method to the one described above, would be having another form of transportation for each board, but from a different perspective. Design 16 is directly over the board, but a multiple linked arm robot is also a possibility. This arm would be lighter, use less material, be faster, and more dynamic than a rigid body. It would be more central in the overall layout and be all automated. The arm would still have the option of moving a defected board to a scrap pile.

18. This design concept would be a different claw method, making more points of contact with the end boards. A four-bar arm might ensure more security in holding each board.

19. Once the boards are securely placed on the loading cart, a track will pinch the boards into the origin point. The end boards are not perfectly stacked on the end board cart, this is a critical aspect of the design concept, ensuring the robot can find, pick up, and locate each end board as it enters the automated packaging system. These two packing arms would just move forward and backwards in one direction.

20. As outlined in the previous design, these arms would have to be rigid and secure. The height would be a minimum of thirty inches so as the last board is stacked, the device would still ensure contact, using a 90 degree bracket to reach the highest board. These two boards would simultaneously compress the boards to the point of origin.

21. This concept is a very simple idea that could potentially be a huge factor in the design process. A long pumper guide on the bottom of the cart would allow the boards to slide onto the loading cart. The current cart drawings have three and four boards on each side to secure and stop each board. There is a potential for the corner of each end board to get caught or stuck before it gets to the point of origin. A simple bumper will allow smooth movement along this surface. This concept would ensure that no corner got stuck in this rapid moving process.

22. If the end boards come in a horizontal location, there would be no lifting of the pallets and a machine arm would slightly angle the outermost board and knock it onto a conveyor belt. This concept isn't fighting gravity, and the end boards fall right into place.

23. This concept builds off of the conveyor belt system, as the end boards move on a belt. If timed right, at the appropriate angle, they could slide right into place, on top of each other. Each board would hit the metal fenders in design 21 to stay properly oriented. This is a stacking method where the end boards would fall off of the conveyor onto the loading cart.

24. Another potential way of accomplishing this would be as the end boards off load onto the loading cart, the device needs to rise along with the stack of the boards, to always be slightly higher than the stack height. This is a vertically adjusting conveyor belt.

25. This is a manual solution with some automated assist. A person would slip two free moving straps on opposite corners of each end board. Upon hitting a button, the device would carry each board to the moving cart. The straps would need to be manually off loaded, as the end boards would fall slightly into place.

26. A similar process would be more effective if multiple end boards were transported at the same time, instead of one. If design 10 or 12 were used to lift and separate between two and thirty boards, you could hoist multiple boards at a time significantly increasing the efficiency of the system.

27. Similar to design 7, an expandable center piece would be one of the more likely options in the long run. This device could be pre-programmed to locate any number of end boards based on the constant thickness of each end board of one inch. This machine arm would enter the center of the hole, and extendable arms would come out under the last end board.

28. Another design concept would be a weight sensing pallet that is parallel to the loading cart. As the end boards unload off this pallet, the pallet will vertically rise. As the pallet gets lighter, the pallet containing the end boards starts to rise, always staying horizontal (level) with the loading cart. This system would be spring loaded.

29. Another critical aspect to this concept is a bar that pushes end boards off individually onto the loading cart. This is essentially a bumper that will push each board off one at a time. This bumper will be made of soft material, and move at a slow velocity so it doesn't damage any end board. There is kinetic and static friction between the boards along with the surface roughness that would have to be studied and analyzed in great detail.

30. This concept would have more integrated parts but would be highly efficient and safe. A suction method for the point of contact to pick up each end board is one by one. Various contact points and maximum weight would have to be calculated along with suction forces. A bar of multiple arms for a vacuum could be studied. Increasing the surface area of suction will allow for a safer solution.

7.1.4 Jack O'Shea's Concepts:

1. External air compressor manipulation

The first concept makes use of two identical air compressors to push the end boards into the back of the cart. After placing the end boards on the cart with the pallet jack, these air cylinders would become pressurized and the two shafts would extend and push the boards into the origin in the back corner of the cart. This solution would be one of the quickest to complete for the operators and would be able to stack 30 end boards at time however this system would not be able to handle multiple stacks of end boards on one pallet. It would only be able to move the end boards if they arrived in the facility in one large stack on the pallet.

2. External air compressor, pushing form corner

This concept is very similar to the previous concept except it only uses one air cylinder to position the end boards. Instead of two cylinders on the two sides of the board, this idea uses an air cylinder mounted on the corner which would push the end boards by the corner into the back of the end board cart.

Below is a rough sketch of the idea.

3. Bottom mounted air compressors

This concept is similar to the previous one in that is uses pressurized air cylinders to move the end boards into the back corner of the cart. The difference is that the air compressors in this concept would be mounted onto the bottom of the cart itself. This concept would succeed in accurately aligning the end boards into the back corner of the cart. This concept is more ergonomic version of the first concept because the air cylinders are already attached to the carts. The difficulty of this solution is the altering of the carts which have already been built. If this challenge is possible to overcome then this may be a very quick and ergonomic solution.

Below is a rough sketch of the idea.

4. Funneling the end boards into the correct location

This concept makes use of a funneled/angled surface on the end board cart which will funnel the end boards into the correct location. By creating this angled box for the end boards to be placed on, the boards will go to exactly the correct location every time. This concept is extremely accurate with the placement of the end boards and it would be easy to obtain the correct coordinates however this concept will require a larger amount of operator work because they would be placing the boards onto the cart.

Below is a rough sketch of the idea.

5. Mechanical conveyor belt

This concept makes use of mechanical rollers to transition the end boards from the pallet to the back corner of the cart. The conveyor could have a variable height to allow for different size stacks of end boards. This concept would not be fully automated however it would be an ergonomic addition to a workstation which would benefit the employees in transferring the end boards and allow them to work quicker.

Below is a rough sketch of the idea.

6. Ball bearing roller

This concept is similar to the previous idea in that it allows the end boards to slide into the correct position in the back of the cart. Instead if an additional conveyor, this concept utilizes ball bearing rollers on the top of the cart which would make it very easy for operators to correctly align the end boards. This concept would however require altering of the cart.

Below is a rough sketch of the idea.

7. Automatic conveyor

This concept is similar to concept #4 however it employs and automatic electric conveyor/treadmill to move the end boards from the pallet to the cart. This would be a more expensive alternative to #4 however it would require much less operator movement. Instead of pushing the end boards down the conveyor, this treadmill would do this automatically which is a much more ergonomic and efficient arrangement.

Below is a rough sketch of the idea.

8. Geared conveyor

This idea is similar to the previous one except instead of using a conveyor to place the board on top of; this idea uses a rotating gripping wheel to push the end boards off the top of the pile and on top of the cart. This would be a good and ergonomic solution for simply moving the end boards.

Below is a rough sketch of the idea.

9. Incline assisted conveyor

Instead of using an automatic conveyor system this idea uses an inclined surface next to the pallet jack to assist the operator in moving the end boards. By placing a ramp next to the cart the operator could place the end boards on the ramp and they would slide down into the cart.
Below is a rough sketch of the idea.

10. Lever arm centering mechanism

This concept uses a lever pivoting at the bottom of the cart to center the end boards. When the boards are placed onto the cart, the operator could lift up the lever which would make it perpendicular to the plane of the end boards. By doing this the two levers would be aligning the two sides of the boards where they should be in the back of the cart. This solution would be a simple method of manually aligning the end boards.
Below is a rough sketch of the idea.

11. Size specific cart.

One of the largest challenges with this project is that the end boards which Toray uses come in many different sizes. This can make it very difficult to find a single solution which allows to various sizes of boards. This concept involves altering the end board carts to make them specific to the four different sizes. On each cart there would be rails which only allow one of the sizes which align the end boards. By doing this we could tell the robot to go to the correct location every time.
Below is a rough sketch of the workstation.

12. Electric winch workstation

This concept is a completely different solution than the others. Instead of moving the end boards from the outside this method would grab a stack of end boards from the inside. To do this a workstation could be built with an overhead electric winch on a rail system. To actually secure and grip the boards a mechanism could be placed inside the core of all the end boards on the pallet. This electric winch would be used to provide the lifting power. The following concepts are designs for the various gripping methods which could be used as an attachment for the electric winch.
Below is a rough sketch of the workstation.

13. Electric winch attachment

This concept is for an attachment to the overhead electric winch. This concept is for a pneumatically expanding shaft which will be placed inside the cores and expand to grip the end boards. This shaft will be a cylinder with protruding pistons which will expand outwards and grip the cardboard material. By attaching this pneumatically expanding shaft inside the cores of the stack of end boards, then actuating the cylinder, the shaft will expand and grip the pile of end boards. Once the stack is gripped by the expanding shaft, the electric winch would be used to maneuver the end boards into the corner of the cart. This method requires a very low amount of labor because the operator can grip up to 30 end boards at a time.

Below is a rough sketch of the expanding pneumatic shaft.

14. Electric winch attachment

This concept is for another attachment to an overhead electric winch. Instead of using a linear grip, this shaft instead uses a series of pneumatic triangular grips which expand when the cylinder is pressurized. This concept is similar to the previous one except the gripping mechanisms are shaped differently and may be better for gripping the loose cardboard.

Below is a rough sketch of the concept.

15. Electric winch attachment

This concept is for another attachment to an overhead electric winch. This concept is similar to the previous concepts however it only grips a single board at a time. Sometimes the boards enter the factory damaged and cracked so it may be advantageous to design a solution which only allows to transporting of one board at a time so that the operator can inspect the board. This concept uses expanding shafts to grip the top board.

Below is a rough sketch of the concept

16. Cam gripping device

This concept is for another attachment to an overhead electric winch. Instead of using a pressurized cylinder, this method takes advantage of the weight of the end boards to grip the end boards. The idea is that by aligning two geared cams on one axis and lowering this into the cores of the s, the device will allow movement in one direction and will grip the end boards when the device is lifted upwards. I have made a rough sketch of the device but also attached a picture of a commercially available device which is often used in rock climbing for the same mechanism; only allowing one directional of travel.

Below is a rough sketch of the concept.

17. Electric winch attachment

This concept is for another attachment to an overhead electric winch. This next concept is similar to the previous one except it uses a spring loaded grapple to grip the center of the end boards. This solution could be used to grab either one or multiple boards at a time.

Below is a rough sketch of the concept.

18. Electric winch attachment

This concept is for another attachment to an overhead electric winch. This concept attaches to the electric winch as well but it uses a suction cup to grab the cardboard. This solution could only pick up one board at a time because they are fairly heavy.

Below is a rough sketch of the concept.

19. Electric winch attachment

This concept is for another attachment to an overhead electric winch. This concept uses a vacuum attached to the suction cups to apply a negative pressure to the suction cups. This is similar to the previous concept however with more suction; the attachment could pick up heavier boards.

Below is a rough sketch of the concept.

20. Electric winch attachment

This concept is for another attachment to an overhead electric winch. This concept uses a mechanical arm with a pneumatic cylinder to grip the outside of the end board. Depending on the length of the arm this could be used to pick up one or multiple end boards which would be advantageous.

Below is a rough sketch of the concept.

21. Electric winch attachment

This concept is for another attachment to an overhead electric winch. This concept is similar to the previous example however it doesn't use a hydraulic cylinder. Instead this concept uses takes advantage of a mechanical advantage and a lever arm to grip the boards when they are lifted. Below is a rough sketch of the concept.

Process Improvements:

The following concepts are improvements to be made to the manufacturing process to solve the problem at hand.

22. Supplier quality

This concept involves improving the supplier quality of the end boards which come from a separate supplier. When these end boards arrive, the center holes of the end boards are often not concentric and are not always centered on the end boards. This inconsistency makes it very hard for Toray to manipulate these end boards. If Toray were to switch suppliers and find a board which is more consistent the boards could be stacked in the center of the cart and the robot could pick them up from there.

Below is a rough sketch of the concept.

23. New end board material

This concept is similar to the previous one but it involves switching the materials of the end boards. Currently the boards are made of a flimsy cardboard material. If Toray were to switch to a new plastic based end board the tolerances on these boards would be much better and allow the robots to pick up the boards with much greater accuracy. This would also allow for longer recycling lifetime of the end boards and could potentially save money.

24. Removal of end boards

This concept is a complete change in the way that the rolls are packaged and shipped. Instead of placing end boards on the coils of material and stacking the coils on pallets for shipping horizontally, I propose removing the end boards all together and stacking the rolls of material vertically on the pallets. This would remove the problem, and reduce material consumption and labor hours.

Below is a rough sketch of the concept.

25. Supplier quality

In this concept I propose we speak with the suppliers to see if it is possible to have the end boards sent on the pallet in the exact same location every time. If we were to get this implemented instead of removing the end boards from the pallet the entire pallet could be placed on the cart and the robot would be able to accurately pick up the end boards because they would be in the same location every time.

26. Robot re-programming

This concept would involve changing the existing cart. Instead of having the back corner of the cart is the origin for the robot I would propose placing a center rod in the cart so the end boards can be placed through that locating rod. By doing this we could re-program the robot to use the center rod as the origin and pick up the end boards from the side using that location.

Below is a rough sketch of the concept.

27. Robot re-programming

This concept would utilize an image analyzing camera and program which the robot could use to locate the end board. If we were to place a camera on the robot arm to analyze where the top is and send this location to the robot, the robot could then use this as a location for picking up the end board. This would definitely be the most efficient method as it would allow the operators to place the pallet directly on the cart and then the robot would know exactly where to go every time.

28. Robot reprogramming

This concept would be another way to reprogram the robot to pick up the end boards. Instead of grabbing the end boards from the outside of the boards, this solution would require changing the grabbing method of the robot so that the arm expands and picks up the end boards from the inside of the core.

29. Adding an additional robot

This concept would be expensive because it involves the purchase of another robot however it would be a good, quick and efficient solution. By purchasing an additional robot and placing it inside the cart this robot could be used only to align the pallets to the back corner of the cart. Once they are accurately aligned, the other robot could come and grab the end boards.

30. Manual solution – temporary

The last solution is one of the most basic which simply involves the manual moving of the end boards from the pallet to the cart. This is probably the slowest solution proposed but it is however the simplest and easiest to implement right away. If Toray is concerned about implementing this new production line this could be the best temporary solution until a more permanent solution is decided upon however I would not recommend this for a long term solution.

7.2 Evaluation

When the End Board Loading Station project was explained to Team 1, there was a clear problem definition. The clear and well defined problem statement of designing a loading station to transfer end boards from the pallets in which Toray received onto the loading cart helped the team generate clear and specific concepts for design. After doing some initial research, the team agreed there were limited ways to successfully pick up multiple end boards at a time. The variety in sizes in which the end boards were received and the uneven pallet stacks were the two biggest challenges presented. All team members did their brainstorming individually so their concepts would be fresh and creative, bringing all ideas to the table.

The team began to generate ideas, keeping in mind safety for the workers, efficiency, and total cost for the project. Some innovated solutions were generated out of the 120 concepts. The three most well liked ideas were solutions that involved grabbing the end boards by the outside edges, an internal gripping mechanism, and a pallet inverter. In the end Team 1 decided to go with the internal gripping mechanism which is being presented in this report.

8 QFD

The completion of design concepts calls for a detailed analysis of each approach by looking into each specification required by the designer to the consumer. To meet these conditions, the designer needs to perform a Quality Function Deployment, QFD, or a structured approach to defining the customer's needs. From this point they are translated into specific plans to produce a product that meet those demands. In this case the consumer or customer buying into the product will be the management within Toray Plastics of America. Figure 10, labeled below, contains two main categories Demanded Quality or Customer Requirements listed on the left side of the graph that are being compared to Quality Characteristics or Functional Requirements in the cells listed on the top portion of the graph. Figure 11 shows Competitive Analysis, in this case, pertains the four main concepts being examined.

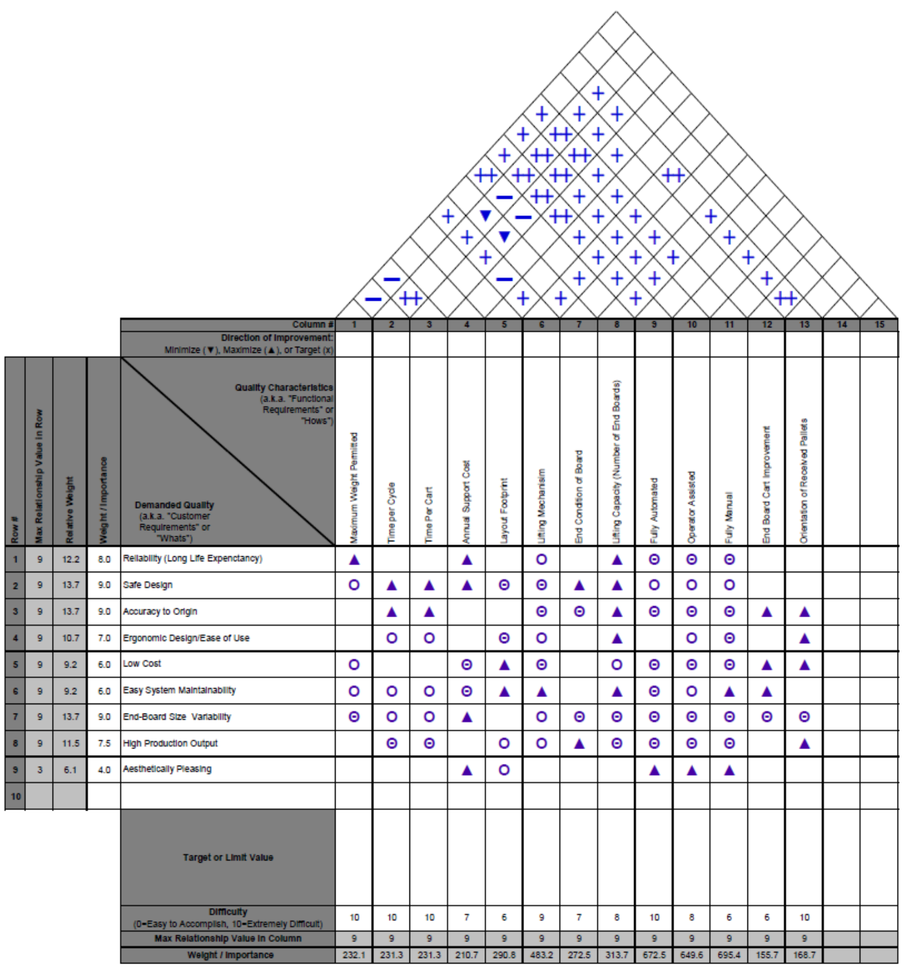

FIGURE 10: QFD Main Body

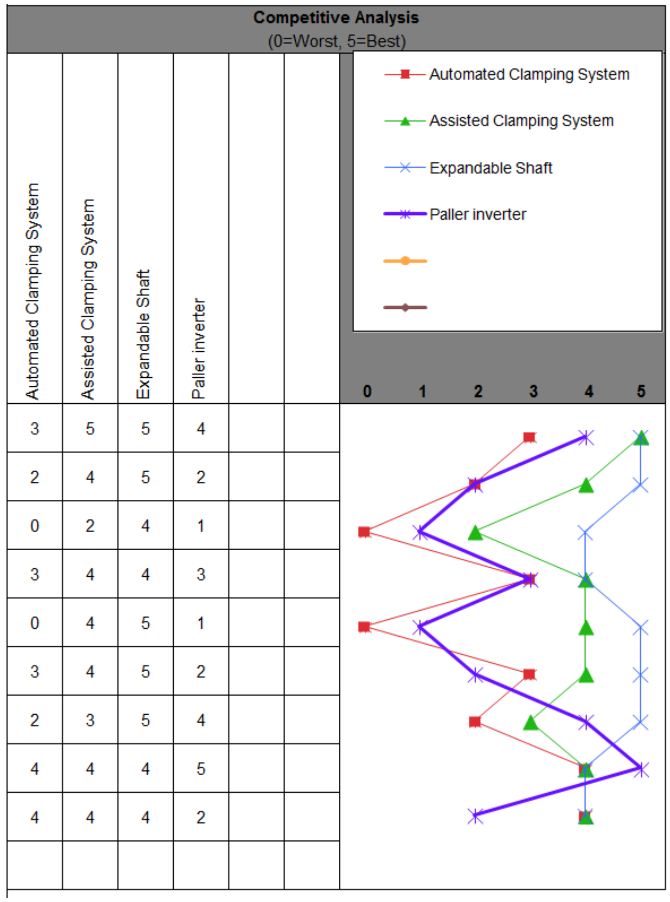

FIGURE 11: Competitive Analysis of Designs

Figure 11 shows the main concern of Toray Plastics while designing an End-Board Loading system. The design engineer emphasized the importance of the nine parameters sectioned on the left side of the figure. These parameters are listed under the Demanded Quality, Customer Requirements, section with the customer being Toray. The problem statement Toray presented had multiple conditions they were looking to accomplish while constructing the design. Looking to increase the efficiency in the initial loading station while still maintaining a high quality of output and the safety of the operators working the machinery. The rate of importance can be found on the left side with the weighting scale showing the means of importance. The weight assigned to the customer requirements was scaled by Toray Plastics problem statement and what they felt had the greatest importance. The greatest parameters that the design needed to meet are Safety and Reliability. The relative weight was accordingly assigned to these two characteristics. The remaining requirements were according assigned values from a range of 9 being the highest and 4 being the lowest. The parameter that received the lowest weight was the category of aesthetically pleasing. How nice the assembly looks is not a top priority to Toray and the Designers. It is being constructed to maintain a high output of efficient products. The overall appeal of the machinery will not cause Toray to sell more products. Even though the final design has a clean cut format it was created for the purpose of getting the job done as smoothly as possible.

8.1 Demanded Quality

Like most companies that are investing, whether it be a new machinery or system, reliability is a major concern. Any section of a manufacturing facility requires risk with the operation and the upfront cost to keep the operation running as efficiently as possible. These processes use a large amount of the company's time and effort and they want to see a working product when it is all said and done no one wants to spend more time and money servicing the device that has just been produced. The design team paid close attention to this factor because of the importance. Team 1 wanted an operation that would stay in functioning working order for an extended amount of time. The construction of the entire process was formulated to have well-built parts to prevent any type of failure. It has been manufactured to limit the amount of re-inspection needed. After the system has been installed it will not need any additional maintenance to run as efficiently as possible.

The safety of the design is a critical design factor that has been expressed by Toray. It is not feasible to work in an environment that is unsafe or could cause harm to any of the workers. At Toray having anything but less than complete safety would not be tolerated. In a manufacturing facility with so many moving parts and operations happening at the same time it is highly reviewed. The design deals with the lifting and transportation of heavy items that if failure occurs could cause injury. That is why the concept has been through extensive engineering analysis and is being tested to assure the safest work environment possible for the operators at and around the station.

Accuracy to origin was a key feature to having the end-boards accepted into the automated system. If the end-boards can’t be located by the gripping arm the process as a whole will need to be put on hold limiting the amount of efficiency. Visiting the factory and testing the tolerance of the end-board loading station it was seen that there was some room to play with. There will only be a small displacement between the end-boards if any with the internal clamping system. The use of the loading cart guide rails helps to keep the particle boards flush on the cart and when it is initiated into the system.

When designing the station, the ease of use was a main concern. Before the consideration to have a more mechanical flow, the end-boards were being transferred to the loading cart manually. This slow and strenuous plan was short lived. Under OSHA requirements a worker can only lift 50 lbs at any time which means one end-board can be placed on the loading cart at a time. Looking into the safety of the workers the design incorporates a mechanically driven lifter that will reduce the stress caused by the manual loading method. It is easy to use and doesn't require much force given off by the worker. The hoist is motor driven that will be used to lift over a ton of material with the push of a button. The easy flowing guard rails make it almost effortless to transport them from the pallet onto the loading cart.

All companies when investing in a new process looks for the most cost efficient solution that will get the job done. At first the design team thought this process was going to cost upwards of thirty thousand to accomplish the job at hand. After completing extensive research and cost analysis of each component we found that this is not the case. Working with an outside manufacture and our concepts the complete design after installation is looking to cost around a third of that initial price.

Most operations with moving parts have a high maintainability factor associated with them. Companies with high maintenance machinery spend almost as much money per year then the initial cost of the overall process. If a section goes down in an automated system it doesn't just affect that one section it affect the entire process. The rest of the machinery is sitting waiting to receive parts or material from early section. With this being said the maintenance of a section as early as the end-board loading system will not be tolerated. Team 1 believes that there will be little to no maintenance on the design concept over the first years.

One of the initial problem statements calls for incorporating multiple sized headboards within the design. At first this was a huge task that needed to be overcome. Having multiple changeovers during operating hours would be not be acceptable. It would limit the efficiency of the design and slow down the overall process. The final design of the internal expandable shaft eliminated the problem at hand. Even though the end-boards vary in size the internal hole size does not vary with a diameter of approximately 6.0625 inches. The internal clamp has been formulated to grip the internal edges of the whole without worrying about the outside edge length.

Having a high production rate is exactly what the final design administers. As stated earlier the current manual process outputs approximately 2 end-boards per minute. This is a slow and not fit process when dealing with the high speed automated system. The design chosen cuts the transfer time immensely. The design incorporated a process that will be able to run 15 to a fully loaded 30 end-boards in the same span of about two minutes. Cutting down the production rate drives the efficiency through the roof when comparing it to the manual process. Saving time and money for Toray Plastics of America.

8.2 Quality Characteristics

The nine Demanded Quality guidelines are being correlated against the top section of the graph. Quality Characteristics, Functional Requirements, which are specifications of the design that need to be met. In the upper left corner of Figure 10 it shows the detailed correlation of the two sections based on importance. These 13 individual sections are factors that need to be considered based on the problem statement.

The Maximum Weight Permitted is pertaining to a full load of end-boards which consists of thirty separate sheets of particleboard. This cell is pertaining to the max weight which deals with the largest sized end-boards. The largest size have dimensions of 42’’ X 42’’ and weigh in at approximately 44lbs per sheet which comes out to be around 1,300lbs for a fully loaded cart. Even though the station might not need to transfer all thirty boards at a time, it is still needed to be inspected for engineering analysis looking to expand towards future goals. This is similar to another section of the Quality Characteristic within the section. The Lifting Capacity (Number of End-Boards) deals with the overall weight of that the transfer station is dealing with.

Time per cycle and time per cart are main cause of efficiency within the design specifications. Currently with the manual system that has been developed it has a running time of two end-boards per minute which is around a half hour per loading cart for a total cycle. This number is not ideal in any case with the automated machinery running at a much faster pace. The designs need to be able to have loading carts loaded and ready to be implemented into the apparatus before the end-boards are cleared to increase the efficiency of the overall process.

An Annual Support cart is important to all businesses in order to generate a large profit margin. A design can't be costing the company more than what is generating. These numbers are achieved through the maintenance schedule of an operation. If a section of machinery is constantly needed work done by the mechanics it is costing the company not only money for replacement parts but can also impact the total output of production that it is effecting down the line.

In this case the layout footprint was a bigger task within the factory than expected. There are a lot of moving parts and sections were having a work station could not be permitted. It is also important to limit the footprint of the operator. He couldn't be spending more time getting material from sections of the warehouse then actually running the overall process. This characteristic is of high importance and needed to be highly reviewed through the Quality Function Deployment and other analysis.

The next three columns are being compared within the QFD analysis the team needed to determine which would be the best choice when conducting the design concepts. In the early stages it was unknown if the process was going to be fully automated, operator assisted, or a fully manual process. Comparing each of these parameters to the Demanded quality have the design team a better understanding of which would be the leading arrangement for this particular set up.

8.3 Competitive Analysis

Note:

- Purple- Pallet inverter
- Red- Automated Clamping System
- Green- Assisted Clamping System
- Blue- Expandable Shaft

Figure 11 goes into detail on the competitive analysis, which in this case were the top four designs that have been formatted for the problem statement. At this point there are the four proposals that need to be analyzed consisting of the Pallet Inverter, Automatic Clamping System, Assisted Clamping System, and the Expandable Shaft method. This process is one of the ways the design team determined which process would be the most suitable for the function. The numbers listed under each design has a range from 0 to 5 with 5 being the best or most importance. They are corresponding to the parameters listed needed to be met by Toray under Demand Quality. By examining the chart, it is clear that the blue line showing that change of values for the expandable shaft is mostly found on the right section under 5. This analysis examined the strength and efficiency in the early stages of design.

The automated clamping system was a quick solution when reviewing the total process. At first look of Toray's automatic machinery they incorporate an automatic clamping system within the loading station. Integrating the same machine outside for the transfer station is a quick solution to the original problem statement. Going into more analysis the team realized it wasn’t that simple. The tolerance of the automated arm was not great enough to deal with the misaligned end-boards being imported on the pallets. Even with talking to the suppliers it would not be possible for them to achieve the degree of accuracy needed for the fully automated process. Also while conducting a cost analysis it was not feasible. Looking at a price tag of over thirty thousand dollars before installation would not be saving the company money in a cost efficient manner. Comparing this design competitor with the customer requirements we can see that it is all over the board. The Reliability aspect is sitting at a three because the design team doesn't have enough info to go off of. The manufacture assures Toray that is a long lasting well build material but without time studies that is yet to be determined. For design safety it received a value of two. The existing automatic arm is enclosed so workers cannot be harmed by the machinery. Once an automatics operation is initiated it has strong motor driven components that will not stop if a person is caught in the cycle. Having to enclose our section would cause the company to spend extra money and make it less versatile to operate. Through other analysts and testing the automated clamping system does not have the requirement to format an accurate measure. The way the end-boards are brought into the facility is outside of the tolerance of the automated machine. If there was a way to format the automated arm to have a higher degree of tolerance it would have the highest and most efficient product output of all the designs. Due to the design flaws this concept had to be removed from the consideration while moving forward with the project.

The Assisted Clamping System is a functioning alternative to the automatic clamping arm. It deals with the same formulation or overall structure that the internal clamping method uses. It is an over the head semi-automatic work station that incorporated a limited space work station. A hydraulic arm is used to eliminate the heavy lifting to overcome the heavy lifting of the operator. It uses outside clamping methods to grip the particle board on the outside edges. It has to potential to be a main design solution to the problem statement. Following the chart, it has been expected to have a long reliable life expectancy based on the mechanics of the design. The mechanism works hand and hand with the components of the internal expandable shaft. It functions as a work station with motor hoist like lifting apparatus. It is run by an operator so it is believed to be a safe concept. The does have some major design flaws that conflict with the parts and problem statement. The tolerance of the clamping mechanism might not fit the parameters for the various sizing of the end-boards. Looking back at the design of the loading cart the outside clamps would interfere with the support bars located around the perimeter. Even though it would be able to stack the end-boards in a very organized fashion it would not be able to transfer the sheets of particleboard down in the fashion the loading carts were designed for. A complete redesign of the loading carts at this stage of Toray's planning would not be economical or cost efficient. Due to these reasons this design concept received low scoring on the End-Board Size Variability and Accuracy to Origin sections of the Quality Function Deployment chart. Based on these discrepancies this Concept was needed to be ruled out as an ergonomic concept to achieve a well-rounded solution.

The Pallet inverter is the third design concept we had to rule out when conducting the QFD analysis. At first it seemed to be a favorite of Toray's Sponsor but after further study and investigation did not seem plausible. It is a design that has been used by multiple companies in the past and if used as a forklift attachment or as a workstation it has a high reliability return. Making sure the inverter is in a safe section of the factory is very importance being an automated machine. There are two common designs for this mechanism. The first consists of a forklift attachment that uses the energy and lifting capacity of the device to invert the stack so that the pallet is able to be removed from the bottom of the end-board. The second design is a total work station. Which sits in a section of the warehouse having material constantly being brought and removed. Having material being constantly implemented into the system creates a less efficient design. A forklift and operator would have to be designated to this section would take it away from the process it was originally assigned. It having an initial cost that of the automatic clamping arm, upward of thirty thousand dollars, makes it not cost effective for Toray Plastics. It is known to have a low maintenance cost but if problems did arise it would completely take the station out of commission. The capacity of End-Board variability is a large strong point for the design concept. It is able to coincide with any side end-board thrown at it which, looking towards the future makes it very versatile. It received a 5 on Production Output because it is able to invert a complete stack being imported in a stack of fifty end-boards but it still doesn't accomplish the transfer section of the problem statement. Due to these reasons the QFD allowed us to eliminate the pallet inverter as a feasible solution.

The last and Final Competitive Analysis that will be reviewed is the Expandable Shaft. Team 1 has chosen this design as the concept that will actually be implemented into the Loading station at Toray Plastics. After much analysis the Expandable shaft will be the design being used to fully complete the problem at hand. It is a reliable solution that does not require much maintenance after the installation of the station. It is a safe design that eliminates the force required to lift the end-boards during the transferring section of the process. The hoist eliminates any over lifting of the operator and is cleared by OSHA requirements. It has a high Accuracy to the Origin allowing the end-boards to be neatly stacked on the loading cart flush against the support rails. It has easy to use functions that allows one worker to operate the whole section throughout the whole process. It was also the most cost efficient solution coming in at a total installation cost between seven and eight thousand which is less than a third of the initial cost when compared to other proposed solutions. It also received a 5 when looking into the variability of the end-board sizes. It has more than enough lifting capacity to lift any size of weight neglecting the overall size of the sheets. They can be neglected because it deals with the internal hole which all has the same specs and size. It is able to lift 15 to 30 end-boards at a time which makes it one of the highest production output having a lift and transfer incorporated in the same process. It can load a total cart in less than 5 minutes which will leave more than enough time for the automatic machinery to run the loaded carts.

9 Design for X

9.1 Design for Efficiency

An analysis for the end-board loading station optimized all the manufacturing functions and efficiencies. Over the past couple of months, the engineers and mechanics at Toray have been in the process of installing a new automated system in a warehouse with an open floor plan. Their layout placed specific sections where the end-boards will be implemented into the new machinery also; they had an idea where the end-boards will be imported and stored within the factory. A major factory of increasing the efficiency was to reduce the amount of travel the operator running our station will need to make in order to keep the operation running. In order the reduce the footprint the loading team created a station that will be adjacent to where the loading carts are plugged into the system. The station that has been formatted to have enough room for pallet jacks and forklifts to drop off stacks of end-boards into the operating area where the internal clamping system will be able to grab the end-boards and transfer them onto the loading cart. Reducing the footprint will save the operating time and keep the system running as efficient as possible.

Over the years at Toray, dealing with their old system, a manual loading process required workers to pick up and place the sheets of particle boards by hand. Toray, like other manufacturing facilities, stress the safety of their workers and others touring the plant. Team 1 was required to wear head to toe gear when touring the overall manufacturing facility. Throughout every section of the facility, safety reminders have been posted on every corner. Under OSHA requirements a worker can only have a lifting capacity of 50lbs at a time. With this being said it means a worker operating this section will only be able to transfer a single end-board onto the cart at a time. This is a timely operation which averages about two end-boards being transferred every minute. With thirty end-boards needed to complete a full cycle the company was looking at a huge time margin to complete only one loading cart. With the design we have cut those loading times tremendously. The internal clamp will be able to lift up to thirty end-boards at a time which means a full cart will be ready to be installed into the loading cart area in the same amount of time the manual process would take to transfer two end-boards. The design abolishes two concerns Toray listed on their problem statement, making an environment that is as safe as possible while also making the process as fast and efficient as possible.

9.2 Design for Accuracy

After the end-board cart has been loaded and implemented into the station the process begins. An automatic arm has been manufactured to locate the end-board cart, position the clamps downward and grip individual boards to install them into the system. It grabs the particle boards from two sides shows it to an inspection camera that will scan the end-board for any breaks or defects and then inserts it onto the edge of plastic material. Toray is a worldwide manufacturer of plastic rolls of material so there are many different sizes and weight considerations. This calls for multiple sized end-boards build to withstand the force acting on the center hole. The end-board sizes consist of four sizes ranging between 24'' X 26'' to 42'' X 42''. The automatic clamping system that has been manufactured for this section of the automatic machinery, show in Figure 12, has a jaw width of 43.55''. This calls for a very accurate stack of end-boards when applying the largest sizes into the station. Over the next couple months Team 1 will be examining the tolerances that will be accepted by the automatic clamping arm. The engineering team know that a method will need to be implemented.

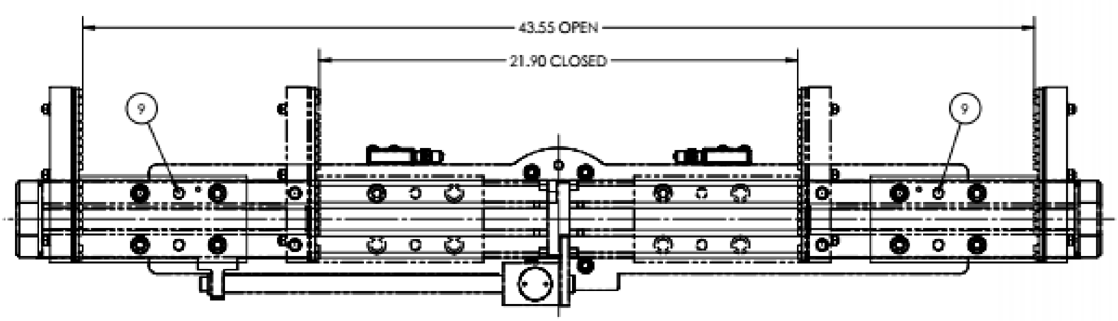

FIGURE 12: Automatic Arm Clamping Jaw

The problem that the process faces is that when manufacturing the end-boards they were not all built to spec. The center hole which was thought to be perfectly aligned in the center shows some degree of displacement. This being said when the internal clamps are inserted into the center hole and clamped down it will misalign the edge of the end-boards to cause a small jagged exterior stack during the transfer section. Ideally the manufacturer would like to see a perfect flush edging when implemented onto the loading cart bars located on the corner edge of the loading cart. This problem statement called for a design of accuracy when dealing with the largest sized end-boards. Taking cost and efficiency into consideration a manual placement bar has been developed. Altering the loading carts to have a small section of material removed so that a rotating bar can be easily attached. This bar will swing upward and using the force exerted by the operator will be used to push the end-boards up against the alignment bars.

9.3 Design for Reliability

Design for Reliability, DFR, is a process that all engineers have to take into consideration while conceptualizing a project. Analyzing the DFR provides the probability that an item or product will perform its intended function for a designated period of time without failure under specified conditions. The issue of having to constantly service or re-inspect devices can become a costly and significant problem. The main concern a company who is investing in machinery or process is that it runs as efficiently and smoothly as it has been designed to run.

While designing the end-board loading station the reliability was a major part of the design considerations. The construction of the entire process was formulated to have well-built parts to prevent any type of failure. The entire framework and hoist system were structured to have close to double the lifting capacity needed during the transfer operation. Also, the expandable shaft or internal clamping system have been through engineering analysis and testing to assure the desired lifting force is applicable. In the preparation of the loading station the maximum loads needed to be taken into consideration. With this being said the internal clamping system designed needed to be examined thoroughly. The plan is to be lift 15 end boards at a time with 44lbs. The process consists of well manufactured parts. It has been constructed to limit the amount re-inspection needed. After the system has been installed it will not need any maintenance to run as efficiently as possible. This is a major step to overcome within a manufacturing facility. If one section of the process shuts down the rest of the line will not run at its desired capacity. Eliminating a changeover time will strongly increase the product output designed for Toray.

9.4 Design for Safety and Ergonomics

The design within itself will increase the safety of the overall manufacturing facility. OSHA guidelines state that an operator is not able to lift more than 50lbs at a time. The end-boards have an average weight of around 30lbs across all sizes so the worker won't be able to lift more than one end-board throughout the transfer process. This reparative bending and lifting process can cause injury for the worker while they are continually transferring the end-boards over to the loading cart. Not only is the manual method not safe for the operator it is also a long process that decreases the efficiency of the overall process.

Team 1 has formatted a design concept that will increase both the safety and efficiency of this section of the manufacturing facility. The hoist system that has been developed will eliminate any stress on the worker that the manual process presents. With just the push of a button the end-boards are able to be lifted off of the pallets and transferred over to the loading cart. With the design having the capability of lifting 15 end-boards at a time it increases the efficiency. Currently the operator is able to transfer around seven end-boards per minute which will take approximately 5 minutes to complete a full cycle of particle boards. With the process that has been developed Toray is looking at a transfer rate of 15-30 minutes within a minute. The new process not only provides a solution to the problem statement but it also increases the efficiency.

10 Project Specific Detail & Analysis

10.1 Product Design Details

This was a problem definition that was only specific to Toray Plastics of America. The only competitors in this industry were the team's individual ideas. Toray Plastics of America is the first branch within their company to invest and experiment with a fully automated packaging system. This is a trial run for future automation processes. The demand for this product is minimal, as the team is only making one automated end board loading station for Toray Plastics. A market analysis says there are some similar methods to solve the problem at hand, but a custom solution needs to be implemented to pick up every end board and relocate them.

10.2 Current End-Board Process

The current process implemented at Toray is a fully manual hands on process. Two suspended corner straps hang on a traverse hoist as a worker slides the strap under one end board at a time, bringing it to a loading table. Here, the worker inserts a plastic insert into the inner diameter of the end board. This is a very time consuming process with lots of room for error. An analysis study was conducted for the current production method referenced in the cost analysis. The results yielded a low production rate, as the worker just picked up one end board and placed it onto the loading cart repeatedly.

10.3 Future End-Board Loading Station

Moving from an entirely manual process to a fully automatic process will save Toray a lot of time and money by reducing the cycle times. When the new system is implemented a production bottleneck effect will be removed and there will be considerable time savings involved. The system which Team 1 has designed will be implemented seamlessly into the new system and the work flow diagram below Figure 13 shows the work production process involved with moving the end-boards from the shipping pallets to the mobile carts.

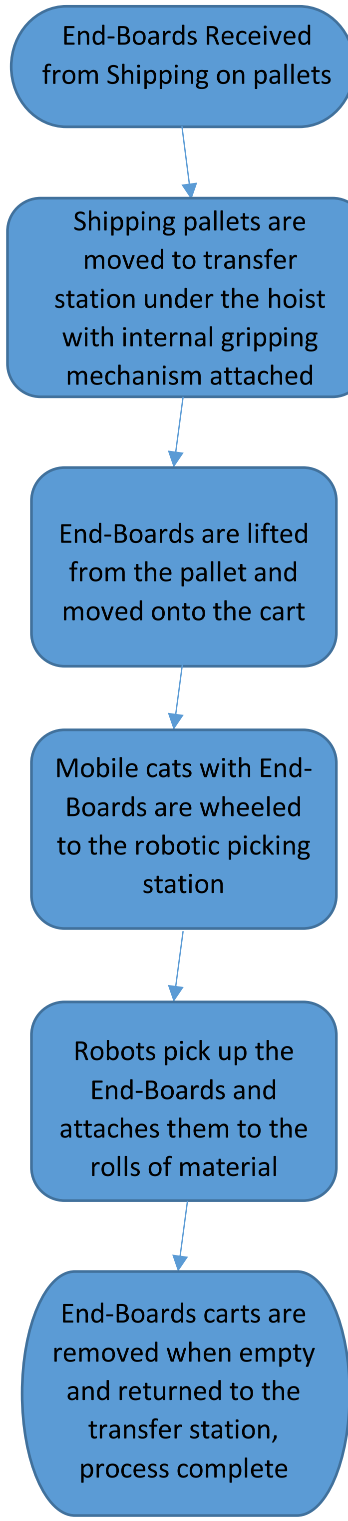

FIGURE 13: Process Work Flow Chart

11 Detailed Product Design

The initial concept chosen by Team 1 was an internal clamping mechanism. The design consisted of four major parts which contributed to the overall design. The device needed to compress to a minimum diameter of 5 inches to allow clearance to fit in the 6 1/6 inch diameter hole in the end-boards. Using basic trigonometry functions, the length of the bars were calculated.

$$a^2 + b^2 = c^2$$

The main idea behind the concept was to not require use of an additional external force. A zoomed in view of the image is shown in Figure 14. The specifics of the design would be developed during the design process. Each part in the design is a critical aspect in the overall performance and safety of the final product. Standard units in inches were chosen for simplicity in the design and to make machining easier for each part. Team 1 designed and dimensioned each part on their own, so tolerances of 0.02 inches were chosen between each part. Each metal component was ordered from McMaster-Carr and was sized as closely as possible to the dimensions of the part, so extra time and excess material wasn't wasted. Market research did not provide any similar solutions to the one that Team 1 was developing. For that reason, every designed part was original and custom to the problem statement at hand. The range of motion incorporated into the final design of the internal clamping mechanism had to be flexible enough for the bottom gripping feet to be in contact with the ground. This would ensure the bottom end-board on the pallet would be in contact with the device and would allow for a successful pick up.

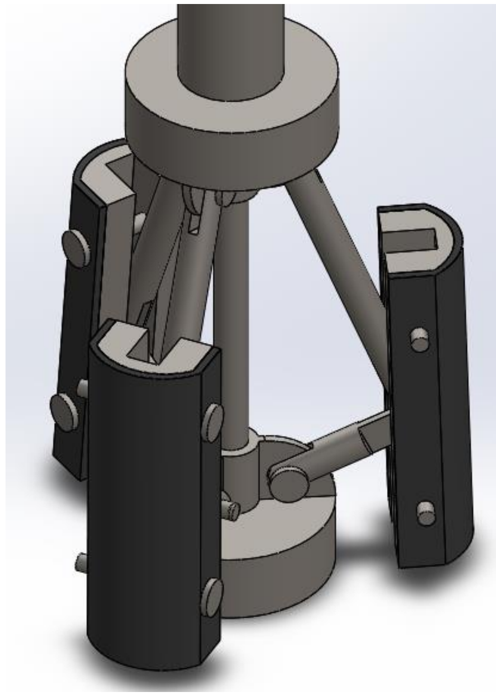

FIGURE 14: Internal Clamping Mechanism

11.1 Design of Gripping Feet

The design of the gripping feet was one of the most critical parts when developing the product. The amount of surface area in contact with the board was inversely proportional to the overall diameter of the internal clamping mechanism. Team 1 wanted to maximize the surface area in contact with the end-boards, so three feet were chosen to contact the boards. Each gripping foot yielded an overall area of 8.48 square inches shown in Figure 15.

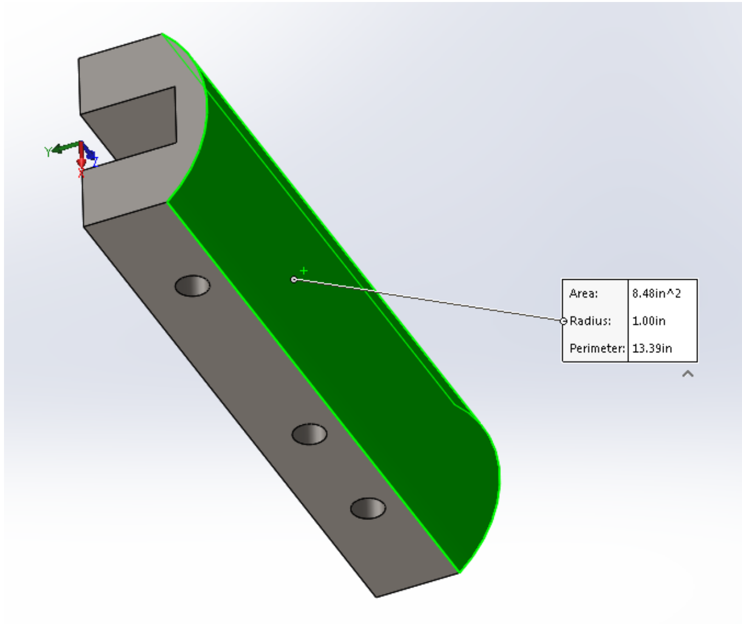

FIGURE 15: Surface Area in Contact with End-Boards

The overall length of the gripping feet was 5 inches. This design was chosen to be in contact with the 5 bottom most end-boards, each having a one-inch thickness. Two ¼ inch holes were made on the top and bottom of the gripping feet, one inch from the top and bottom. This design was implemented to securely fasten the neoprene material to each foot. Ease of use was taken into consideration, knowing the rubber material will fatigue and wear out, so an easily replaceable design was necessary. The third hole was drilled in a strategic location, two inches from the bottom of the gripping feet. This hole allowed the gripping feet to mate with the rest of the device, at the hinge with the bottom and top bars. The location of two inches from the bottom was chosen because it still favors the bottom, allowing the maximum force to be exerted outward on the bottom most end-board. The top three inches still can pivot on the horizontal axis. Each hole was board out to prevent burrs which would ultimately lead to stress fractures and failure. This was a necessary step in the machining process when dealing with a brittle material.

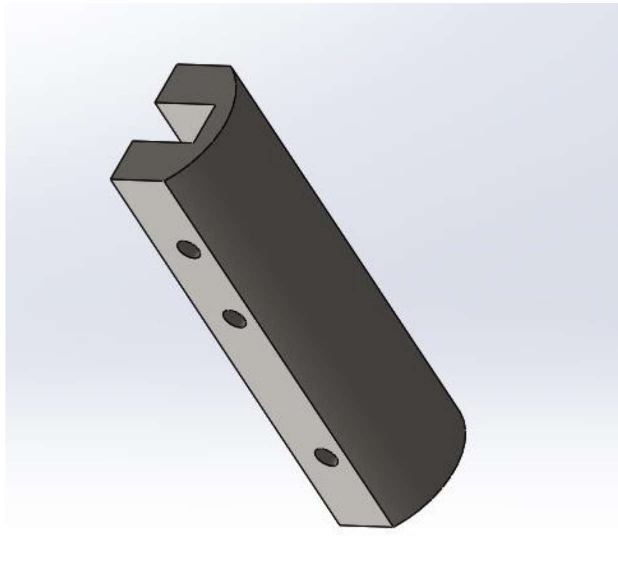

FIGURE 16: Individual Gripping Foot

10.2 Design of Bottom Bar

There are a total of three machined bottom bars in the final design. The overall length of the bottom bar was designed at a length of 2.81 inches. This was the required length to satisfy the appropriate forces and maximum/minimum lengths. The chosen bar diameter half an inch to ensure safety with a tensile strength of 52,000 psi using 1018 CR Steel. The drilled holes were ¼ inch and designed for mating to the bottom hinge, gripping feet, and upper control bar. Team 1 machined the bar edges round to ensure no interference with the upper control bar and the bottom hinge upon rotation. The bottom bar was designed to have a male mated component to connect with the upper control bar. The middle section was left in full at a length of 0.81 inches to ensure strength and to not allow deformation when maximum weight loads are applied. Team 1 tried to limit the machining processes required for the bottom bar to save material, and not implement any more stress fractures on the component.

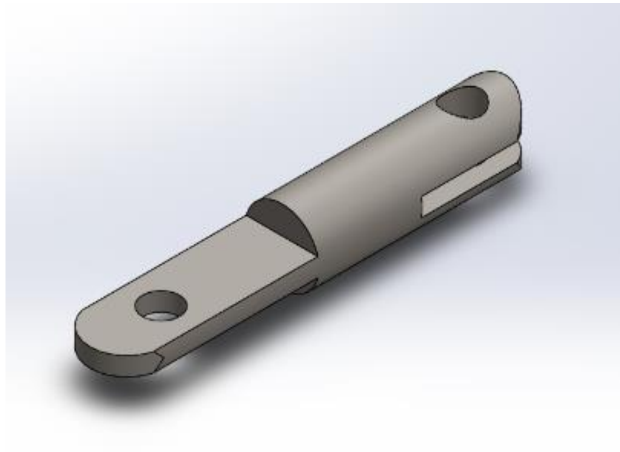

FIGURE 17: Individual Bottom Bar

10.3 Design of Top Bar

Team 1 took a similar approach as designing the bottom control arm, when designing the top bar. The features remained the same, and mating components were designed to fit without interference on the bottom arm and hinge of the device. Each mating component had a +/- 0.02 inch tolerance to allow the parts to successfully mate with no interference. The overall length of the top bar was 5 inches to meet the length requirements of the Pythagorean Theorem equation. The upper bar, lower bar, and cable formed a triangular shape with minimum and maximum bounds of 5 and 7 inches respectively along the horizontal axis. The length of each bar had to be precise in order for the product to function properly. For ease of installation the top bar and bottom bar had the same dimensions when mating to the upper and lower hinges. This would allow the manufacturer to make three of the same parts, and the installer to use any upper bar, and mate it with any lower bar.

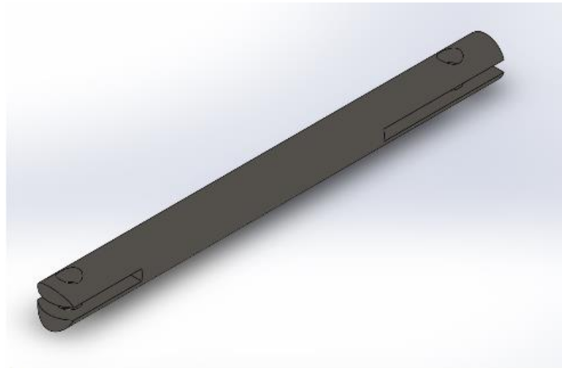

FIGURE 18: Individual Top Bar

10.4 Design of Hinge

The design of the top and bottom hinges were an important aspect of connecting multiple components. Stock parts were ordered with 3 inch diameters out of 1018 CR Steel, which Team 1 knew would fit into the internal diameter of the end-boards. The hinges were designed with the consideration of what machines were available for use at the University of Rhode Island's machine shop. A ½ diameter hole was drilled through the center of the hinge for the main rod to go through. Additional holes were drilled on the side of the tabs to allow screws to fasten the bottom and top rods to the hinges. Extra material was left on the top and bottom of the hinge to allow extra support, as the bottom hinge had all of the weighted force applied on it.

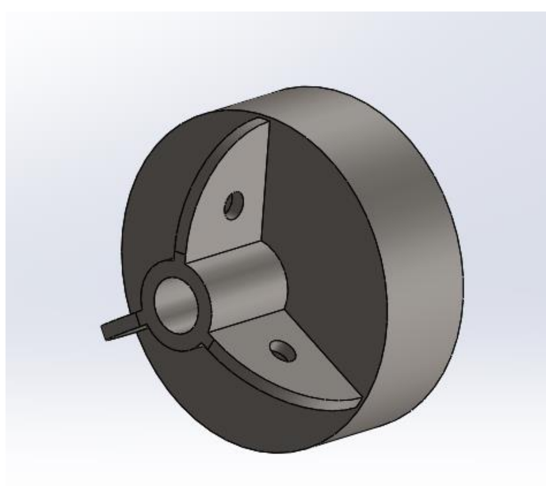

FIGURE 19: Individual Hinge

Bill of Materials:

Table 7 is a complete Bill of Materials for the final product's design. Each previously described component is included within this table. Many raw materials were ordered and needed additional machining. Refer to the Appendix for additional 2D CAD drawings with full dimensions labeled.

TABLE 7: Bill of Materials

Bill of Materials					
Item	**P/N**	**Manufacturer**	**Cost/Unit**	**Quantity**	**Total Cost**
High Strength Neoprene Rubber	8599K31	McMaster-Carr	17.56	1	17.56
6ft x .5" Diameter 1018 Steel Rod	8920K155	McMaster-Carr	14.04	1	14.04
3" Diameter 3" Length Steel Rod	7786T36	McMaster-Carr	23.34	1	23.34
1.5"x2"x2ft Steel Rectangular Bar	8910K83	McMaster-Carr	77.35	1	77.35
3ft Steel Tube	7767T62	McMaster-Carr	25	1	25
Steel Clevis Pin W/Retaining Ring	92735A220	McMaster-Carr	7.05	1	7.05
Steel Clevis Pin W/Retaining Ring	92735A260	McMaster-Carr	7.9	2	15.8
Foam Grip Handle	9445K21	McMaster-Carr	10.48	1	10.48
Foam Grip Handle	9445K22	McMaster-Carr	10.48	1	10.48
Hoist Ring	2994T41	McMaster-Carr	55.19	1	55.19
Steel Coupling Nut	90268A125	McMaster-Carr	8.37	1	8.37
				Total Cost	264.66

10.5 Proof of Concept

This section of the Detailed Product Design explains how Team 1 developed a full scale prototype of the internal clamping mechanism. Team 1 wanted to implement a full scale model primarily for functionality testing and proof of concept. The engineers wanted to make sure the model would fit in the internal end-board hole, expand to the required dimensions, and assure no interference at the mating joints. This 3-D prototype was a necessary step in proving the concept, making sure everything met the design plan before ordering expensive parts and machining each component. In addition, Finite Element Analysis simulations were conducted on the end-board and screws to ensure functionality and quality. The prototype design was developed and proven during the proof of concept portion of the semester. The design was tested and redesigned during the Spring Semester.

10.5.1 Full Scale Prototype

The functionality of the prototype was constructed and tested using a full scale 3-D CAD model. This full scale working model showed that the prototype functioned properly, there was no interference, and met the proper length requirements necessary to lift a stack of end-boards. It also exposed a small design failure, in that the bottom gripping feet were not fully in contact with the ground in the resting position. This problem was later solved in the redesign phase in the Spring Semester. The purpose of the model being full scale was because Toray provided Team 1 with a stack of end-boards for initial testing. These end-boards were full scale, and Team 1 waned to make sure the prototype lengths were all dimensioned properly. The upper and lower arms were made with a 0.5 inch diameter in the resin printer at Schneider Electric. There was an additional post-printing step required to clean additional resin off each bar and blast out the ¼ inch holes with water. The resin printer was set to print at 100% infill which costs $150/kg. The bulk of the design, the gripping feet and hinges, were printed on the ABS plastic printer, which is five times cheaper at $25/kg and 25% infill settings.

TABLE 8: Full Scale 3-D Prototype

The full scale prototype was successful in engaging the perimeter of the internal diameter of the end-boards. The desired location for engagement was when the bottom control arms were almost horizontal to the lifting surface. If this length is too small, the device collapses inwards, and if the length is too large, not enough force will be applied to grip the boards and significantly reduce the mechanical advantage. Overall the functionality of the full scale 3-D prototype was a success.

12 Engineering Analysis

To analyze the solution that was proposed we divided the engineering analysis into several sections. In order for the scissor jack to operate effectively, it is required to lift the end-board stack vertically without the end-board sliding off or falling. The design includes an internal clamp in which a force is applied on the interior hole of the end-board rather than the exterior edges. The interior of the hole is a 1’’ thickness and therefore the available surface area is less when the force is applied on the interior than on the exterior perimeter of the square end-board. To account for time efficiency and ease of use, the set end-board amount for transitioning was 15 end-boards. To analyze the end-board for fracture analysis and for the maximum stresses received the heaviest end-board was analyzed. The dimensions and corresponding weight of the largest end-board is 42’’ by 42’’ with a weight of 44 lbs.

12.1 Prototype Engineering Analysis - Car Jack Design

The next important step in assurance of the solution through engineering analysis is evaluating the clamp size of the specimen. The scissor jack must fit within the hole of the end-board and expand outward to exert a force equal to or greater than the normal force for the corresponding static coefficient of the two materials in contact. Upon conversing with a Toray representative, and furthering the project definition it is clear that the end-board stacks are not concentrically aligned. The particle board of the end-boards is recycled and the suppliers are diverse. The inner scissor jack is required to have a clearance that allows for an open and closed position while encompassing a misalignment factor. To increase the surface area of the contact and thus decreasing the stress applied to the end-board, analysis for one clamp is within the range of 0.25 to 0.5 of the end-board circumference. Each end-board, although varying in outer dimensions has a defined inner diameter. To include a clearance the closed position of the scissor jack must be less than the 1 inch diameter and the surface area in contact with one clamp is to be less than 0.5 of the circumference. Therefore when analyzing the total applied area with two clamps the fraction of contact of a singular clamp is thus doubled. For the clamp shape, the clamp is designed to have an equivalent diameter as the end-board hole. If the shape of the clamp does not match the corresponding end-board then the area in contact will be minimized. An illustration of the concept is shown below to reinforce the importance of this topic,

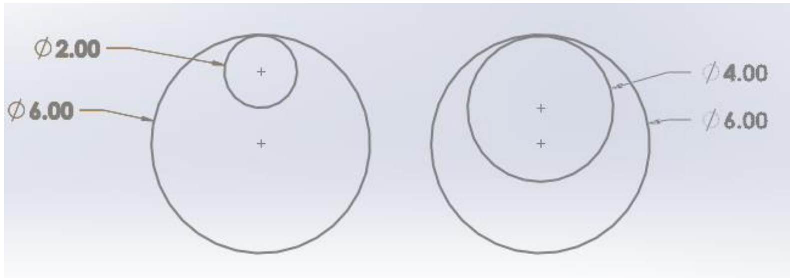

FIGURE 20: Solidworks Drawing of Contact Surface Area

An equation involving the Sagitta or arc height (clamp height) was developed to calculate clearance between open and closed positions [2],

$$h = r - r\cos(\theta)\,, where\ \theta\ is\ measured\ in\ radians$$

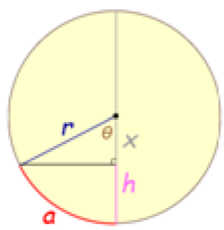

FIGURE 21

For clearance purposes the following is calculated,

$$Open\ Position, Closed\ Position = distance\ between\ clamps\ at\ given\ state$$

$$Clearance = Open\ Position - Closed\ Position$$

$$Clearance = (Diameter - 2 * h), where\ the\ h\ is\ the\ height\ of\ each\ clamp\ (2\ total)$$

TABLE 9: Clearance Values

Size of One Clamp	**0.25**
Size of Two Clamps	0.5
θ	45
θ (radians)	0.785398163
Cos(θ) (radians)	0.707106781
h(in)	0.878679656
Open Position (in)	6
Closed Position (in)	1.757359313
Clearance (in)	4.242640687

TABLE 10: Clearance Values as Function of Clamp Size

Size (fraction of endboard circumference)		
Single Clamp	System	Clearance (in)
0	0	6
0.05	0.1	5.926
0.1	0.2	5.706
0.15	0.3	5.346
0.2	0.4	4.854
0.25	0.5	4.243
0.3	0.6	3.527
0.35	0.7	2.724
0.4	0.8	1.854
0.45	0.9	0.939
0.5	1	0

The size of the clamp has an effect on the tension force needed to balance the vertical load of the 15 end-boards,

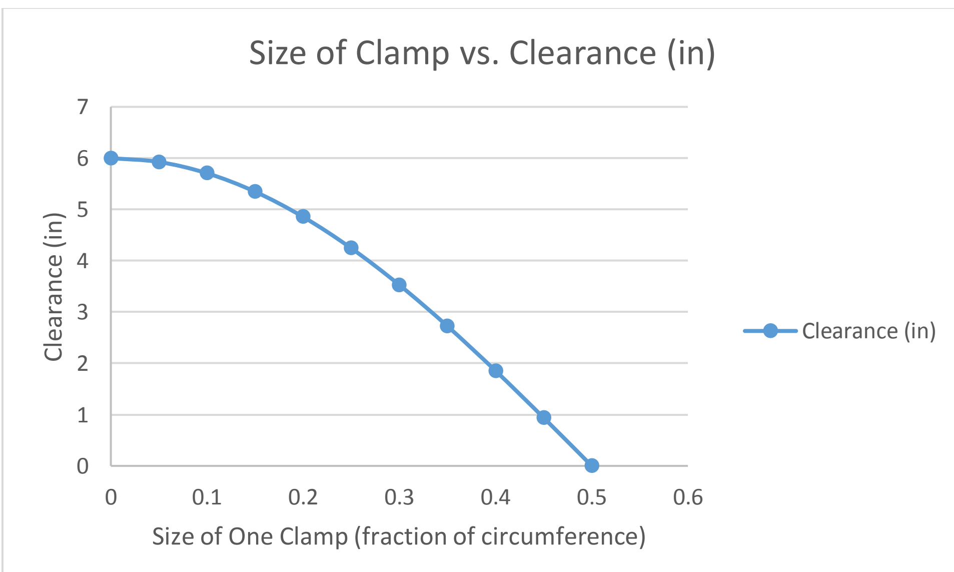

FIGURE 22: Clamp Size vs Clearance

The end-boards are in compression and tension during the process of transferring the stack to the loading cart. The tension applied to the inner surface of the end-board is calculated by,

$$\sigma_{tension} = \frac{F_{normal}}{Inner\ Hole\ Contact\ Surface\ Area}$$

$$System\ fraction = (Clamp\ Size\ fraction) * 2$$

$$Contact\ Circumference\ (in) = System\ fraction * (d * \pi)$$

$$System\ thickness = (endboard\ thickness * number\ of\ endboards)$$

$$Contact\ Surface\ Area = (Contact\ Circumference * system\ thickness)$$

TABLE 11: Tensile Stress Values for Corresponding Singular Clamp Values

Size of Clamp	Tensile Stress
0.05	700.282
0.1	350.14
0.15	233.427
0.2	175.07
0.25	140.056
0.3	116.714
0.35	100.04
0.4	87.535
0.45	77.809
0.5	70.0282

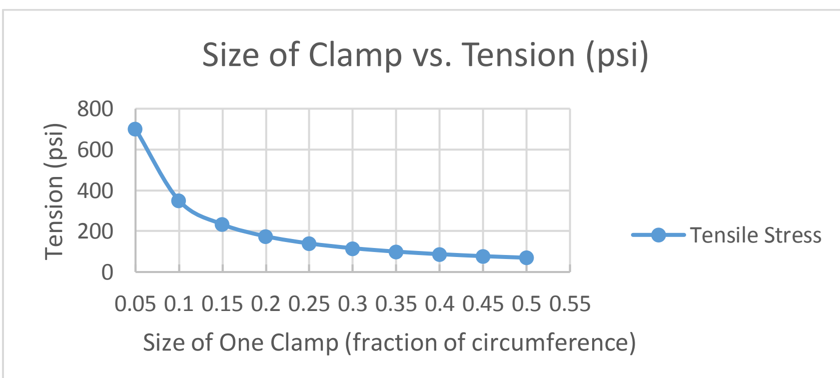

FIGURE 23: End-Board Tension as Function of Clamp Size

The next crucial concept to monitor was the amount of force required to exert the minimum normal force on the interior of the end-boards. The force analysis included moment equilibrium about a point on the scissor jack. This moment diagram will allow provide information with regards to the optimal design dimensions of the scissor jack to accompany 15 end-boards. An assumption was made that both clamps exert an equal force on two opposite sections of the end-board. A simple sketch of the moment equilibrium is included below to address the features included in the calculations.

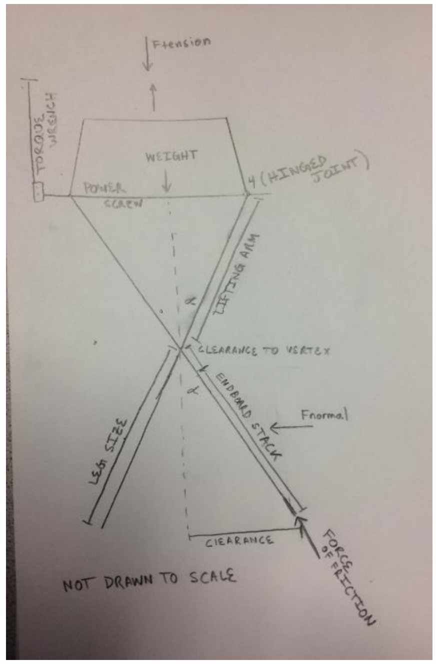

FIGURE 24: FBD for Moment Equilibrium Calculations About the Hinged Joint

When the scissor jack is in the open position and is in contact with the end-boards, the system is stationary with no acceleration present. Therefore an assumption is made that the system is in equilibrium. Summing the moments about the hinge joint the following equation was used to address the force applied to the torque wrench or crank shaft feature.

$$\sum M_{about4} = -M_{ffriction} - M_{fnormal} + M_{weight} + M_{fapplied}$$

The force of friction, weight of the end-boards, and normal force required were all calculated in the force equilibrium in the horizontal and vertical planes. The normal force applied acts on the centroid of the 15 end-boards with each end-board 1'' thick. To calculate the normal force moment arm to the hinged joint, the following was used,

$$MArm_{fnormal} = \frac{(number\ of\ endboards * thickness)}{2} + clearance\ to\ vertex$$

To calculate the leg size for contact with 15 end-boards, with a clearance to the vertex of the lifting arms,

$$leg\ size = (number\ of\ endboards * thickness) + clearance\ to\ vertex$$

$$MArm_{ffriction} = F_{friction} * lifting\ arm, where\ the\ lifting\ arm\ was\ choosen\ arbitrary$$

Microsoft excel was managed to observe how changing the size of the scissor jack feature affected the amount of force required. To calculate the moment of the force applied a torque wrench or crank shaft of arbitrary length was chosen.

$$MArm_{fapplied} = \left(F_{applied} * torque\ wrench\ length\right)$$

The unknown in the moment equilibrium is the force applied. Changing the length of torque wrench, and the lifting arm sizes, one can experimentally find the optimum dimensions for the least required force. The weight of the 15 end-boards was assumed to be acting in the centroid of the stack, or at the vertex of the lifting arms (point 3). To find the angle α, trigonometric equations were used,

$$\alpha = sin^{-1}(\frac{clearance\ to\ vertex}{leg\ size})$$

Then to solve for the weight moment arm,

$$\sin(\alpha) = \frac{MArm_{weight}}{jack\ crank}, then\ solving\ for\ the\ MArm_{weight}\ the\ following\ is\ obtained,$$

$$MArm_{weight} = jack\ crank * \sin(\alpha)$$

An excel algorithm was managed, in which the bolded terms are the independent variables that are chosen arbitrarily.

TABLE 12: Excel Algorithm for Optimum Force and Dimensions

Clearance (in)	0.93860679
Fn Moment Arm	9.5
Clearance Rubber to Vertex	**2**
Leg Size	17
Lifting Arm	**1**
α radians	0.055240254
α Degrees	3.165033413
Torque Wrench Length	**48**
Weight Moment Arm	0.055212164

To select the dimensions of the design, the moment of the force applied was the highest priority. Other than the observed dependent feature, the arbitrary dimensions were held constant. These arbitrary features include the following, torque wrench length (48in), size of one clamp (0.25), lifting arm length (1in), and clearance to vertex (2in). Evaluating one arbitrary value in incremental measurements involved holding the other features constant at the dimensions listed above.

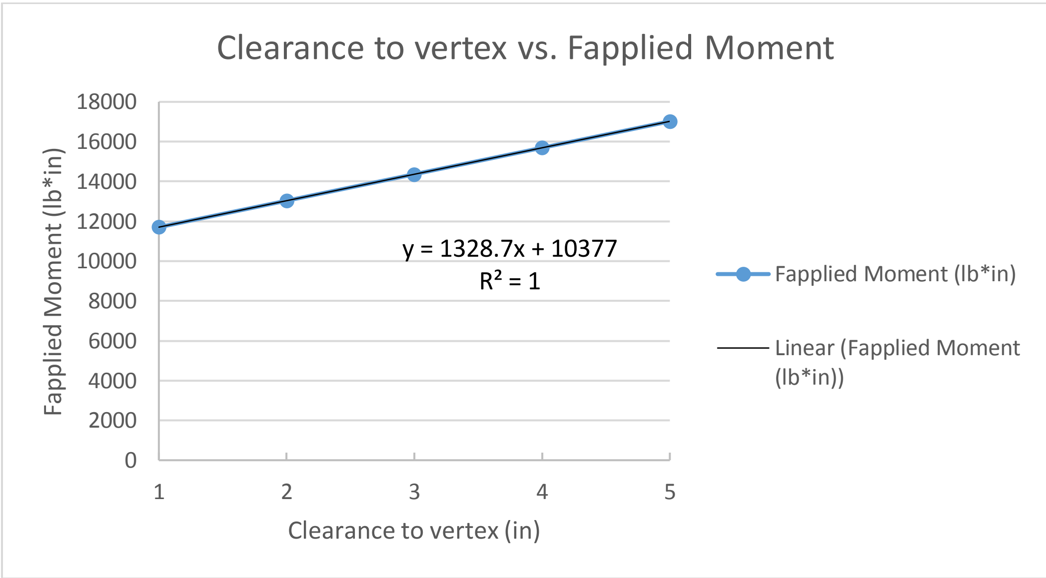

FIGURE 25: Moment Required to Turn Screw

TABLE 13: Moment Required to Turn Screw

Clearance to Vertex (in)	Fapplied Moment (lb*in)
1	11704.991
2	13035.285
3	14364.437
4	15692.624
5	17019.993

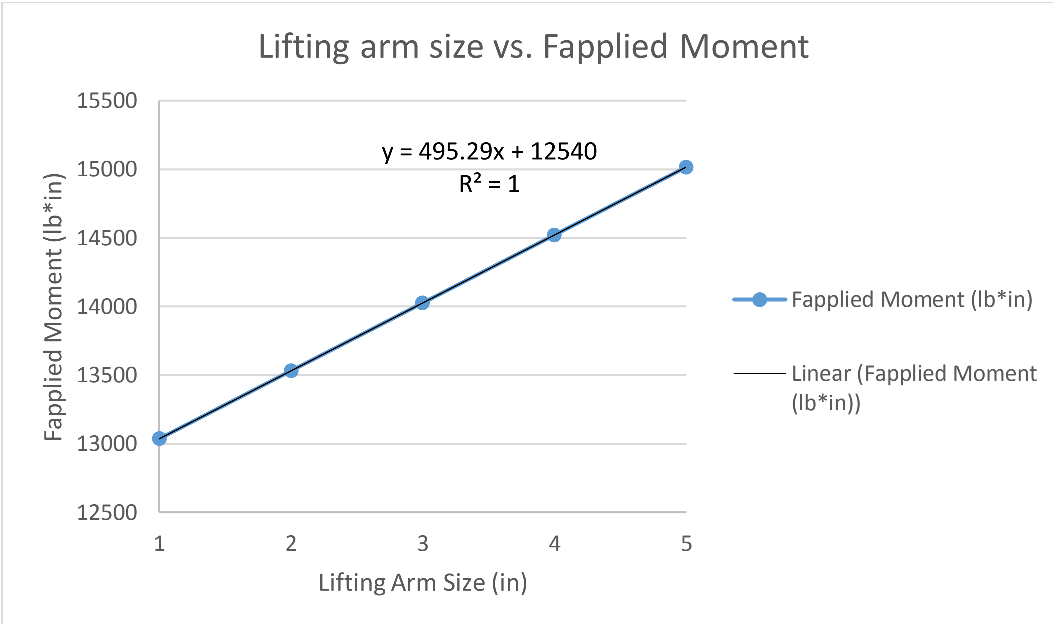

FIGURE 26: The Required Force Moment in Terms of the Lifting Arm Size

TABLE 14: The Required Force Moment in Terms of the Lifting Arm Size

Lifting Arm (in)	Fapplied Moment (lb*in)
1	13035.286
2	13530.571
3	14025.857
4	14521.143
5	15016.429

To minimize the force applied to the power screw, the force applied moment was also decreased. Therefore, by have a minimal required force applied, the operator exerts less force onto the machine for relative ease of use. The dimensional analysis above was used for the part dimension of the scissor jack.

12.2.0 Final Design Engineering Analysis

12.2.1 Force Equilibrium Calculations

A free body diagram (FBD) allowed for the required normal force to be calculated. With the end-board designated stack at 15 end-boards and the largest end board weight of 44 lbs the entire column has a weight of 660lbs in the vertical direction. With the hoist system being a factor in accelerating the end-board and transferring the particle board from one station to the next, force equilibrium can be calculated between the frictional force applied and the weight of the end-boards. The frictional force is a function of the static coefficient of the two materials in question. The purpose of design is for the end-boards to be stationary once the inner scissor jack is applied. The static coefficient measures the frictional force prior to the end-boards acceleration. To increase repeatability and decrease time for maintenance for exchanging the materials used, a hard, durable steel of yield strength 36,000psi will be used for the scissor jack tongs that are in contact with the end-boards. Summing the forces in the vertical direction and equating the results,

$$F_{friction} = F_{normal} * \mu_{static}$$

$$\sum F_{vertical} = 0 = F_{friction} - W_{15\ endboards}$$

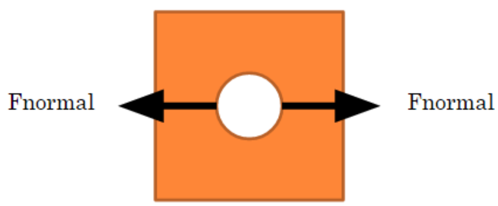

FIGURE 27: Simple FBD

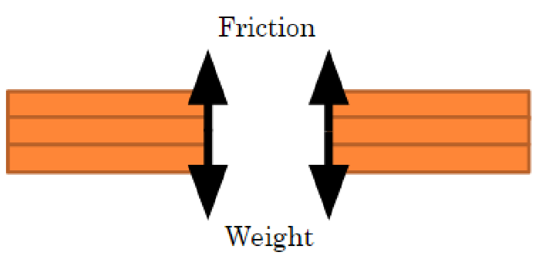

FIGURE 28: Simple FBD

The static coefficient of friction between steel and particle board is in the range of 0.5-0.6. Using the lower limit of 0.5 one can approximate the maximum force applied to the structure. Substituting in for the static coefficient term, the normal force to sustain 15 end-boards is 1320lbf. The range of static coefficient terms as a function of the normal force within the range specified for steel on wood the following graph displayed how increasing values of the static coefficient by changing the materials of the scissor jack can decrease the amount of force needed to be applied.

TABLE 15: Coefficient of Static Friction

Coefficient of Static Friction		
Material:	**θ**	**μ_s**
Particle Board on Particle Board	23º	0.424
Particle Board on Metal	17º	0.306
Particle Board on Rubber	38º	0.781

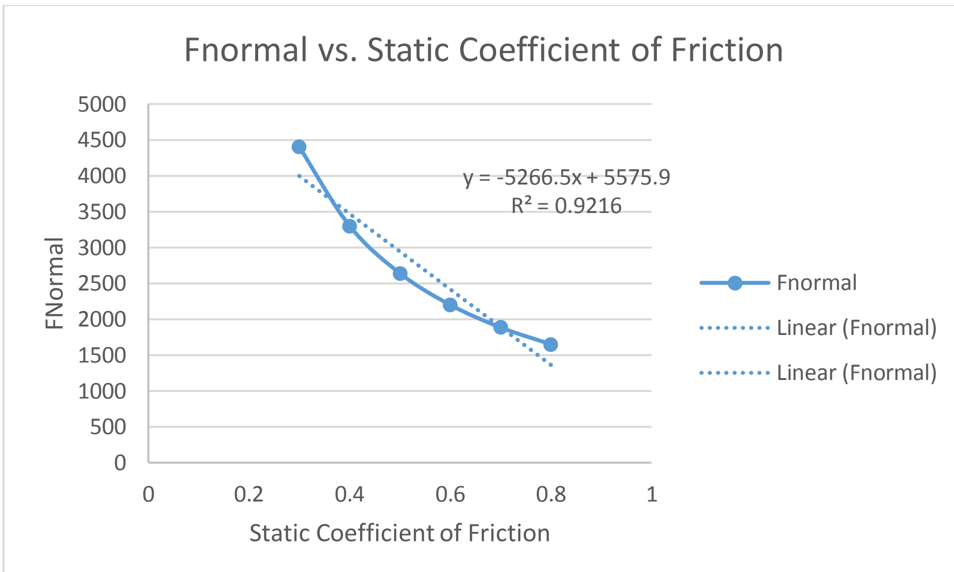

FIGURE 29: Normal Required Force as a Function of the Static Coefficient of Friction

12.2.2 End-Board Finite Element Analysis

The maximum compression is exerted on the bottom end-board. This particular end-board supports the weight of the 14 end-boards that are organized on its top surface. To calculate the maximum compression exerted onto an end-board,

$$\sigma_{compression} = \frac{Weight_{14\ endboards}}{Top\ Face\ Contact\ Surface\ Area}$$

$$Top\ Face\ Contact\ Surface\ Area = (Length * Width) - (\pi * radius^2)$$

To balance the tension force and the clearance of the clamp a singular clamp range within (0.25-0.5) was selected. To predict the maximum stress of the proposed solution the following conditions will be induced to the bottom end-board; minimal coefficient of static friction, maximum compressive stress, and maximum tensile stress (with in the 0.25-0.5 fractional clamp arc length). Finite element analysis (FEA) will provide the resources to determine the state of the end-board after applying the stresses. If the bottom end-board receives the total tension exerted by the normal force then the following exists,

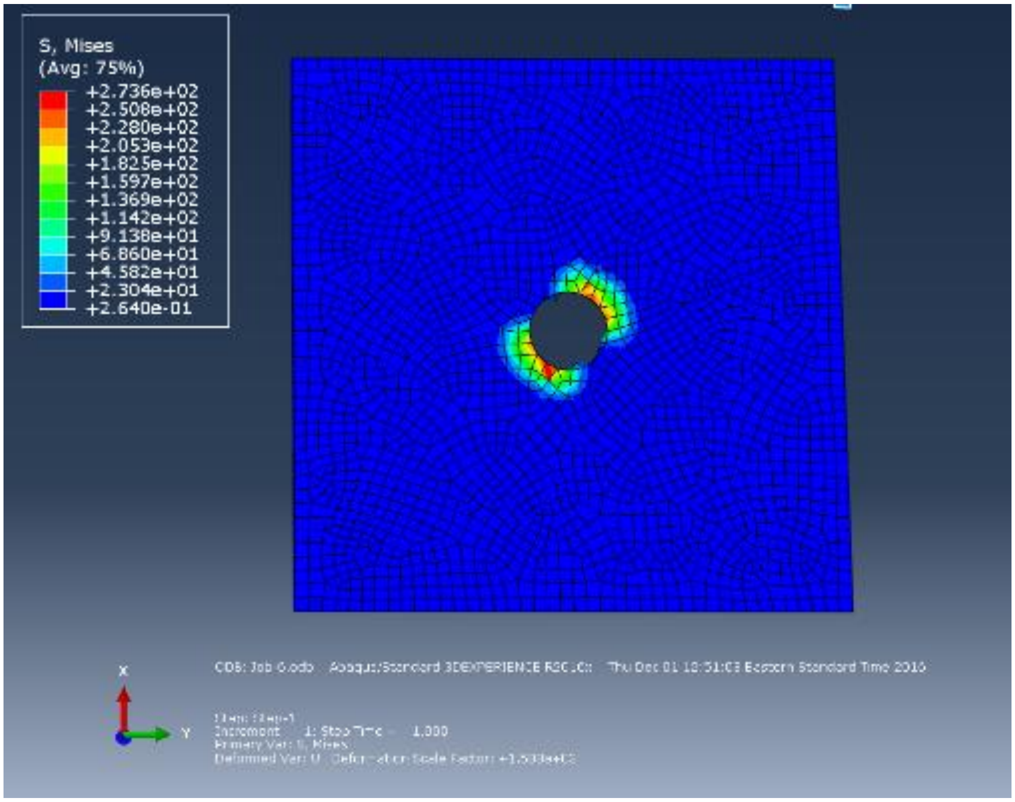

FIGURE 30: Abaqus Von Misses Stress on End-Board

The maximum von misses value was located at the inner hole with a value of 273.6 psi. This value fell below that of the yield strength of the particle board. The yield strength of wood is 810 psi. The yield strength of the steel support structure is 36,300psi [3]. A factor of safety of 2.96 exists. The factor of safety was calculated by,

$$FOS = \frac{yield\ strength}{von\ mises\ \max stress}$$

This calculation provided reassurance in the unexpected condition that this scissor jack is only in contact with the bottom surface of 1’’ thick particle board. For the intended solution, the entire stack of 15 end-boards are in contact with the scissor jack. By increasing the number of end-boards in contact with the scissor jack the stress exerted is decreased.

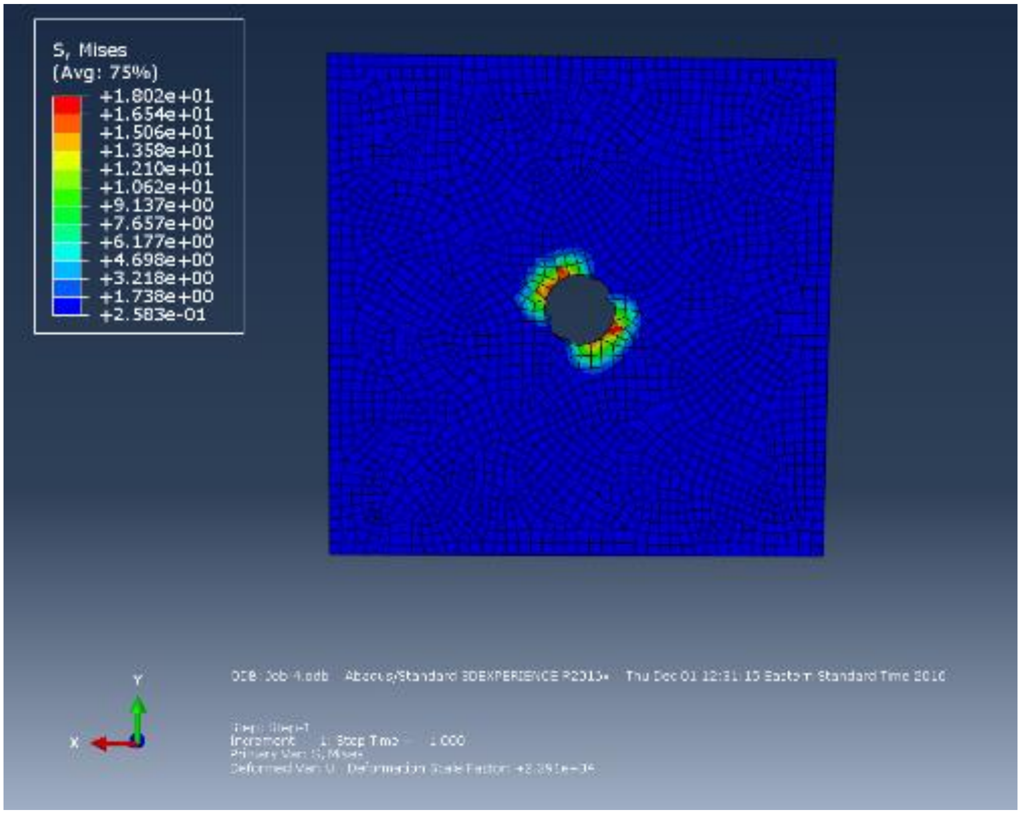

FIGURE 31: Abaqus Von Misses Stress on the Bottom End-Board (15 End-Boards)

The maximum von misses value was located at the inner hole with a value of 18.02 psi. This value fell below that of the yield strength of the particle board. A factor of safety of 44.95 exists.

Our actual design with the three feet was in contact with .6 of the entire circumference of the internal hole. For the engineering analysis, our initial design applies a force directly to the end-boards. However, in the actual design the weight of the end-boards is used advantageously to act in the direction of the frictional force. With the internal clamp size of .3 of the circumference the tensile stress required to hold the end-boards up is 155.61 psi. Clamping size fall within the bounds that was experimented on abaqus and therefore the design is structurally sound.

12.2.3 Bolt Finite Element Analysis

The top bolt of the design is screwed into the hoist mechanism. Therefore the top bolt will be exposed to a shearing force of the weight of the entire end-board set and the internal clamping design. Calculations for the applied pressure on the screw threads of the for a UNC ½-13 bolts demonstrated structural reassurance on the design. The top screw exposed to the total shearing stress calculated by the following equation was 265.9 psi which is significantly lower than the yielding strength for the material (63800 psi).

$$\sigma_{shear} = \pi * n * L_e * D_{min}\left[\left[\frac{1}{2n}\right] + 0.57735(Dmin - Enmax)\right]$$

$$where\ the\ D_{\min} \quad = \min major\ diam\ of\ the\ external\ threads$$

$$Enmax = \max pitch\ diameter\ of\ the\ internal\ threads$$

$$n = thread\ per\ inch$$

$$L_e = length\ of\ thread\ engagement$$

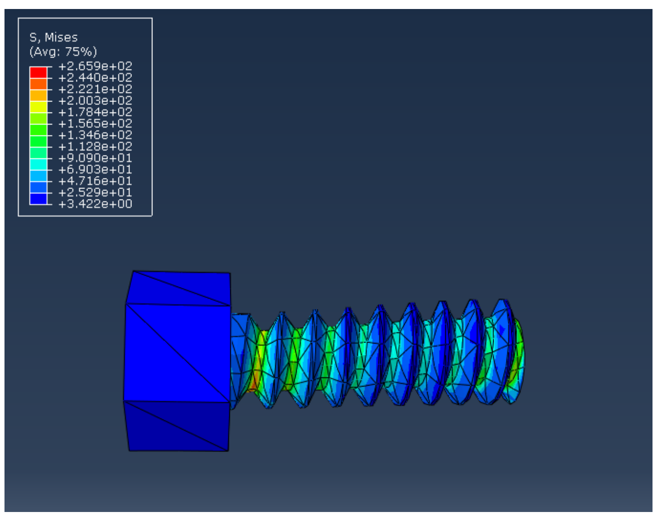

FIGURE 32: Bolt FEA

With knowledge that the top bolt would resist the shear stress applied to the threads, began to analyze the bearing stress on the 9 bolts crucial in the assembly of the product. To analyze the maximum force applied to the bolts, the following equations were used for the 9 shoulder screws of ½'' length, 10-24 thread size and 3/8'' head diameter and head height.

$F_{max} = \frac{F_{weight}}{9} + (Moment\ Arm * (\frac{F_{normal}}{3})$

$$S_{sy} = .577 * minyieldstrength$$

$$A_{bearing} = thickness * diameter$$

$$F_{max} = 1778.53 lbs$$

$$\frac{F_{max}}{A_{bearing}} \leq \frac{S_{sy}}{n}, where\ n\ is\ the\ number\ of\ bolts$$

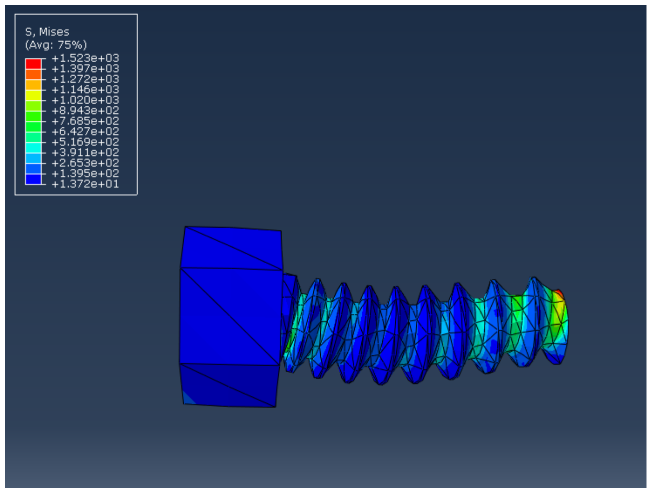

FIGURE 33: Bolt FEA

The applied pressure of the sum of the end-board weights and the internal clamping system was applied to the upper half of the bolt. The boundary conditions allowed the bolt to function as a simple beam. The applied bearing stress was calculated to be 1523psi. The yield strength of the 1018 cold rolled steel was arbitrary at 53700psi.

12.2.4 Bottom Weld Analysis

The bottom weld of the rod and hinge attachment was designed to withstand the weight of 30 of the largest sized end-boards. The required carrying capacity for this design was 1320lbs. In order to calculate the pressure applied at the circumferential butt weld, the surface area of the applied force on the filleted weld needed to be calculated. In order to calculate the area of the weld surface, the weld shape was assumed to be a fraction of a cone. Continuing the slope of the weld to complete the overall cone shape the dimensions of the cone were .85''(height) x .52'' radius. The height of the weld was .15''. Therefore, the bottom area in contact with the net force vertically is .3158''. The applied pressure was calculated neglecting the weight of our design in the total vertical force applied.

$$Cone\ Area = \pi * r\left(r + \sqrt{h^2 + r^2}\right) = \pi * .52\left(.52 + \sqrt{.85^2 + .52^2}\right)$$

$$weld\ pressure = \frac{1320lbs}{.3158in^2} = 4179.86psi$$

The resulting maximum Von Mises as shown through Abaqus was 4599psi. This compare to the yield strength for 1018 cold rolled steel at 53700psi. Therefore, a factor of safety of 11.6 exists in the welded joint.

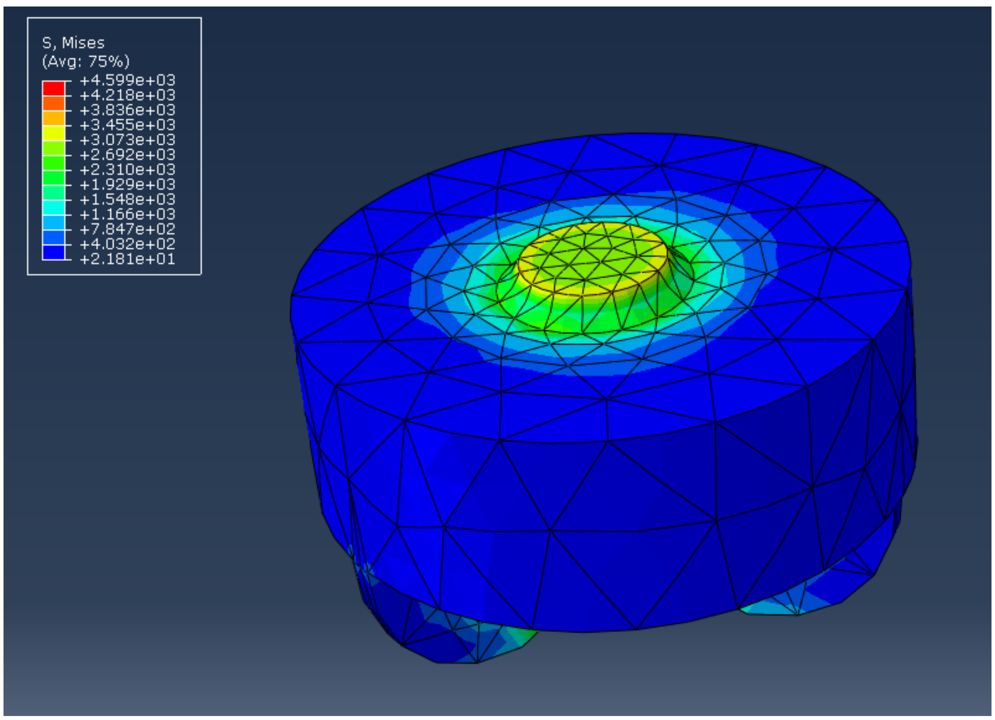

FIGURE 34: Bottom Circumferential Butt Weld Analysis on Rod and Hinge Joint

To reassure the results of the analysis, theoretical calculations for a circumferential butt weld were analyzed. The corresponding equation for a butt weld in tension is

$$\sigma_{weld\ allowable\ tension} = .6 * Sy = .6 * 53700psi = 33294psi$$

$$for\ a\ factor\ of\ safety\ of\ n = 1.67$$

The calculated value for the maximum Von Mises stress on the weld is significantly lower than that of the permissible yield stress in tension.

13 Build/Manufacture

13.1 Prototypes

The final solution was progressively formulated through multiple prototypes. The first prototype employed the internal mechanism of a "car jack." The team purchased equipment from a local hardware store and assembled the design to showcase before the class and sponsor for our concept design review in December. The internal gripping mechanism represents a car jack that applies force to the inner diameter of the end-boards. The first prototype is shown below.

FIGURE 35: Prototype #1

The next prototype developed was 3-D printed on the new machines available at the Schneider Electric facility. Once the team decided on a solution that met the specifications of the product and the engineering analysis on the design was proven to be structurally sound, the group set the file to the TA for a review of the mechanism. Each individual part of the assembly was 3-D printed prior to the purchasing of steel parts to ensure the group that the device would fit properly into the end-board, and that no serious design problems existed. The overall process of 3-D printing took a period of a day. The second and final prototype is shown below.

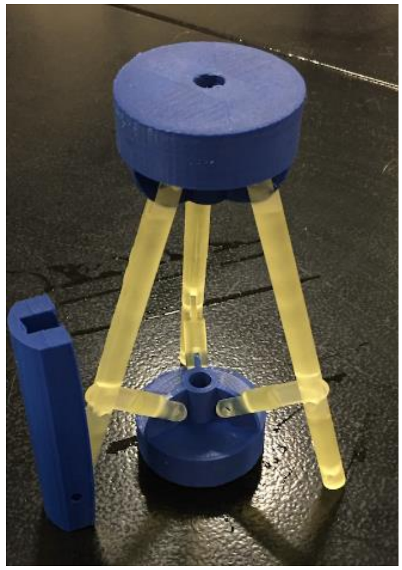

FIGURE 36: Prototype #2

13.2 Final Build

There were many manufacturing processes involved in the construction of the final internal clamping device. The initial materials were ordered from McMaster-Carr and it is mostly composed of 1018 stainless steel raw stock. Team 1 choose stainless steel after discussions with the URI machinists who provided insight on the best possible materials and procedure for manufacturing the internal clamping device. This device comprised of many intricate parts that must be manufactured individually prior to assembly. The lower and upper control arms were cut to length with the vertical band saw. By carefully monitoring our fingers, and wearing eye protection we then polished the resulting arms with the sanding machine. The majority of the manufacturing of the arms were cut with the mill machine. The machine was zeroed at the approximate location and the corresponding drill, and chuck were inserted. Due to the relative hardness of the material, coolant and pressurized air were constantly applied to the cut to lower the temperature of the drill bit. The time for manufacturing on the mill was lengthy. The inserts were cut layer by layer with .05'' cuts. Then a center drill was inserted for the drilling of the holes for the placement of the bolts.

The feet were ordered in rectangular stock. Referencing the drawings available on Solidworks, the feet were cut accordingly on the horizontal band saw. The relative time of this process was 20 minutes. The slab was then faced on the milling machine with a face drill bit.

This slab was now in the overall outer dimensions. Using the marked up drawings the mill machine was zeroed and the inserts of the feet were cut with horizontal passes of the milling machine. The part drawing was sent to an experienced machinist for further machining with the CNC machine to attain a curved surface finish to fit the circumference of the end-board. The same drilling steps ensued to add the corresponding holes into the feel for bolt attachments.

The hinges were order in large disks and cut to size using the horizontal band saw. Going forward to speed the process of manufacturing, these two hinges should be outsourced at the specifications provided. This will eliminate the rather lengthy of cutting the hinges to size with the horizontal band saw. The hinges were faced to the correct dimensions with use of a dial indicator. The next step in the construction of the hinges was to drill the center holes for weld attachment and the insertion of the metal rod for opening/closing of the device. The hinge was fastened into the chuck of the lathe and the end drill was applied carefully into the center of the hinge. Once the center holes were cut the material was shaved by the milling machine and the corresponding holes were drilled. The drilling process included attaching the hinges on an angular chuck that could rotate to 120, 240 and 360 degrees for equal drilling spacing.

The manufacturing process was heavily focused on the facing and sanding of materials the required specifications. This process could be eliminated by outsourcing the hinges and feet to size. Due to the intricacy of the design, and the high resistance of the materials used, this part would likely not be mass produced. Furthermore, the design allows adaptability and proportional changes to accompany different internal diameters. In order to increase the efficiency of the manufacturing process, we could rearrange the machines of the machine shop to be in one continuous motion for the operator. This will dissolve unnecessary walking between steps and decrease the total cycle time for each of the parts machined. In total the entire process of manufacturing the device took around 11 hours and the distribution of the hours spent in the machine shop is outline below in the following pie chart.

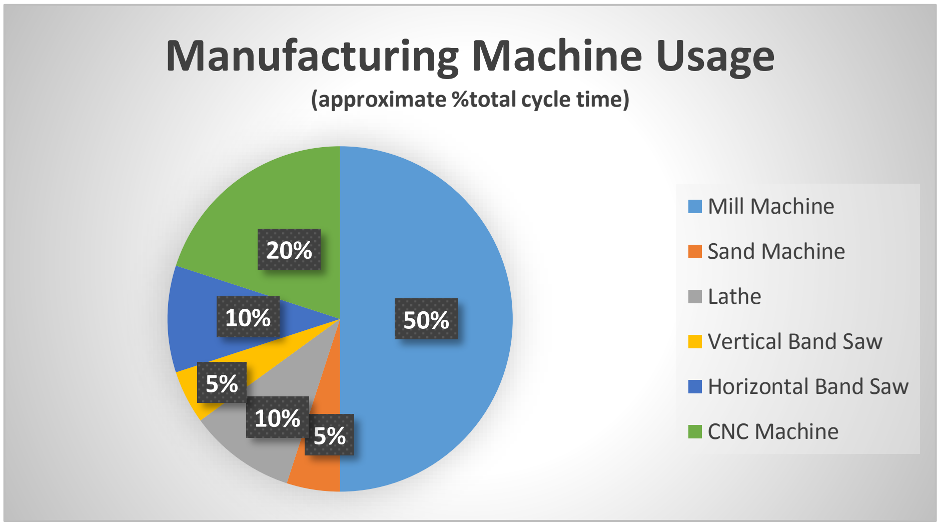

FIGURE 37: Manufacturing Machine Usage

14 Testing

After the manufacturing of the prototype was complete, the design needed to be extensively tested and re-designed to ensure the mechanism was safe and effective. There were initially two phases of testing of the design. The first focused on the ease of use and the ergonomics of the design and the second focused on the safety of the design and the overall ability to secure a maximum amount of end-boards. This section details the two separate phases of testing and the next section explains the re-design which resulted from this testing.

14.1 Phase I – Material Selection

The first phase of testing which was completed immediately after the design was built focused on selecting the most appropriate and safest material to use on the feet for securing and lifting end-boards. The ability for the design to lift end-boards depends entirely on the material which is placed on the metal feet. Without any material on the metal, the design is unable to lift any end-boards, this is because the metal has a very low coefficient of friction with the end-boards. To maximize the amount of end-boards which can be picked up and to increase the safety of the design the best material had to be selected to be used on the feet. To accomplish this, Team 1 identified a variety of potentially good materials based on strength, durometer, and thickness and then proceeded to test the coefficient of these materials against the end-board particle board materials. The table below shows the materials chosen and the derived coefficients of friction from testing.

TABLE 16: Coefficient of Friction Testing Tabulated Results

Coefficient of Friction Testing		
Material	Angle of Slip (degrees)	μ
Stainless Steel	17	0.3
Polyurethane	23	0.42
Neoprene	38	0.78
Adhesive Sandpaper	41	0.86

As shown above the highest coefficient of friction on the particle board was the adhesive sandpaper, followed by the neoprene rubber. Because these materials had the highest coefficients of friction we expected these materials to secure and lift the most end-boards.

Once Team 1 obtained the coefficients of friction for the materials that would be tested it was time to actually test these materials on the design and see how many end-boards could be lifted. To accomplish this the testing would be done by lifting up end-boards and incrementally adding more and more weight to the boards until the end-boards started to slip. The testing for this phase was done using an electric winch with a max lifting capacity of 1 ton. Each test with different materials was preformed five times. To test the effectiveness of the different materials the following testing steps were used:

Testing Steps:

1. Secure the material to be tested onto the metal feet by adhesive or bolts
2. Enter the lifting device into 5 end-boards and lift them above the ground
3. Once securely lifted, incrementally add 50lb bags of sand to the tops of the end-boards until the bottom end-board started slipping and falling off.
4. Record the amount of weight lifted with each material and repeat the above steps for five trials for each material.

The following table is the testing matrix with the results obtained:

TABLE 17: Testing Matrix

Test Matrix			
Trial	Weight Lifted Before Slipping (lbs.)		
	Neoprene Feet	Polyurethane Feet	Adhesive Sanding Feet
1	550	400	200
2	500	350	150
3	600	500	150
4	500	400	200
5	550	400	100
Average	540 lbs.	410 lbs.	160 lbs.

After this testing phase Team 1 determined that the neoprene rubber was the best material to use. This material could withstand an average of 540lbs before the last end-board started slipping and fell of the design. It is important to note that in all of these tests, it was only the last end board which slipped off, in none of the trials did more boards slip off. In comparison to the other materials the neoprene vastly outperformed the other materials. The neoprene held an average of 130 lbs more than the polyurethane and 380 lbs more than the adhesive sandpaper. The adhesive sandpaper also yielded surprising results with its average of 160 lbs. This low lifting capacity was a result of the sandpaper actually slipping off the metal which rendered it useless, even though this material had the highest coefficient of friction, this material was not well suited for the application. After preforming these tests, it was made clear that the best material for gripping the end-boards was the neoprene rubber. This material was chosen to be attached to the feet on the final design.

14.2 Phase II – Ease of Use & Ergonomics

The second phase of testing focused mostly on the functionality of the design and how easy it was for operators to use the design. The design that was built by Team 1 is intended to be used in a manufacturing facility constantly throughout the day. For this design to be successful it needs to be easy for the operators to use repetitively with ease and without injury. For the design to be successful from an ergonomic standpoint we determined it needed to accomplish the following:

- Adhere to OSHA standards for ergonomics in the work force
- Require little effort to lift, attach, and detach the device from the end-boards
- Be safe to use

To test these traits which Team 1 determined to be crucial to the success of this project, Team 1 returned the hoist to operate the design. To learn how easy the design was to use and understand ways in which it could be improved, Team 1 took turns lifting and moving the end-boards in the lab. Each member took notes on their experience using the design for prolonged times and identified ways to make the design easier to use. The following items are notes which team members took with an accompanying re-design which will make the design easier to use.

- Feet should be moved lower to the ground to make the last end-board easier to grip.
- Handles should be added to the design to make the device more comfortable to use

The actual re-design will be analyzed more in the next section however the initial testing phase was able to highlight some great ideas for re-design. These various factors were identified to make this design easier to use repetitively and constantly throughout the day but overall the ergonomics testing phase of the design was very successful.

Currently in the factory operators are picking up the heavy end-boards one at a time and transporting them onto end-board carts. This current process is not adhering to ergonomic standards set by OSHA which dictates that the maximum amount a person can lift should not be in excess of 50 lbs but often, operators are lifting more than that. After using this device for prolonged periods, it is evident the design is much more ergonomic and safe than the current process. The final design adheres to all OSHA standards and is also much easier and efficient for operators to use. After this testing phase Team 1 is confident the design is an effective solution and several factors were identified to improve the functionality. After some re-design to address the issues found in the testing phase, this design will be improved and ready for use.

15 Redesign

After completing the initial build of the internal gripping mechanism, Team 1 went straight to testing to identify ways in which this design could potentially be improved in terms of safety, ergonomics and general ease of use. There were two initial phases of testing which resulted in two different redesign phases to improve the design. The two stages were material selection and ergonomics/ease of use. This section goes into depth about those stages and also touches on some other areas where future redesign could be implemented.

15.1 Phase I – Material Selection

The first phase of testing the design went through was vigorous testing to determine the most appropriate material for gripping the end-boards. The first step in this process was to determine the best coefficient of friction for the end-boards which was tabulated in Table 16. From this testing Team 1 then tested the internal gripping mechanism with the different materials and determined the neoprene was the best material for gripping the end-boards. This material selection was the first phase of redesign and once this was decided upon more neoprene for the feet was purchased. This redesign was a very important step and it allowed the design to pick up a maximum amount of end-boards. Once Team 1 determined the material, the neoprene was bolted to the design which allows for replacement material to be attached in the event that the neoprene became worn out over use.

15.2 Phase I – Ergonomics & Ease of Use

The second phase of testing focused mostly on the functionality of the design and how easy it was for operators to use the design. The design that was built by Team 1 is intended to be used in a manufacturing facility constantly throughout the day. For this design to be successful it needs to be easy for the operators to use repetitively with ease and without injury. To learn how easy the design was to use and understand ways in which it could be improved, Team 1 took turns lifting and moving the end-boards in the lab. Each member took notes on their experience using the design for prolonged times and identified ways to make the design easier to use. The first redesign which was identified was that the design should have handles to make the gripping of this device easier. To accomplish this Team 1 purchased foam handles to attach to the rods of the metal. After applying these handles, it was found to dramatically improve the ease of use of the design especially over a prolonged time.

The second redesign which was identified was that the design was consistently unable to secure and pick up the last end-board in the pile. This malfunction was because the feet were positioned to high on the gripping mechanism. When the design was entered into the center of the end-boards it would slip over the last end-board and not pick it up. To fix this issue Team 1 decided to drill new holes into the feet to move the feet lower to the ground. It was decided that the holes were drilled 1 inch lower to fix this issue. After this was done. Team 1 went back to testing to see if this resolved the issue. After testing it was clear this solved the issue as the last end-board was now easily secured and picked by the center gripping mechanism.

15.3 Future Redesign

The redesign phase of Team 1's built was extremely successful in fixing every identified issue. After the redesign the center gripping became easier to use, more ergonomic, and also safer for the operator to use because it was not dropping the last end-board. In the future there is one more factor which Team 1 has identified which could help make this design even better. The potential future redesign is a safety feature which Team 1 would like to add to the center gripping mechanism. To improve the safety, Team 1 would like to include an extended handling bar on the shaft of the design. This bar would protrude about four feet and have a handle on it for the operator to grab and move the end-boards with. This functionality would help make this solution safer because once the end-boards are suspended this would add distance between the operator and end-boards in case one were to fall. This is not absolutely necessary however it is an another fail safe to potentially be added into the design. Overall Team 1 found the redesign phase of the design to be very successful in identifying and fixing a few small issues and fixing them to maximize safety, ergonomics, and general ease of use.

16. Operation

16.1 How it Works

The task at hand assigned to Team 1 was to develop an internal clamping mechanism to move end-boards off the pallet in which they are received at Toray, onto a loading cart which will then be placed into the overall automated packaging system. The internal clamping mechanism is designed to fit into a 6 1/16" diameter hole, located in the center of the stack of end-boards. When fully extended vertically, the device has a minimum diameter of 5 inches. When the device is fully compressed vertically, it has a maximum diameter of 7 inches. The minimum diameter of 5 inches was chosen so the internal clamping mechanism can fully submerge to grab the last end-board on the bottom of the pallet. The end-board holes are not perfectly aligned due to shipment handling before Toray receives the pallets. The 5-inch minimum diameter was designed to allow the device to enter the hole alignment without interfering with the perimeter of the hole. The maximum diameter of 7 inches was designed to interfere with the perimeter of the hole, exerting an outward force along the circumference of the hole. The device has a handle feature to control the motion of the internal clamping mechanism; either extending the two handles, or compressing them. This handle was designed for ease of use for the operator, allowing them to engage or dis-engage the gripping feet from the end-boards.

Toray receives the shipment in stacks of 30 end-boards. The target goal of picking up 15 end-boards per load was achieved. The device can be lowered to any target range to pick up various amounts of end-boards. The operation ideally would be to lower the internal clamping mechanism to 15 inches, picking up the top 15 end-boards. Once the end-boards are lowered onto the loading cart, the operator would return to the pallet and lower the device, picking up the last 15 end-boards and move them onto the loading cart. The design allows for a variable range of end-boards to be picked up and placed down elsewhere.

The three gripping feet are designed to come in contact with the bottom most end-board, and are able to slightly pivot to adjust to an uneven stack of boards. The pivot axis for the gripping feet are located 2 inches from the bottom of the feet, allowing the maximum force to be exerted to the bottom most end-board. This design allows the devices to fully operate under the power of its own weight. The device will be controlled with a handling bar extension for safety assurance when moving the stack of end-boards from the pallet to the loading cart. The height on the vertical axis will be controlled by an “up” and “down” range of motion from the industrial lifting hoist.

15.2 Installation

The strategy for installation was taken into consideration early in the design phase. This allowed for an easy and simple installation process when the operator is using the internal clamping mechanism in the field. The operator starts by attaching the three neoprene grips to the feet of the device. This is done by inserting a screw through the top of the feet, and bottom of the feet, followed by attaching washers to the back end of the screw. Once all three feet have the neoprene gripping material securely fastened to the device, the operator is ready to attach the internal clamping mechanism to the industrial lifting hoist. This is done by taking the hook from the hoist and clamping it onto the designed hook on the device.

17. Maintenance

17.1 Consumer Maintenance

Upon receiving the internal clamping device, the consumer should thoroughly inspect all of the components listed in the Bill of Materials. It is important to ensure no chipped or burred edges have been machined that would lead to failure. This is critical to get maximum usage out of every part. A hairline fracture could potentially lead to the 1018 stainless steel material to not having its full yield strength properties and causing failure. All parts should be measured and inspected to make sure they are machined to spec for successful usage. The user should inspect the gripping neoprene material periodically to maintain the best gripping strength and the proper coefficient of static friction, greater than 0.80. The neoprene pads will periodically need to be changed out after many cycles have been conducted. It is smart to inspect for loose nuts and bolts before use for safety and quality purposes. The steel frame structure will have a very long life span if the product is used correctly and only with end-boards.

17.2 Recycling and Disposal

After termination of the products successful lifespan, the neoprene rubber material should be removed and recycled. The rest of the steel based parts can be melted and successfully disposed. Toray, being a heavily based chemical company, should use a pre-existing disposable outlet. Bringing the used parts to a scrap yard can also be easily obtained. The operational cost will be extremely low for disposing and recycling the internal clamping mechanism because the device was designed and created using all of the same material. Scrap yard shipments or melting arrangements would only take place rarely, when the products lifespan is over. Metal is a non-renewable resource and is often recycled for other uses, making this complete cycle environmentally beneficial. It is recommended that the product owner checks with local town and state governments for disposal instructions.

18. Additional Considerations

18.1 Economic Impact

The internal clamping design established by Team 01 contributes considerable economic impact for Toray Plastics of America. As previously discussed the manufacturing facility currently has a manual method for the loading section of the automated packaging line. The station consists of multiple workers running this one operation. First a forklift driver is required to bring multiple pallets of end-boards to the location where an additional two operators are assigned. After the pallet is conveyed from the docking area to the station they are removed from the shipping pallet and conveyed to the loading cart. Under OSHA (Occupational Safety and Health Administration) and NIOSH (National Institute for Occupational Safety and Health) a laborer cannot lift a weight exceeding 50lbs. There are four sizes of end-boards weighing in at 14, 22, 24, and 44 lbs with this being said only a few are able to be transported two at a time and due to the configuration of the particle board sheets they're not the easiest to maneuver, most of the time they are transported one at a time. This is a long and repetitive task that can cause strain of constantly bending and lifting these heavy sheets of wood composite. Through a time study shown in Table 2 this method also takes a considerable amount of time to be completed at around 7 end-boards/minute. The design developed by the team removes most of these factors and cuts down the time it takes to fully prep the loading carts. Only one worker is required to run this operation due to the maneuverability of the station. A forklift driver is still required to deliver pallets that can weigh in as much as 2,200lbs. Once they are brought into position the internal clamping system does exactly what it is designed to do. Suspended by a hoist system the clamp is lowered into the center hole where it grips the external diameter and lifts multiple end-boards off of the cart and transfers them onto the loading cart. Testing of the gripping mechanism showed it is more than capable of transferring at least fifteen of the heaviest sized end-boards in a single lift. This cuts down the transfer time down to around 15 end-boards/minute which eliminates a massive production bottleneck. An in-depth cost savings analysis is also performed in section three which outlines this. By implementing this solution Toray Industries will certainly see immense economic benefits by cutting down on labor costs and having a more efficient transfer station.

18.2 Environmental Impact

The design that has been constructed will have little impact on the environment. The clamping system itself does not use an external power supply of any kind. The mechanism is powered dependently on the weight of end-boards being lifted. The only section that will use a power supply is the hoist system. This system will only be running in short intervals for a few times a day. The output energy is neglectful to any environmental impact.

18.3 Societal Impact

The work being done by Team 1 for Toray does not have a societal impact. The design has been built for Toray's specific challenge and application of this design to any other application is extremely limited and is not intended to be used elsewhere. This solution has only the immediate effect of assisting Toray's manufacturing environment in North Kingstown RI and nowhere else.

18.4 Political Impact

Political Impact is a considerable topic within any manufacturing facility. The primary aspect pertaining to lawsuits within the workplace. Very common throughout this industry an employee will be performing a regular task, in this case manually transferring end-boards, and pull a muscle or strain their back. When this happens the company is responsible to cover any medical expenses and continue paying them for the time that is missed. The internal clamping design eliminates this factor. The build takes away lifting and bending required by the employee that he currently is assigned every day. This solution phases out the worry of an operator making a compensation claim in this section of the facility. Safety is a major area of concert for unions and management and this solution eliminates a potential cause for lost work hours or worker compensation.

18.5 Ethical Considerations

The work being done by Team Toray does not have ethical considerations associated with the build. The design is meant to operate in house and does not have any limitations as to who is able to operate the mechanism.

18.6 Health, Ergonomics, Safety Considerations

When this design was being built safety and ergonomics was a large consideration. The problem statement came down to one main topic, eliminating the current manual system of the loading station. It is a long strenuous duty that is not suitable for the environment. It can ultimately impair workers and put the company in a position to cover medical bills and deal with lawsuits. The design is a safe and efficient way to get the job accomplished. The design includes a critical fail safe because the clamping and lifting does not depend on an external force or motor. Because of the gripping of the end-boards relies on the weight of the end-boards it is impossible for the design to fail and drop the pile of end-boards at one. The end-boards will only detach from the device when they are no longer suspended which removes a large safety concern. The new design is also much more ergonomic then the past method of end-board transferring and transfers the lifting requirements from the operators to an electric hoist.

18.7 Sustainability Considerations

The design that has been developed by Team Toray has been built to last. It has been constructed from high grade steel and through testing has not failed thus far. This material is not harmful to the environment once the part is past its lifespan it is able to be broken down and reused for other applications. The only section of material that will need to be checked monthly is the neoprene gripping pads. This location will be experiencing the most wear due to the constant contact with the particle board. Even with this consideration it is a very durable material that does not break down or tear very easily. Through all the test that the design has experienced, with loads over 650lbs, the material is still strong and functional. The design has been constructed so that the neoprene sheets are easily removable without jeopardizing the integrity of the lifting capacity.

19. Conclusions

Constant communication between team members, sponsors and capstone representatives allowed Team 1 to design a cost-efficient, high quality solution to the design challenge presented by Toray Industries. After speaking with Toray and understanding their desires, Team 1 outlined and defined a very specific set of design and engineering specifications which needed to be met to satisfy the customer which was Toray. Toray made it very clear that safety, efficiency, and high production rates were some of the more important goals for this design challenge. These desires are shown in the set of specifications in Table 6. The three main and most important aspects were as follows; the design needed to conform to all safety codes, the design needed to allow for higher production rates by lifting up to 15 end-boards at once and the design needed to be flexible enough to secure all sizes of end-boards and needs to be accurate enough allow the end-boards to be lifted by the robots. To accomplish these goals, Team 1 decided upon the internal gripping mechanism as the best means to maneuver the end-board. The design which Team 1 created was specifically designed for this application and for Toray's new automated packaging facility. The progression of this design spanned over the entire year as Team 1 made different prototypes, redesigned, and tested to perfect the internal gripping mechanism. At the final phase of the project, Team 1 machined the internal gripping mechanism entirely out of 1018 stainless steel in the URI machine shop. In total the design cost only $264 which came from the raw materials.

After the design was complete Team 1 went to testing to determine the effectiveness of the design. In the testing phase, the design was continuously improved and the materials for the feet was chosen to maximize the gripping ability while adding safety. In the testing phase the design was proven to go above and beyond the design requirements for lifting capacity which Toray had presented. The design was able to easy lift 15 of the end-boards at once which will dramatically increase the production rate. The internal clamping aspect of the design also allowed for the design to secure any variable sizes or weights of end-boards which was also a crucial design specification. The device was also proven to be a much safer alternative to the current method. One of the design specifications which Toray demanded of Team 1 was that the design must adhere to the OSHA safety guidelines which limits the lifting capabilities of the operator to 50 lbs. When the design that Team 1 built is implemented, the operators will no longer be asked to lift the end-boards and the design will make this loading process much less physically demanding.

After many discussions with Toray, the customer has been very pleased with the year-long development of this solution. The design has been proven to go above and beyond all aspects of Toray's design specifications and Toray is planning on implementing this solution into their new automated packaging facility as soon as possible. Currently in the facility, this problem is causing a massive bottleneck effect and is limiting the packaging output of the new packaging systems. Toray has resorted to hiring additional workers as well as allowing overtime hours so operators can manually lift end-boards onto the end-board cart. The design which Team 1 has derived will solve all of these issues and has been proved in this design report to satisfy all design challenge requirements. Team 1 will continue to work with Toray Industries to assist in the implementation of this solution so this production issue is resolved as quickly as possible. The internal gripping mechanism designed by Team 1 is a safe, efficient, and flexible solution which will eliminate a massive production bottleneck in Toray's new automated packaging facility.

20. References

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[10] Dieter, George Ellwood., and Linda C. Schmidt. Engineering Design. New York: McGraw-Hill, 2013. Print.

21. Appendices

21.1 Solidworks Drawings

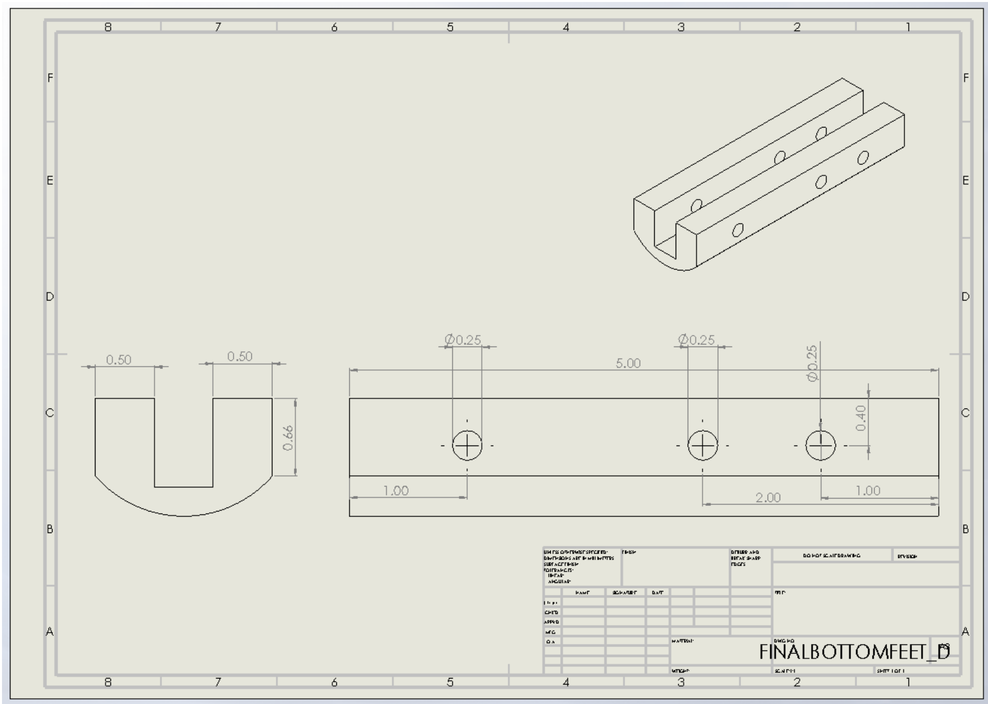

FIGURE 38: Bottom Feet Solidworks Drawing

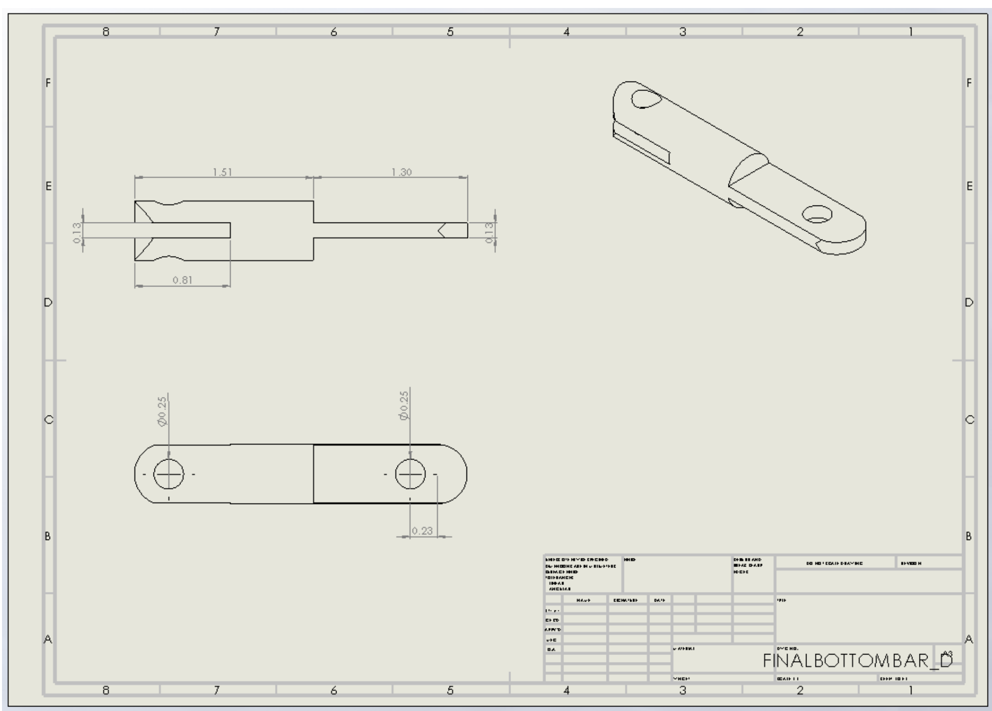

FIGURE 39: Bottom Bar Solidworks Drawing

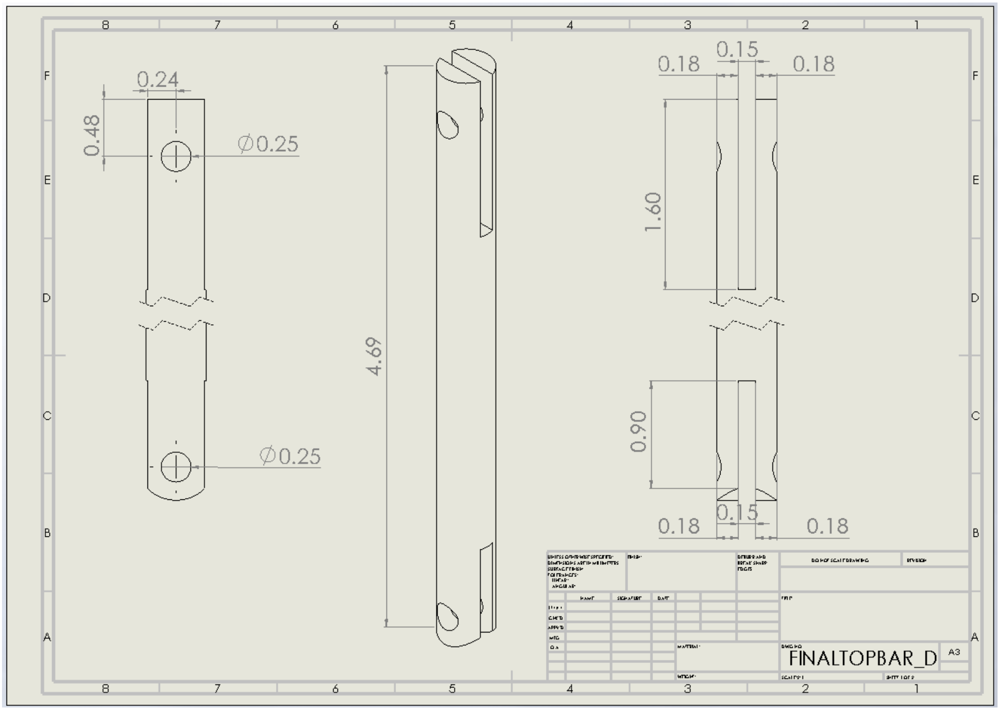

FIGURE 40: Top Bar Solidworks Drawing

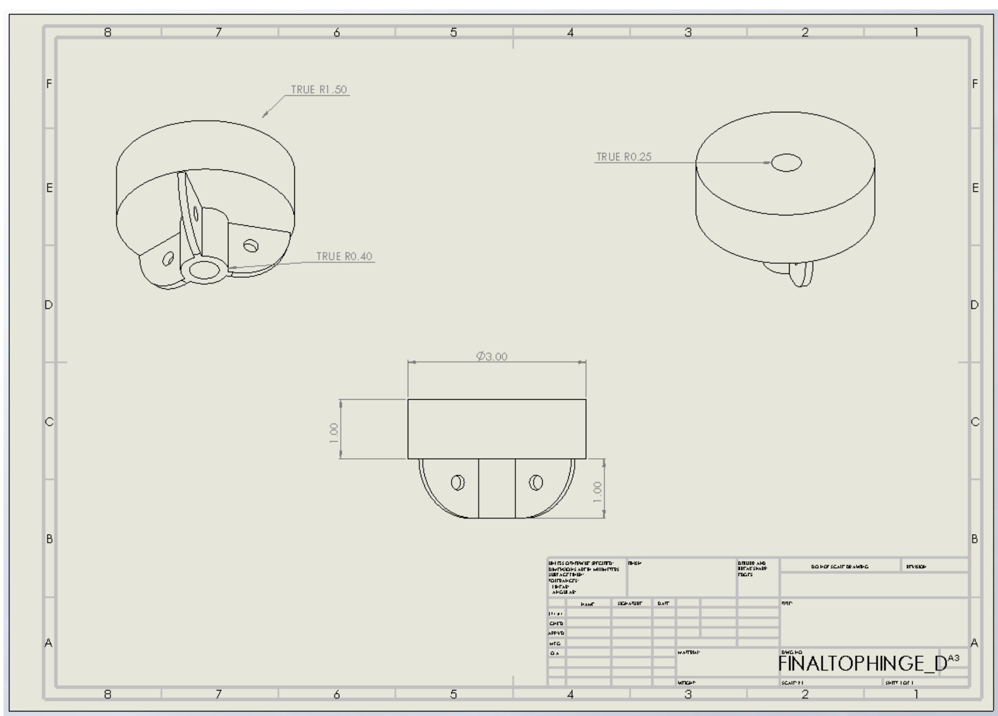

FIGURE 41: Hinge Solidworks Drawing

21.3 Capstone Order Forms

MCISE Capstone Order Request Form

	4103			03/01/17
Auto-fill	Vendor Name		McMaster	
	Web Address		mcmaster.com	
				401-874-2524
	Capstone Design			
	URI Department of Mechanical, Industrial & Systems Engineering			
	51 Lower College Road, 230 Pastore Hall, Kingston RI 02881			mceoffice@e(
	Team #	Team Number	1	MPA #:
	Project Sponsor:	Toray	Name of Sponsor	
	Project Name:	Title of Project	End Board Loading Station	

Forward this form electronically to: Professor Nassersharif
Email: bn@uri.edu

Quantity	Part Number	Description	Unit $	Subtotal
1	9445K21	Buna-N Foam Gri p Handle	$10.48	$10.48
1	9445K22	Buna-N Foam Gri p Handle	$10.48	$10.48
				$0.00
				$0.00
				$0.00
				$0.00
				$0.00
				$0.00
				$0.00
		No Tax -- URI is Tax Exempt -- RI Tax Exempt 189		$0.00
		Shipping Cost		$0.00
			Total	$20.96

FIGURE 42: Capstone Order Form #1

MCISE Capstone Order Request Form

Auto-fill

4103

03/07/17

McMaster Carr

Web Address www.mcmaster.com

401-874-2524

Capstone Design

URI Department of Mechanical, Industrial & Systems Engineering

51 Lower College Road, 230 Pastore Hall, Kingston RI 02881

mceoffice@e

Team # 1 Team Number 1

MPA #:

Project Sponsor:Toray Plastic Name of Sponsor

Project Name: End Board Loa Title of Project: End Board Loading Station

Forward this form electronically to: Professor Nassersharif

Email: bn@uri.edu

Quantity	Part Number	Description	Unit $	Subtotal
1	8920K155	6 ft. 1018 Cold Drawn Low Carbon Steel 1/2" Diameter	$14.04	$14.04
2	7786T36	3" Diameter 3" Length General All Purpose Steel	$23.34	$46.68
1	8910K83	1.5" X 2" x 2ft Low Carbon Steel Rectangle Bar	$77.35	$77.35
9	91259A537	Shoulder Screw	$1.09	$9.81
				$0.00
				$0.00
				$0.00
				$0.00
				$0.00
				$0.00
		No Tax -- URI is Tax Exempt -- RI Tax Exempt 189		$0.00
		Shipping Cost		$0.00
			Total	$147.88

FIGURE 43: Capstone Order Form #2

MCISE Capstone Order Request Form

Auto-fill

4103		03/01/17
McMaster Carr		
https://www.mcmaster.com/		
		401-874-2524
Capstone Design		
URI Department of Mechanical, Industrial & Systems Engineering		
51 Lower College Road, 230 Pastore Hall, Kingston RI 02881		mceoffice@e
Team # 1		MPA #:
Project Sponsor:	Toray Industries	
Project Name:	Endboard Loading Station	

Forward this form electronically to: Professor Nassersharif
Email: bn@uri.edu

Quantity	Part Number	Description	Unit $	Subtotal
1	46585A41	Quick attach sanding sheet	$6.31	$6.31
2	4023A63	Sanding pads	$2.77	$5.54
1	8716K61	60A Durometer polyerethane	$29.43	$29.43
1	86205K12	Foam sheets	$5.71	$5.71
1	63825T74	Antislip Floor Coatings	$18.32	$18.32
1	6970T64	6970T64	$9.64	$9.64
1	6289T2	strips with Multidirectional Pattern	$13.38	$13.38
1	3536T87	Grab Hooks with Clevis	$21.30	$21.30
				$0.00
				$0.00
		No Tax -- URI is Tax Exempt -- RI Tax Exempt 189		$0.00
		Shipping Cost		$0.00
			Total	$109.63

FIGURE 44: Capstone Order Form #3

MCISE Capstone Order Request Form

4103		04/05/17
McMaster Carr		
https://www.mcmaster.com/		
		401-874-2524
Capstone Design		
URI Department of Mechanical, Industrial & Systems Engineering		
51 Lower College Road, 230 Pastore Hall, Kingston RI 02881		mceoffice@e
Team #	1	**MPA #:**
Project Sponsor:	Toray Industries	
Project Name:	Endboard Loading Station	

Auto-fill

Forward this form electronically to: Professor Nassersharif
Email: bn@uri.edu

Quantity	**Part Number**	**Description**	**Unit $**	**Subtotal**
1	2994T41	Hoist Rings—For Lifting	$55.19	$55.19
1	90268A125	18-8 Stainless Steel Coupling Nuts	$8.37	$8.37
				$0.00
				$0.00
				$0.00
				$0.00
				$0.00
				$0.00
				$0.00
				$0.00
		No Tax -- URI is Tax Exempt -- RI Tax Exempt 189		$0.00
		Shipping Cost		$0.00
			Total	$63.56

FIGURE 45: Capstone Order Form #4

MCISE Capstone Order Request Form

	4103	03/01/17
Auto-fill	McMaster Carr	
	Web Address www.mcmaster.com	
		401-874-2524
	Capstone Design	
	URI Department of Mechanical, Industrial & Systems Engineering	
	51 Lower College Road, 230 Pastore Hall, Kingston RI 02881	mceoffice@e(
	Team # 1	**MPA #:**
	Project Sponsor: Toray	
	Project Name: Endboard Loading Project	

Forward this form electronically to: Professor Nassersharif
Email: bn@uri.edu

Quantity	Part Number	Description	Unit $	Subtotal
2	92735A220	Stainless Steel Clevis Pins with Retaining Ring Groove Package of 5	$7.05	$14.10
1	98408A120	Side-Mount External Retaining Rings Package of 25	$5.55	$5.55
1	92735A260	18-8 Stainless Steel Clevis Pins with Retaining Ring Groove Package	$7.90	$7.90
1	7767T62	3 ft. Steel Tube	$25.00	$25.00
				$0.00
				$0.00
				$0.00
				$0.00
				$0.00
				$0.00
		No Tax -- URI is Tax Exempt -- RI Tax Exempt 189		$0.00
		Shipping Cost		$0.00
			Total	$52.55

FIGURE 46: Capstone Order Form #5