Lower Freezer Lift Insert
Phase 3 Final Report
Andromeda Technologies
Team 5
ME 26300 - 106
1 May 2020

Lab Coordinator: Timothy Simon
Lab Assistant: Yuhang Fang

Trevor Ladner	*Nathan Robb*	*Christina Yu*	*Donghyun Lee*
Trevor Ladner	**Nathan Robb**	**Christina Yu**	**Donghyun Lee**
5/1/20	5/1/20	5/1/20	5/1/20
Date	**Date**	**Date**	**Date**

Executive Summary

For the past several months Andromeda Technologies has been hard at work designing their Lower Drawer Freezer Lift Insert. The goal of this device is to reduce the issues that people with back pain and disabilities face when trying to access the contents of their lower drawer freezer. It also works to assist people who own this style of freezer and struggle with issues of disorganization in it. Overall, the design that has been created is an insert that features mounted plastic shelves on a frame. The frame is then mounted to a set of rails that allow for the device to easily move up and down.

The primary goal of the design was to make a device that was easy to use, quick to use, safe, and overall reliable, amongst other goals determined from target user surveys. These goals played a heavy hand throughout the entire design process leading to the design goals of minimizing the force required to lift the device, minimizing the number of moves the design makes when in use, minimizing the number of parts, etc. The design Andromeda Technologies created does a good job at keeping these in focus without sacrificing too much functionality. One goal of the design was for the insert to be able to hold 100 lbs, and that target has been met with only one shelf. Having an additional two to three shelves further increases this potential. But, other aspects of the design limit this weight such as the springs. However, with safety in mind, the design has definitive room for improvement, namely the maximum speed it could reach on collapse. As expected, the design is beating the benchmarks that have been laid out simply because there is no product that compares to the goals of this product. Another part of the design that isn't desirable is the overall cost. It costs over $180 to produce the product making the retail price at over $720--well above the goal price

Phase III provided some critical details to the final design. The pre-assembled device, made mostly of plastic, used spring assisted rails mounted to a solid base to lift the frame and shelves upwards out of the freezer. The shelves have multiple levels of mounting allowing for user customization. The entire device has two rods in the solid base that extend outwards to lock the device in the freezer--working similar to a shower rod. Once this design had been settled on, it was important to work on modeling the design to expose limitations. The primary takeaways from this were that each shelf could hold nearly 100 lbs before the shelf would break--an impressive feat. It also revealed that the maximum energy the springs will provide to assist in the lift process is 10 inch-lbs, and the maximum weight the springs can support in total is 65 lbs including the frame. Unfortunately, that is not a lot of assistance to the design and is a weight capacity well below the goal. This also led to the discovery that if the design were to collapse, it would reach a maximum speed of 7 ft/s in the fall before the springs would slow it down. The final major takeaway was the friction force required of the extending rod to keep the device secure in the freezer, this was found to be around 108lbs. While some of these values are not necessarily ideal, they provide strong encouragement that the design, with little modification, can be ready for actual testing in just a brief period.

While the design is not ready for mass production, Phase III indicates a very promising future with minor alterations for the Lower Drawer Freezer Lift Insert. The primary changes Andromeda is looking at involve including a hydraulic system and reducing cost by modifying the frame or producing more parts in-house. When moving the design to mass production, the processes of plastic injection molding and thermoforming would most likely be the primary methods for creating the device. Andromeda Technologies is eager at the prospects this device has and the amount of people that can be helped through the creation of this product.

Table of Contents

Introduction

The purpose of this report is to provide an in-depth explanation of Andromeda Technologies' design to provide a better solution to bottom drawer freezer storage. The team discovered that many adults struggle with back issues and the market currently lacks a solution that provides better access to low freezers. Users often have to bend over to reach food below the waist and a recent study determined over "540 million people [are] affected globally… and it is the main cause of disability worldwide" [1]. Over the last couple of years, the majority of refrigerators, roughly 61.7%, sold in the United States have contained bottom drawer freezers that often end up disorganized and users with back issues or other disabilities may find them difficult to use [1]. Based on this problem statement, the team targeted a few personas including those who experience back pain, those who are older with physical limitations, adults who prefer a better organization method, and children who are in the household.

This report will cover the team's process from the design to the manufacturing phase. This will begin with the market and customer research and establishing target customer groups. Moving forward, the team addresses design considerations and the selection of an initial design. This is followed by modeling of design components for functionality and feasibility and the manufacturing processes used for specific parts. In the end, the report will analyze the materials selected for the design and the economic analysis of the design will be explained.

Customer and Market Research

Andromeda Technologies researched the market of potential customers to evaluate the needs and preferences of customers. The target demographics analyzed were decided upon by evaluating which consumers would be most affected by the lower drawer freezer insert. The team chose to focus on a selected group that represented the target users: people with disabilities or back pain, and people who required an organized freezer. Surveys were gathered to get data on user demographics as well as customer preferences to a potential solution. The results of the poll were used to prioritize what customers were most concerned about in the final design. According to the result, the team found out that the consumers value ease of use and customizable options of locking heights the most.

From here, the design team researched benchmarks of similar products on the market and patents that bear similarities. The first benchmark was a refrigerator that had a freezer on the top, as seen in Appendix A. The second benchmark used was a side by side refrigerator that had a freezer on the left side [2], as seen in Appendix B. A third benchmark was used for more comparison which was a French door refrigerator that included a freezer on the bottom that is a pull out drawer, as seen in Appendix C [3]. The team was able to find a patent for a similar product that contained removable storage units [4], as seen in Appendix D. These benchmarks were scored based on the customer requirements and engineering specifications in HOQ. They were then used to create numerical goals for the design to meet as compared to the benchmarks.Once there was a better understanding of customer needs and what is currently missing on the market, the team was able to move forward in the design process and begin considering different design aspects.

To gain a deeper understanding of the problem and what was the most critical to finding a solution, a House of Quality was developed, as seen in Appendix E. The house of quality features a number of customer needs and engineering requirements. The scores, gathered from customer surveys and polls, provide a clear rating for each persona group as what is most important. The highest-rated were ease of use, quick use, safety, and different locking heights. Using these values and the weights of customer requirements, the team discovered that the number of customization options and the number of moves to use the device had the greatest impact on the design. Comparing the benchmarks mentioned above to the customer needs and engineering requirements indicated that the Side-by-Side refrigerator met the customer requirements the best and that the patent matched them the worst. All of this came to fruition and will solidify a focus for the goals moving forward.

Human Centered Design Considerations

Based on the findings from the House of Quality (see Appendix E), the team considered human user interactions with the design. The engineers needed to understand who they were designing for. Refrigerators are a common household item meaning they affect users daily. The four personas aided in analyzing how different groups will use the product. Important considerations revolved around how easy and safe the product is to use.

The engineers considered how the user will install the device into a drawer freezer. Refrigerators vary in size and model, presenting the issue of needing an adaptable design. A design constraint is that the installation process should not require more than one person and have no more than 5 parts to assemble. For this reason it was chosen to have the device completely pre-assembled as one piece for customer usage.

Another important factor to consider was ease of product use. It may be used multiple times in a day and if it takes a long time, users will be frustrated. The design should require no more than 6 seconds to use. Because this product targets users that struggle with back pain and bending over, the number of degrees that the user bends over to lift the device influenced the design. It should also be lightweight so the final design uses mostly plastic instead of metal. Another design constraint was the amount of force required to pull the insert shelf up. The maximum force the user should exert is 10 lbs. The device should also be safe for children in the household to use as well. This placed a design constraint on the number of sharp edges exposed. The final design has rounded edges and is mostly made of plastic. Children tend to be curious about complex devices meaning the device should have a safety mechanism to prevent it from collapsing accidentally. Speed and simplicity were important as well as how the product appears, its aesthetic will affect how it performs on the market. These design considerations were influential in improving the final design.

The Design: Lower Freezer Lift Insert

The final design is a multifunctional option that provides a solid solution to the problem. It features a sturdy plastic frame, seen as M1-M3, in Figure 1, with supports at multiple levels to support the various shelves. The shelves, M4, are a basic plastic shelf with lipped edges to provide an overall open design helping with ease of access to the contents of the shelf while still providing enough support to prevent items from falling off of the shelf. On three sides of the frame, plastic grating has been included to also aid in preventing object fallout while still allowing the user to see the contents, as seen in P5. The plastic frame has four ball bearing rail carriages, P2, mounted to it at the lower corners. Each carriage is placed in a vertical guide rail that is mounted to a lower base, shown as P3. The rails allow the primary frame to move vertically lifting and lowering the contents of the shelves. The lower base, M10, is a solid piece of plastic with two cutouts that run through it to allow for an extending rod. This rod extends out in a similar fashion to how a shower curtain rod would: creating a tension force between the rod and the sides of freezers to lock the base in place. The rod can be seen as P6. Below each of the carriages is a spring, P4, that compresses as the lift is lowered; thereby, providing energy to the system to aid in lifting the device vertically. At the top of the frame is a mounted plastic handle for the user to hold on to, shown as M5. This design would come preassembled for the user and provides an easy to use solution to the problem.

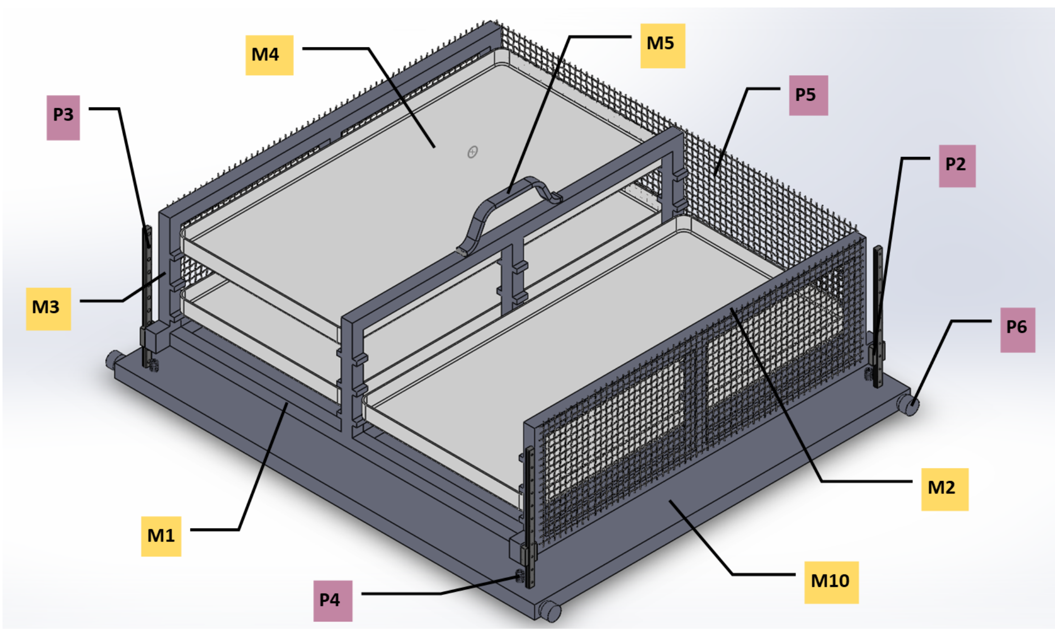


Figure 1: CAD Model of the Design with Labeled Parts

In total, the design has five purchased parts. Among those are the rail, rails carriages, extending rods, side grating, as well as various fasteners. The purchased parts are the ones in purple boxes in Figure 1. There are four primary parts manufactured, namely the frame, shelf, handle, and base. These can be seen in the yellow boxes. The frame itself features a few different parts that could either be pre assembled or connected based on how they are manufactured. This design features a relatively small number of total parts--an early goal due to how this helps the ease of use for the product. When looking at the cost of this design, one part stands above the rest as being the most expensive: the frame. The estimated cost to produce the frame is in the neighborhood of $75, around 40% of the production price. Now this estimate may be a bit off due to the fact the best estimate came from the frame being solid plastic and would most likely actually be hollow tubing. This would significantly reduce its cost. The rail system is the next most costly part of the overall design. These two combine for nearly 60% of the total design production cost.

Overall, the design has two main components. The raising cart that contains the contents of the freezer and the stationary support piece. Unfortunately, early designs featured a cable system that ran from the handle to the carriages that would lock and unlock the carriages. However, no consistent information as to the cost of these could be determined leading the idea to be left out of the current design. This means that currently there is no way for the lift to lock at the top height. The overarching design is not something truly complex that features any parts that would be difficult to make. The design is not perfect, but it is in a very promising place that meets many of the goals laid out from the customer requirements and engineering specifications.

Engineering Modeling

The first engineering model the team analyzed was the shelf support. The team wanted to determine the maximum load that the shelf could hold before failure. The model found that a single shelf can support up to 98.5 pounds which is nearly double what the team initially predicted. This weight results in a maximum deformation of only 0.0032 inches vertically which is very small, but the material used is ABS plastic which does not deform very much prior to failure. A graphical relationship of the shelf deformation related to weight is shown in Appendix F This is very beneficial for the design because the shelf will undergo wear and tear during use, and this signifies that the shelf will remain sturdy after significant customer use.

The second engineering model the team analyzed was the spring lift system. The team wanted to determine how much lift assistance the springs provided to the user while they were lifting the cart with contents. The cart refers to the frame and all of the contents it holds. The four spring system provides a maximum of about 10 in-pounds of energy to assist the user when the shelf unit is at its maximum carrying capacity of about 40 pounds. The mathematical relationship for the model was determined to be $E = 0.0024w^2 + 0.1197w+1.4998$ where E represents the lift energy from the springs in in-pounds and w is the weight of the contents on the lift. This relationship is depicted in the plot in Appendix G.

The third engineering model the team analyzed was the free-fall velocity of the shelf unit from its maximum height. The team wanted to analyze this model regarding the user's safety to avoid any finger or hand injuries. The maximum velocity of the cart was determined to range from 2.6 ft/s to 7 ft/s depending on the load capacity (see Appendix H). The weight of food on the shelves would have to be less than 10 pounds for the velocity to satisfy the team's goal of 1 ft/s which applies a lot of limitations to the user. A key takeaway from this model is that the maximum velocity is more impacted by weight than friction with a mathematical model of $V = -0.0003w^2 + 0.0518w + 4.9786$ where V is the velocity of the cart in ft/s and w is the weight of the food on the shelves of the cart. This relationship is shown on the graph shown in Appendix I.

Overall, the team realized that they needed to address this flaw in their design to make the product safer for the user without sacrificing practicality.

The fourth engineering model the team analyzed was the friction force between the rod and the wall to establish stability. The team wanted to test this model to ensure that the base of the product would be stable enough to hold still when in use. This model concluded that the pushrods needed a coefficient of friction between the wall of at least 0.3 to support the empty cart. In addition, the maximum friction force of the pushrods to secure the product comes out to about 108 lbs for a loaded cart. This relationship is depicted in Appendix J.

Each of these models contributed to calculations or interpretations that benefit the final design. The shelf support and push rod support models showed that these parts would hold up to normal use; however the spring energy and velocity models exposed some key safety and force problems in the design. Therefore, the team decided that a hydraulic press component would assist the springs in the lifting of the cart and help to control the free-fall speed of the cart from the maximum height. This lift could be related to the lift gate hydraulic systems on the trunk door of cars. This team is also concerned with how the hydraulic unit will perform in the frigid temperatures of the freezer. They researched fluids and found a low temperature hydraulic fluid that is designed for “extreme low temperature operations where high fluid mobility is of utmost importance” [5]. This fluid would hold up to the freezer temperatures better than more water based fluids and improve function. Lastly, the friction force of the pushrods should more than support the device in the freezer but more support rods can easily be inserted into the base should additional support be needed.

Manufacturing and Materials

The manufactured parts of the design will utilize a combination of three different manufacturing techniques - plastic injection molding, plastic welding, and thermoforming. Plastic injection molding will be used for the handle and the hollow rods for the frame. The handle is rather simple and will not be a very complex mold. Based on the average cost for plastic injection molds ranging from $4,500-$16,000 depending on part complexity, the handle mold was estimated to be about $5,000 [6]. The frame mold will be a singular hollow rod that is universal for all lengths of the frame body because the frame has the same cross sectional area throughout. These rods are then cut to the appropriate dimensions before later being attached. This mold is estimated to cost about $10,000 based on size. Lastly, the shelf supports will be plastic injection molded and only one mold is needed because all supports are the same size. This mold is estimated to be $2,000. The material for all of these parts will be ABS plastic which costs $1.50 per pound [7].

The frame rods and the shelf supports will then be assembled by using plastic welding. This is the "process of creating a molecular bond between two compatible thermoplastics" and it is the most efficient way to assemble the frame after manufacturing the rods [8]. This would use the same ABS plastic material as the plastic injection molded parts mentioned above which simplifies the material variety.

Lastly, the shelves will be manufactured using thermoforming. This is the process where sheets of material are placed under a heating element and subsequently molded using a force of a sheet pressing and creating form for the shelf which is a flat base with lipped edges. The cost for the thermoforming mold is estimated to be $5,000 based on its simplicity in addition to each plastic sheet of material costing about $40 [9] .

As mentioned above, the initial assembly of the frame and shelf supports will be done by plastic welding. The handle will be attached to the top of the frame bar via plastic welding as well as the mesh grating surrounding the frame. The spring system will then be attached to the base and the purchased push rods are slid into the slots in the base plate. Holes are then drillen into each of the side beams of the frame and the rail carriage is attached via screws. The shelves can then be laid on their appropriate supports.

Benchmark Comparisons

The final design of the Lower Freezer Lift Insert was compared to current products on the market that have similar functions to evaluate how it would perform against them and what it has to offer that is different and beneficial. The lift insert will be an add-on product, a device customers can purchase separately. Currently, there are different types of refrigerators that have freezers in varying configurations and a patent for a freezer design with removable shelves.

Many refrigerators sold today contain freezers on the top at eye-level (see Appendix A). Users who are unable to bend over will be able to use the top freezer with no issues. This benchmark creates a new problem of the user having to bend over to access items in the lower refrigerator. The second benchmark, a side by side refrigerator configuration, as shown in Figure #, contains a freezer that spans the full height of the refrigerator. For users with pack bain, the top half of the freezer would be easily accessible. The lower half requires bending over, therefore putting unwanted stress on the back. However, the team's final design would not fit in this type of refrigerator, as it is designed specifically for a lower drawer freezer. The third benchmark is a refrigerator with a bottom drawer freezer (see Figure 2). The lift insert is being designed specifically for this type of freezer. The user would have to bend over or a significant amount to maneuver and access food stored at the bottom. These three benchmarks have shelves that move horizontally. However, they do not move vertically, meaning the shelves cannot be adjusted height wise. The final design eliminates this problem by creating a shelf unit that extends completely out of the freezer, adjusting it to a more accessible height. It also has customization options with the shelf configuration.

Figure 2: Top View of Freezer of Whirlpool 25.2-cu ft French Door Refrigerator

The final benchmark is of a patented design that has moveable storage units in the freezer (see Figure 3). The shelves are attached to poles and are lifted and rotated to allow access to the bottom shelves [4]. It is not adaptable to different types of freezers and is specific to chest freezers. The team's final design provides lift assistance as opposed to the patented design that has none. Users would also have to buy a completely new freezer in order to be able to benefit from the adjustable storage shelves. There is not a current product on the market that solves the issue of users who experience back pain with food items stored below waist height. The projected market price is $732.72 which is below current benchmarks that average $2,250 [10].

The team's final design will not replace all of the benchmarks, but it does have aspects that prove it to be a better option for those experiencing back pain and other physical limitations.

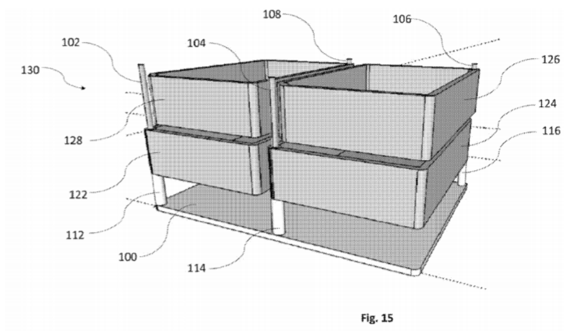


Figure 3: Inside view of freezer design US Patent No. US10088223-B2

Economic Analysis

To gain a greater understanding of the economic viability of this project, a deeper economic analysis was created. The cable system has been removed from the design because the team reached out to the seller of the cable and never heard anything back; therefore the team had insufficient information to add to the model. This resulted in a new production price of $183.18 which further led to the updated retail price of $732.72. The goal production of 15,000 units per year remained as an upper bound for determining the values. With the numbers that had been given or calculated, the minimum production to have a Net Worth of zero was 7,537 units annually and to have a Net Worth Present Value of zero was 8,662 units annually. The goal production falls above this to ensure a return on the investment.

At the goal production of 15,000 units annually, the Net Worth after 15 Quarters is $820,200 and the Net Present Value Worth is $578,500. This results in a payback period of the 10th quarter. The Rate of Return (ROR) from this level of production works to be 44.383%

showing how quickly the company would make a profit with this level of production. The Return on Investment (ROI) at this level of production is 26.402%.

Conclusion

Currently, the majority of refrigerators have bottom drawer freezers that require bending over to access the contents stored within. The team has completed the final design of the Lower Freezer Lift Insert which aims to provide a solution to people struggling with back pain or seeking better storage methods. Through modeling and analysis, the design proved to have many strengths and weaknesses that offer areas for further improvement. A few strengths include the design being adaptable and customizable. The base has an extendable rod allowing it to fit securely into various sized freezers. The shelves can be adjusted to any preference making it advantageous over designs with fixed shelves. The device lifts upwards to a more accessible height which reduces the amount of strain on the user's back.

The design suffers in not being lightweight and affordable. The weight used for modeling the empty card was 25 pounds. It also contributes 40% of the manufacturing cost. During actual production, the frame will be made hollow instead of solid plastic. This reduction in material will reduce both the weight and the cost significantly. Further modeling is needed to determine how that will affect the structural integrity. The projected market price is $732.72 which is 14 times the target price, but it does beat current benchmarks that average $2,250 [10]. It is important to note the lift insert will not replace the benchmarks, rather be an add-on item which should be reflected in the cost. Other areas for cost reduction include manufacturing the rail system instead of purchasing it and removing the center of the base of the device. This means instead of having a solid block as the base, it would be a shell, with essential material supporting the rail and rods (see Appendix K).

Current models show that the maximum velocity the shelf will reach if dropped ranges from 2.6 ft/s to 7 ft/s. These high speeds pose a safety issue. These weaknesses expose areas in the design where the team can make improvements to make a more beneficial product for the customers. However, the team is still choosing to move forward with the Lower Freezer Lift Insert design, make necessary adjustments, and put it on the market.

Table 1. Current performance of final design

Customer Requirement	Engineering Specificaiton	Unit	Threshold	Target	Current Performance
Lightweight	Weight of Device	pounds	35 lbs	15 lbs	25 lbs
Low Cost	Consumer Cost	USD	$250	$50	$732.72*
Easy to Use	Force required to lift mechanism	pounds	10 lbs	5 lbs	55 lbs
Can Support Sufficient Weight	Weight Shelf Can Hold	pounds	100 lbs	75 lbs	98.5 lbs
Easy to Install	Number of Parts for Assembly	#	15	5	1
Safe	Number of Sharp Edges	#	4	0	4
Different Locking Heights	Number of Locking Positions	#	2	4	1
Food is Accessible	Maximum Height	inches	40	50	20
Storage Customizable/Options	Number of Custimization Options	#	2	4	12
Quick to Use	Number of Moves Required	#	4	2	2
*calculated by multiplying manufacturing cost of $183.18 by 4					

Table 1 outlines the major engineering specifications that were met and not met. Yellow cells indicate values meeting the threshold but not target, and the red indicates unmet specifications. Many design decisions considered cost. The original manufacturing cost was $912.51, but in order to reduce cost, cheaper springs were chosen and the brake cable assembly was removed. These decisions negatively impacted model performances. There is currently no locking mechanism when the device is in use which is not ideal as the user would have to hold the device up with one hand while accessing food. Moving forward, the team must find more cost effective options to improve the design's performance. One major change would be implementing a hydraulic system to add better lift assistance. One model found the current springs support up to 40 pounds of food. A second model found the friction force on the rails is not enough to slow the device down safely when it falls vertically. Another model determined the shelves can support 98.5 pounds each with minimal deformation. However, there must be sufficient support to counteract this weight and reduce the required lifting force. The hydraulic system would replace the springs, eliminating their cost, and make the device easier to lift and lower with compression (see Appendix L). It would also reduce the falling velocity as it would catch the device due to the pressurized fluid. Further modeling would need to determine how temperature would affect the fluid in the hydraulic system. It was found that water-based fluids are more advantageous, producing 20 gallons from one gallon of concentrate [11]. In order to continue reducing cost with the addition of the hydraulic system, the team will use fluid that not only performs well under low temperatures, but also has a long life-span and low maintenance cost.

Although in the future the team will have to focus on major cost reduction and design improvements, the team feels the product is a very unique idea and will better serve those struggling with back pain which is a significant population, making it a practical solution. The team is encouraged by how the design has progressed, and there is a clear gap in the market for this product. An annual goal production rate of 15,000 units per year results in an ROI of 26.402%. The team is satisfied by the current economic status of the project, but with continual improvements, believes the product will be successful on the market. The team aims to make the product affordable because they want it to reach as many people as possible that could benefit from it.

References

[1] Sarner, M. (2018, June). Back pain: how to live with one of the world's biggest health problems. Retrieved March 26, 2020, from https://www.theguardian.com/society/2018/jun/14/back-pain-how-to-live-with-one-of-the-worlds-biggest-health-problems

[2] *Frigidaire 25.5-cu ft Side-by-Side Refrigerator with Ice Maker (EasyCare Stainless Steel).* Lowes. Retrieved January 28, 2020 from https://www.lowes.com/pd/Frigidaire-25-5-cu-ft-Side-by-Side-Refrigerator-with-Ice-Maker-EasyCare-Stainless-Steel/1000245233.

[3] *Whirlpool 25.2-cu ft French Door Refrigerator with Ice Maker (Fingerprint-Resistant Stainless Steel) ENERGY STAR.* Lowes. Retrieved January 28, 2020 from https://www.lowes.com/pd/Whirlpool-25-2-cu-ft-French-Door-Refrigerator-with-Ice-Maker-Fingerprint-Resistant-Stainless-Steel-ENERGY-STAR/1000228559.

[4] Roullett, F. A. (2018). *US Patent No. US10088223-B2. Retrieved for* http://apps.webofknowledge.com/full_record.do?product=DIIDW&search_mode=GeneralSearch&qid=10&SID=8DSS2ngbRNXY7MLOOAn&page=1&doc=1.

[5] Gannon, Mary. "Low-Temperature Hydraulic Fluids." *Fluid Power World*, 22 May 2016, www.fluidpowerworld.com/low-temperature-hydraulic-fluids/.

[6] ICOMold. (2017, February 27). Plastic Injection Mold Cost: ICOMold. Retrieved April 26, 2020, from https://icomold.com/much-injection-molding-cost/

[7] Rogers, Tony. (2015, July 13). Everything You Need to Know About ABS Plastic. Retrieved April 26, 2020, from https://www.creativemechanisms.com/blog/everything-you-need-to-know-about-abs-plas

[8] DUKANE. (n.d.). What Is Plastic Welding? We Explain the Processes. Retrieved April 22, 2020, from https://www.dukane.com/plastic-welding-process/

[9] 3Space. (2019, July 24). Thermoforming Cost. Retrieved April 26, 2020, from https://3space.com/blog/thermoforming-cost/

[10] Keen, Stevie. *Best French door refrigerators 2020: Keep your food fresh.* Top Ten Reviews. Retrieved April 28, 2020 from https://www.toptenreviews.com/best-french-door-refrigerators

[11] *Engineering Essentials: Hydraulic Fluids* 01 January 2012, Retrieved April 30, 2020 from https://www.hydraulicspneumatics.com/technologies/hydraulic-fluids/article/21882660/engineering-essentials-hydraulic-fluids

Appendices

Appendix A: Frigidaire 18-cu ft Top Freezer Refrigerator

Appendix A is the first of the benchmarks used for the design process. It is a Frigidaire Top Freezer Style Refrigerator. This product moves the freezer from the bottom where the user would use the device to the top, so the device would not be needed in this fridge. This is a costly solution to the issue however.

Appendix B: Frigidaire 25.5-cu ft Side by Side Refrigerator

Appendix B is a Frigidaire Side-by-Side Refrigerator that is one of the benchmarks used for the design. This design also helps solve many of the issues the user faces, but is a costly solution. It moves the freezer to be on the same level as the fridge, arguably creating more issues with reaching contents in both.

Appendix C: Whirlpool 25.2-cu ft French Door Refrigerator

Appendix C is the third benchmark used. It is also the type of refrigerator that the produce is designed for. This is a Whirlpool French Door Refrigerator with a Drawer Freezer. This is the most common type of fridge sold in the United States. This is where the primary issue arises and does not present any solutions.

Appendix D: Inside view of freezer design US Patent No. US10088223-B2

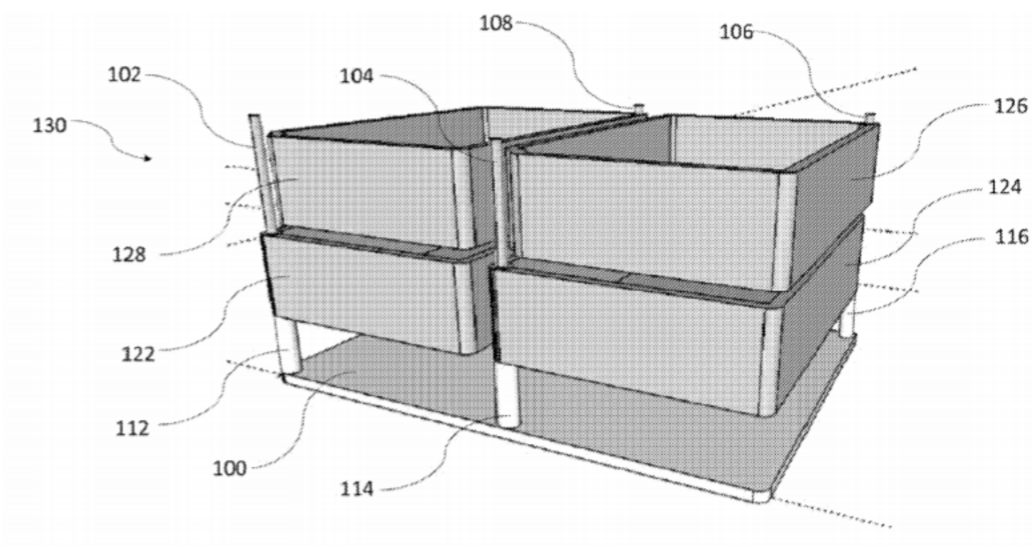


Fig. 15

Appendix D is a patent used as a benchmark for the team's design. It addresses the team's goal for organization of the storage device but is designed for a chest freezer instead of a bottom drawer freezer. This patent also has insufficient space usage which the team wanted to improve in their design.

Appendix E: House of Quality Diagram

HOUSE OF QUALITY	Who (Customers)							How (ES)																Now (Benchmarks)			
	People with Back Issues	Children	Compulsive Organizer	Disabled People	Total	Percentage (%)	Rank	Weight of Device	Consumer Cost	Time required to use	Revenue	Force required to lift mechanism	Volume Lost	Weight Able to Hold	Number of Parts for Assembly/Disassembly	Average Life Span	Number of Sharp Edges	Lowest Temperature of Functionality	Number of Locking Positions	Maximum Height	Number of Custimization Options	Number of Moves Required	Totals	Frigidaire 25.5-cu ft Side-by-Side Refrigerator w/ Ice Maker	Frigidaire 18-cu ft Top-Freezer Refrigerator (White)	Whirlpool 25.2-cu ft French Door Refrigerator with Ice Maker	US10088223-B2
								lbs.	USD	sec	USD	lbs.	ft^3	lbs.	#	years	#	°F	#	inches	#	#	#				
What (Customer Requirements)								↓	↓	↓	↑	↓	↓	↑	↓	↑	↓	↓	↑	↑	↑	↓	-				
Low Cost	9.2	2.27	7.27	7.98	26.73	6.69%	9		9		9					3							21	1	3	1	
Space Efficient	4.91	4.55	6.58	8.54	24.58	6.15%	10						9						3	3	9		24	5	2	4	5
Quick Use	10.43	18.18	9.04	8.68	46.34	11.60%	2	3		9		3			1						3	9	28	5	4	5	3
Ease of use	10.43	22.73	9.17	10.22	52.55	13.15%	1	3		9		9			1				3		3	9	37	5	5	5	3
Safe	10.43	11.36	9.61	8.54	39.95	10.00%	4					3					9			3			15	4	3	4	3
Mechanism withstands freezing temperatures w/ min wear & tear	7.98	2.27	9.87	8.82	28.95	7.25%	7									3		9					12	5	5	5	5
Easy to Clean	8.59	2.27	8.8	8.12	27.79	6.95%	8								9								9	3	5	3	2
Easy to Install	4.91	2.27	7.02	7.84	22.05	5.52%	11	9							9						3		21	3	3	3	3
Reliable	9.2	6.82	9.94	10.08	36.04	9.02%	5		3		3			9		9		3					27	5	5	5	
Can Support a Decent amount of Weight	7.98	9.09	8.13	6.58	31.78	7.96%	6		3		3			9									15	5	5	5	
Storage Customizable/Options	6.74	2.27	7.27	5.74	22.03	5.51%	12		3		3								3		9	9	27	3	3	1	1
Different Locking Heights	9.2	15.91	6.82	8.82	40.75	10.20%	3					3							9	9	9	3	33				3
Total	100	100	100	100	400	100%		15	18	18	18	18	9	18	20	15	9	12	18	15	36	30					
Average																								4	3.91	3.73	3.11
Importance								16.24	19.28	20.23	19.28	20.14	9.55	19.53	21.37	16.23	9.90	12.92	19.66	16.40	38.88	33.03	292.63				
% Importance								5.55%	6.59%	6.91%	6.59%	6.88%	3.26%	6.67%	7.30%	5.55%	3.38%	4.42%	6.72%	5.61%	13.28%	11.29%					
Importance Rank								11	8	4	8	5	15	7	3	11	14	13	6	10	1	2					
Frigidaire 25.5 ^3 Side-by-Side Refrigerator with Ice Maker									$989.00				1.6				20		0	28.625	3	1					
Frigidaire 18 ft^3 Top Freezer Refrigerator								250lbs	$499.99	-		-	3.5	-	-	-	4	-	0	14.273	0	1					
Whirlpool 25.2-cu ft French Door Refrigerator with Ice Maker								-	$1,399.00	-			0						0			1					
US10088223-B2								-	-	-	-	-	-	-	22	-	-	-	3	-	1	2					
Target (Delighted)								15lbs	$50	3 sec	$100	5 lbs	0.2 ft^3	75 lbs	5	15	0	-20 °F	4	50	4	2	-				
Threshold (Disgusted)								35lbs	$250	6 sec	$20	10 lbs	1.5 ft^3	100 lbs	15	10	4	0 °F	2	40	2	4					

Ratings Legends:

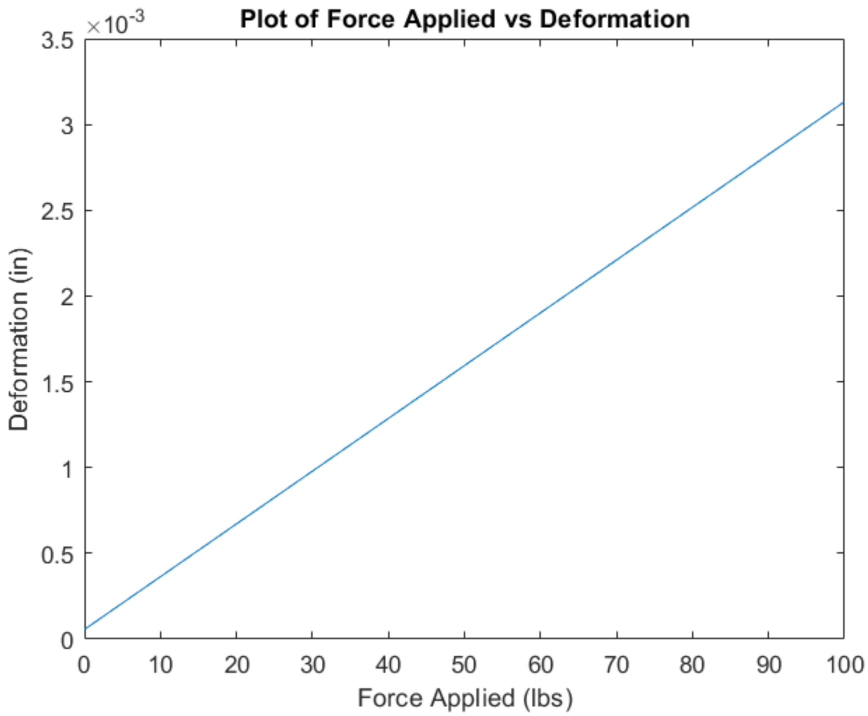
Now vs What:
1 = does not meet requirement
2 = meets requirement slightly
3 = meets requirement somewhat
4 = meets requirement mostly
5 = meets requirement completely

How vs What:
blank (=0), 1, 3, 9

Who vs What:
weights summing to 100

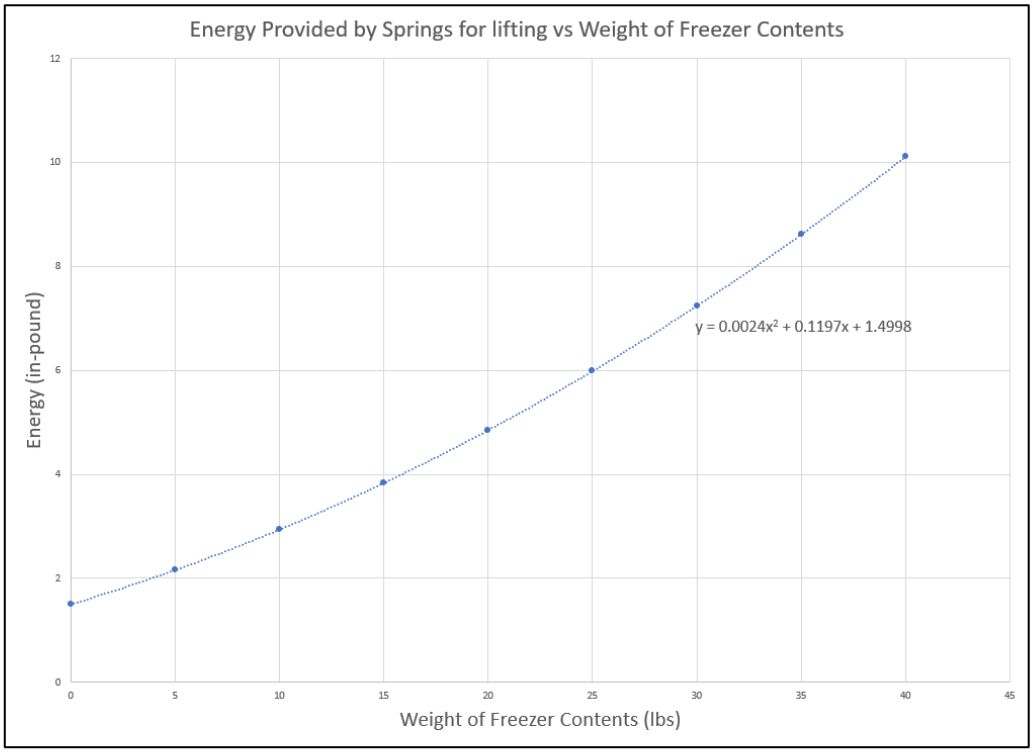
Appendix E is the House of Quality Diagram for the Project. It features the primary target audiences: children, disabled, people with back issues, and the disorganized. It also features the weighting of each of the customer requirements and engineering specifications. The table also provides ratings of how each benchmark compares to both CRs and ESs. Finally it provides target and threshold values for each of the engineering specifications in the design.

Appendix F: Shelf Deformation Graph



Appendix F is the plot representing the relationship of force (weight) and deformation of the shelf from the model for the shelves. The maximum force that can be applied is 98.5 lbs which equates to 0.0032 in.

Appendix G: Spring Energy Graph



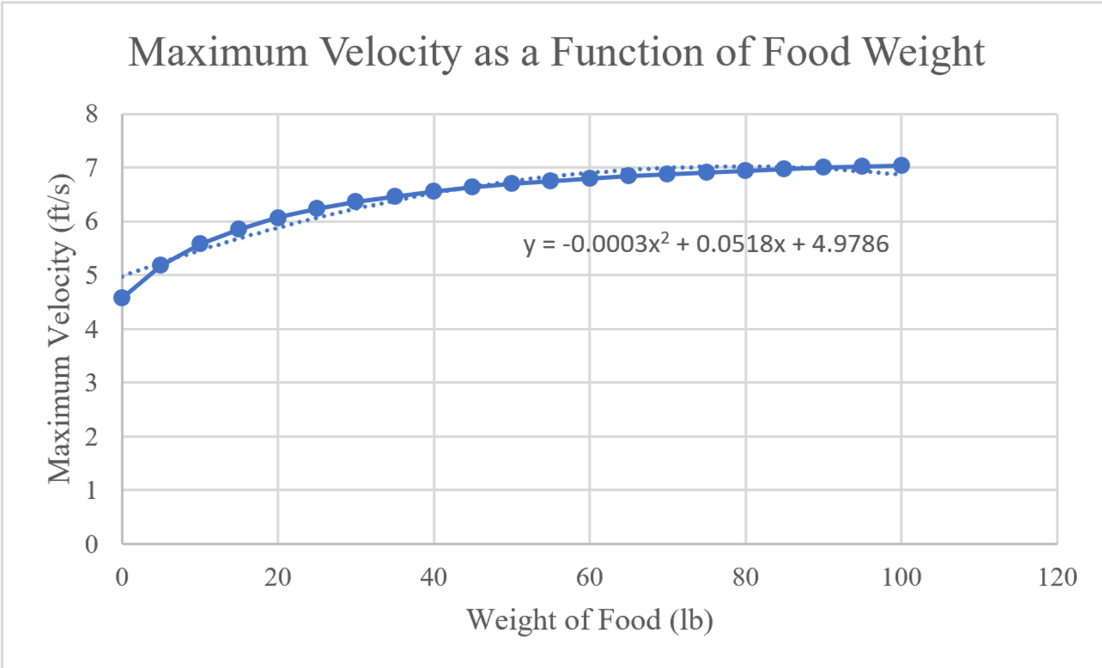
Appendix G is the graph representing the relationship between potential spring energy and weight on the device. Energy is in in-pounds and weight is in lbs. The potential energy is maximum at about 10 in-pounds where the frame and shelves are loaded with 40 lbs of contents before the spring system reaches its maximum compression.

Appendix H: Data for Varying Weight and Maximum Velocity

Data: Calculated Velocity with Varying Weight			
Weight of food (lb)	**Total weight for model (lb)**	**Total mass (slugs)**	**Max Velocity (ft/s)**
0	25.06	0.778986634	2.6855
5	30.06	0.934410942	3.9322
10	35.06	1.08983525	4.6216
15	40.06	1.245259559	5.0778
20	45.06	1.400683867	5.4062
25	50.06	1.556108175	5.6553
30	55.06	1.711532484	5.8513
35	60.06	1.866956792	6.0097
40	65.06	2.0223811	6.1406
45	70.06	2.177805409	6.2506
50	75.06	2.333229717	6.3445
55	80.06	2.488654025	6.4255
60	85.06	2.644078334	6.4961
65	90.06	2.799502642	6.5582
70	95.06	2.954926951	6.6134
75	100.06	3.110351259	6.6626
80	105.06	3.265775567	6.7068
85	110.06	3.421199876	6.7467
90	115.06	3.576624184	6.783
95	120.06	3.732048492	6.8161
100	125.06	3.887472801	6.8464

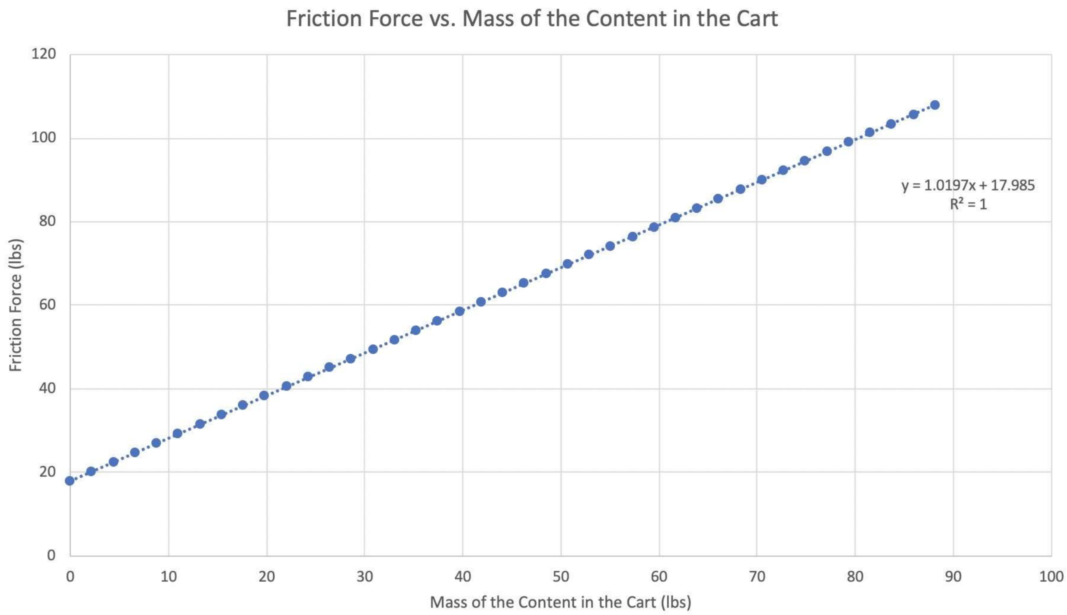
Appendix H is a table containing data values obtained from the maximum free fall velocity model. The values range from there being no weight in the shelves up to 100 pounds of food. The maximum output velocity ranged from 2.6 ft/s to 6.8 ft/s.

Appendix I: Free Fall Maximum Velocity Graph



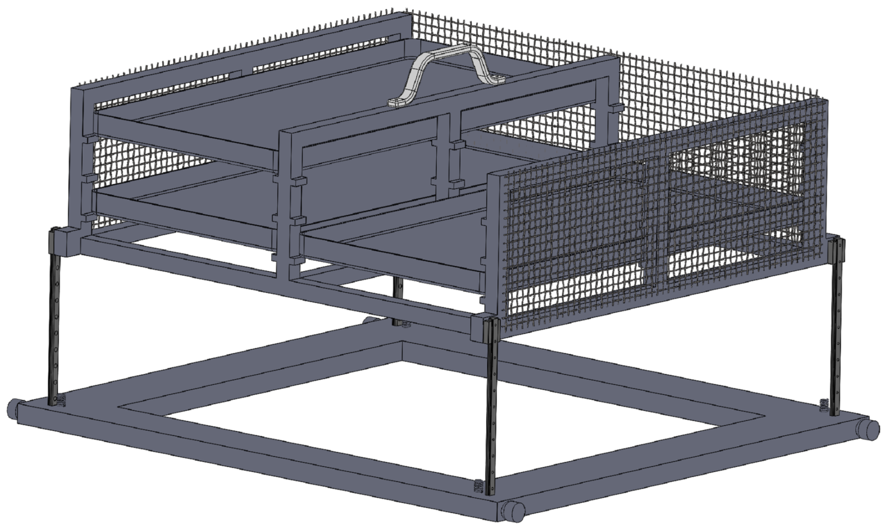
Appendix I is the relationship of the free fall velocity of the cart as a function of weight on the cart form the free fall model. This model and plot shows that the current design posed potential safety risks to the user.

Appendix J: Friction



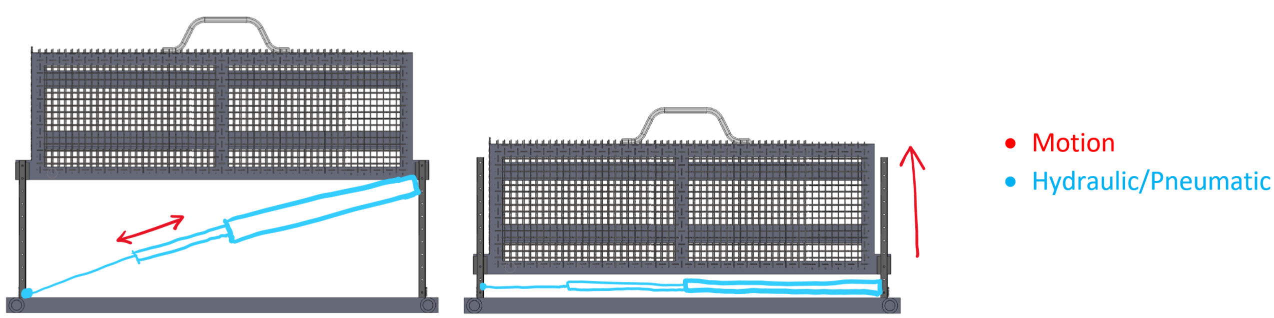
Appendix J represents the relationship from the pushrod model for the frictional force of the rods related to weight of the device. This relationship is linear as expected and confirms that the pushrods can provide a maximum of 108 lbs of force to secure the device which is more than substantial considering casual use of the product.

Appendix K: Potential future design change - removing material from the base.



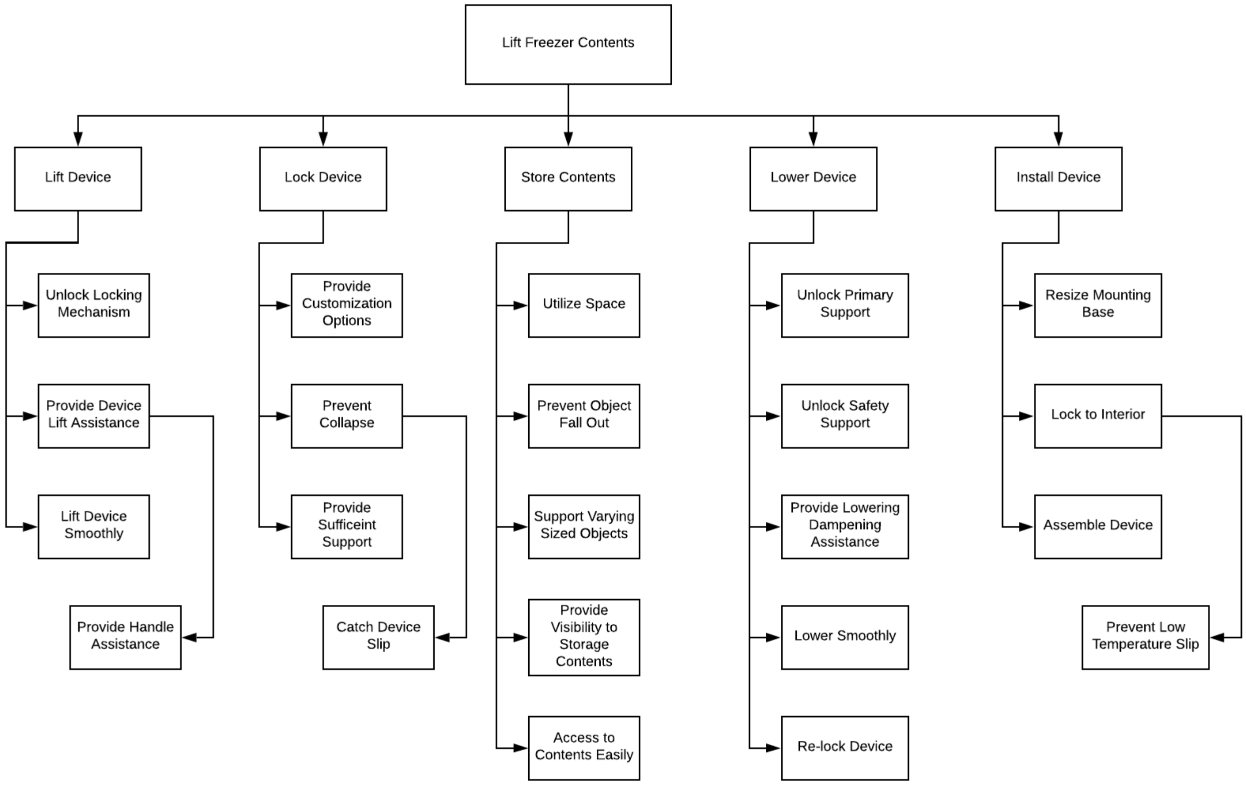
Appendix K is a 3D CAD model of a potential future design improvement. The base was redesigned to have less material; the center of the base was cut out to reduce the cost of its material as well as the total weight. The base holds the extendable rods and four rails and the excess material was not pertinent to the design.

Appendix L: Potential future design change - removing the springs and adding a hydraulic system



Appendix L is a drawing of a potential hydraulic system the team will implement moving forward with the design. It is drawn in blue while the red arrows represent the motion of the devices. It will replace the current springs in the design and be connected to both the base and frame, providing improved lift assistance.

Appendix M: Functional Decomposition



Appendix M features the functional decomposition of the project. There were 5 primary functions determined: lifting the device, locking the device, storing the contents, lowering the device, and installing the device. These functions were then broken down into components to perform the function. These components were then used to brainstorm the ideas in the morphological chart that led to the final design.

Appendix N: Decision Matrix

CUSTOMER REQUIREMENTS	WEIGHTS	CONCEPTS Concept 1	Concept 2	Concept 4	Concept 5	Concept 6	Concept 7	Concept 8	Concept 9	Concept 10	Concept 11	Concept 12	Concept 13	Concept 14	Concept 15	DATUM (Concept 3)
Low Cost	2	+1	+2	+1	+1	0	0	0	+1	-1	0	+1	0	+1	+1	0
Space Efficient	2	+1	+1	-1	-1	0	0	0	0	-2	0	0	-1	-1	0	0
Quick Use	5	0	-1	0	0	-2	0	0	0	-1	-1	-1	-1	-2	0	0
Ease of use	5	0	-1	-1	-2	-1	-1	-1	-1	0	-1	0	0	+1	-1	0
Safe	4	-1	-1	-1	-1	-1	-1	0	-1	-1	+1	-1	0	0	0	0
Mechanism withstands freezing temperatures w/ min wear & tear	3	+1	+1	+1	+1	0	0	-2	+1	-1	0	+1	0	0	+1	0
Easy to Clean	2	+1	-1	+1	-1	-1	+1	0	+1	-2	0	-1	-1	-1	0	0
Easy to Install	1	0	0	0	0	-2	+1	-1	-2	-1	-2	-2	-2	0	-1	0
Reliable	3	+1	+1	+1	+1	+1	+1	0	+1	-1	0	0	+1	+1	+1	0
Can Support a Decent amount of Weight	3	-1	-1	0	-1	0	0	0	0	+1	0	0	0	0	0	0
Storage Customizable/Options	1	+1	+1	0	-1	0	-1	+1	0	-1	+1	0	0	-1	+1	0
Different Locking Heights	4	+1	+1	+1	0	-1	+1	0	0	0	0	+1	+1	+1	+1	0
	Total +	7	7	5	3	1	4	1	4	1	2	3	2	4		0
	Total -	-2	-5	-3	-7	-8	-3	-3	-4	-11	-4	-5	-5	-5		0
	Overall Total	-2	2	2	-4	-7	1	-2	0	-10	-2	-2	-3	-1	0	0
	Weighted Total	10	-2	3	-14	-24	0	-11	-1	-24	-7	-4	-4	-1	7	0

+ 2	Much Better
+ 1	Better
0	Same
-1	Worse
-2	Much Worse

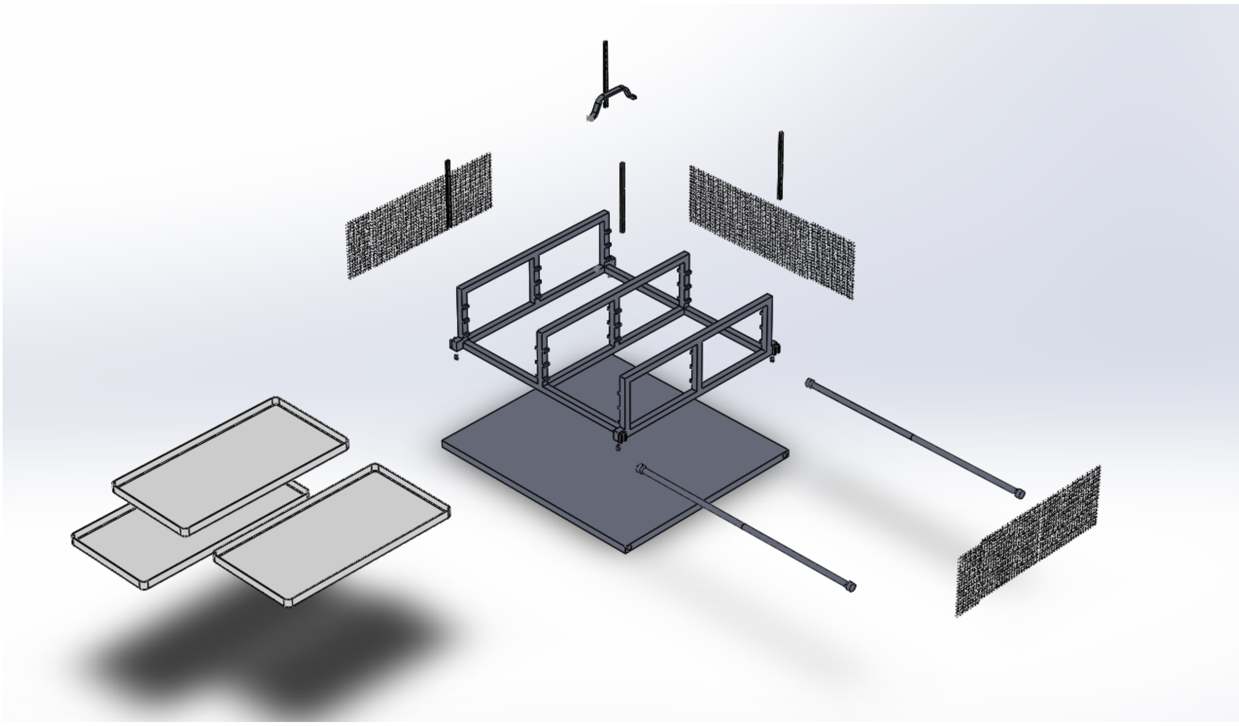
Appendix N is the decision matrix that was used for each of the initial ideas that led to the decision of what final design to use. The third concept was used as a datum for the design. Ultimately the best performing design, Concept 1, was what became the initial design for the product. The table also reveals that concepts 4 and 15 also performed better than the datum design chosen.

Appendix O: Bill of Materials

Item No.	Part No.	Part Name	Units	Qty	Material / Description	Source	Catalog No.	Unit Cost ($)	Unit Processing Cost ($)	Assembly Cost ($)	Line Total Cost ($)
1	A1	Final Assembly	-	1	Final assembly of shelves	-	-	0	0	2.00	2.00
2	A2	Extendable Base Assembly	-	1	Assemble extendable rod to base of frames	-	-	0	0	2.00	2.00
3	A3	Frame and Rail Assembly	-	1	Assemble rails to side frames	-	-	0	0	3.00	3.00
4	A5	Handle Assembly	-	1	Assemble handle to frame	-	-	0	0	3.00	3.00
5	A6	Frame Assembly	-	1	Assemble Frame (welding)	-	-	0	0	10.00	10.00
6	P1	Screws	pcs	32	1" #8-32 thread zinc screw	McMaster-Carr	93878A199	0.04555	0	0.00	1.46
7	P2	Rail Carriage and Bearings	pcs	4	Brass Carriages and PTFE Plastic Bearings	McMaster-Carr	9829K3	1.34	0	0.00	5.36
8	P3	Rail	mm	2000	Anodized Aluminum Guide Rails	McMaster-Carr	9829K13	0.0125	0	0.00	25.00
9	P4	Springs	pcs	1	Stainless steel support springs to assist lift	McMaster-Carr	1986K118	1.4325	0	0.00	1.43
10	P5	Side Metal Grating	pcs	1	24" x 24" Aluminum grate to prevent object fallout	McMaster-Carr	9302T123	7.0625	0	0.00	7.06
11	P6	Extendable Rod (27-47in)	pcs	2	Plastic shower rods	Amazon	BEOKRUE	4.7475	0	0.00	9.50
12	P7	Nuts	pcs	32	#8-32 1/8" aluminum hex nut	McMaster-Carr	93181A009	0.01	0	0.00	0.32
13	P8	Washers	pcs	32	#10 0.2" Nickel-Plated Brass Washer	McMaster-Carr	92917A135	0.0145	0	0.00	0.464
14	M1	Horizontal Frame Long	pcs	2	ABS Tubing 85cm x 2.5cm x 2.5cm (Machined)	Plastic Cost Estimator	-	6.93	1.03	0.00	15.92
15	M2	Depth Frame	pcs	6	ABS Tubing 70cm x 2.5cm x 2.5cm (Machined)	Plastic Cost Estimator	-	5.73	1.03	0.00	40.56
16	M3	Vertical Frame	pcs	6	ABS Tubing 22.5cm x 2.5 cm x 2.5cm (Machined)	Plastic Cost Estimator	-	1.93	1.03	0.00	17.76
17	M4	Shelves	pcs	5	ABS 38.75cm x 74cm x 3.5cm (Molded)	Plastic Cost Estimator	-	3.07	0.22	0.00	16.45
18	M5	Handle	units	1	Plastic handle to lift device 22cm x 2cm x 7cm (Molded)	Plastic Cost Estimator	-	0.32	0.15	0.00	0.47
19	M6	Shelf Slots	-	1	Cut 36 slots for shelves	-	-	0	6	0.00	6.00
20	M7	Rail Mounting Holes	-	1	Drill 12 mounting holes on frame for rails	-	-	0	3	0.00	3.00
21	M8	Handle Mounting Holes	-	1	Drill 2 holes to mount handle	-	-	0	1	0.00	1.00
23	M9	Grating Mounting Holes	-	1	Drill 18 holes ton frame for grating	-	-	0	5	0.00	5.00
24	M10	Lower Base Support	pcs	1	Plastic block w/ rod mounting holes 85cmx75cmx2.5cm	Plastic Cost Estimator	-	6.02	0.41	0.00	6.43
									Total Purchased Parts		50.59
									Total Custom Manufactured Parts		112.59
									Total Assembly Cost		20.00
									Total Cost		183.18

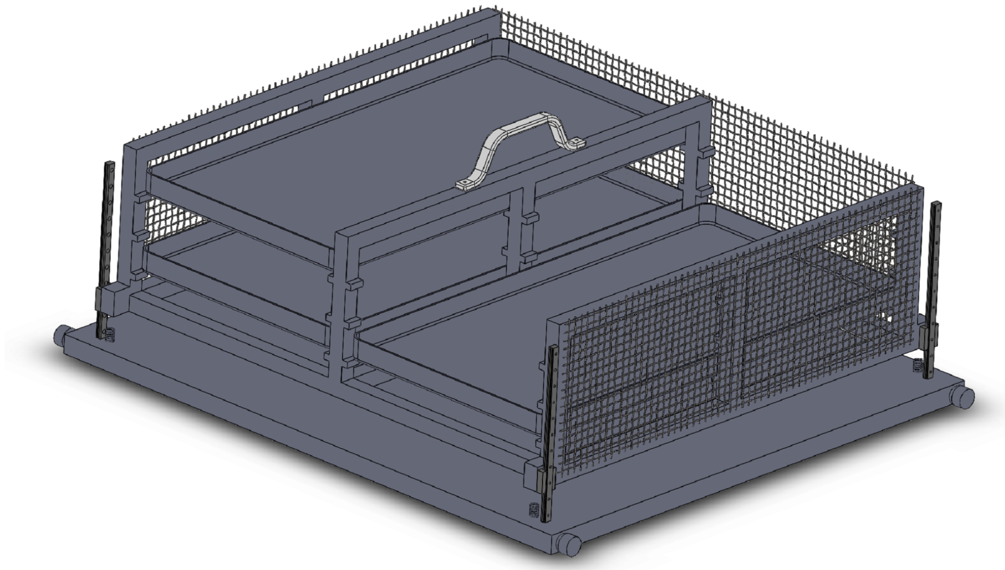
Appendix O is the Bill of Materials for the design. It is broken down into three main categories, assembly parts, manufactured parts, and purchased parts. The design featured 9 total primary parts as well as fasteners. The BOM reveals the breakdown of costs. The cost of the purchased parts is $50.59, the cost of the manufactured parts is $112.59, the cost of the assembly is $20.00, bringing the overarching design cost to be $183.18.

Appendix P: Full Model Exploded View



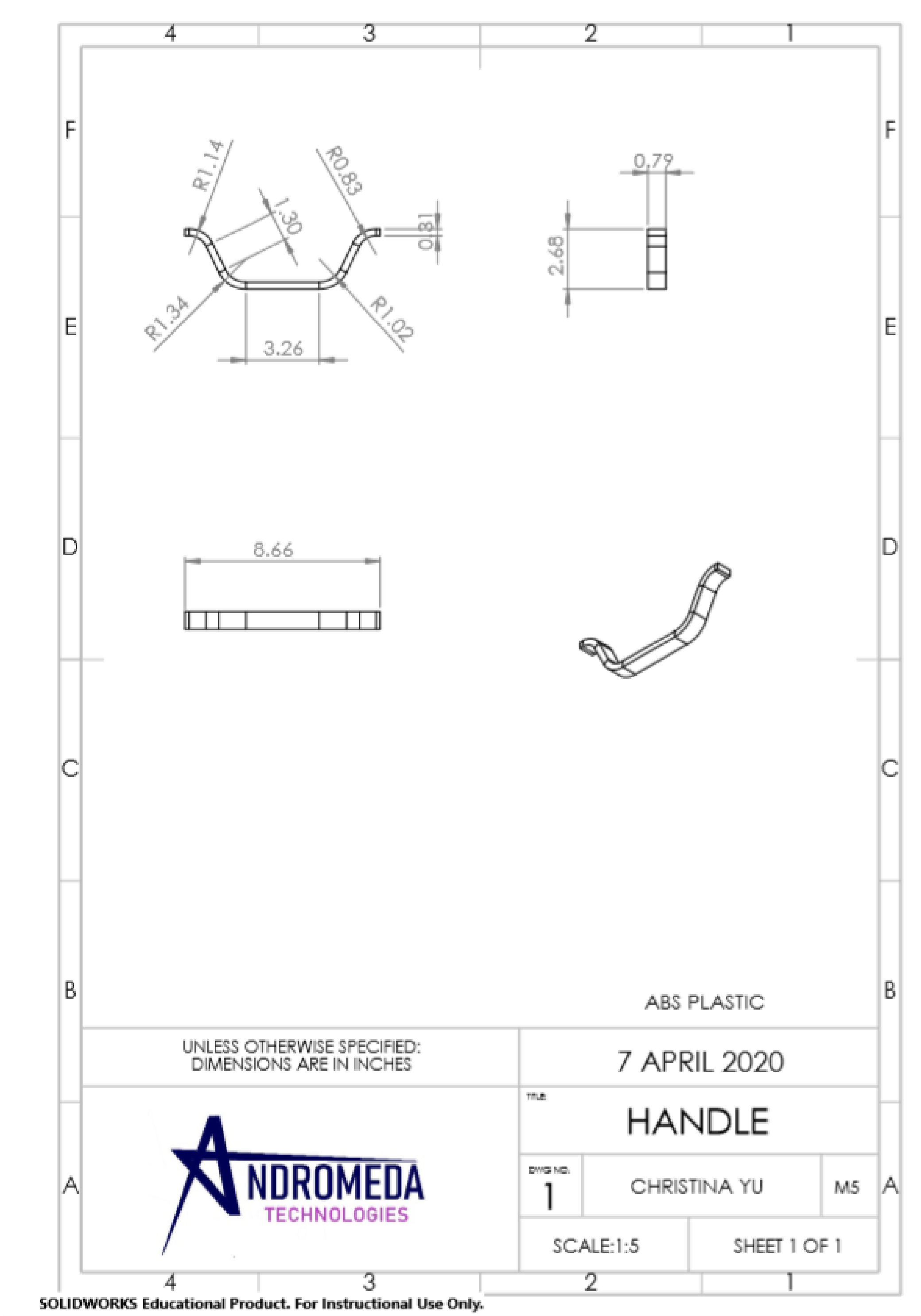
Appendix P is an exploded view of the CAD model. It shows each part separated from its constraints to give a visual understanding of the overall assembly.

Appendix Q: Full Model CAD Assembly



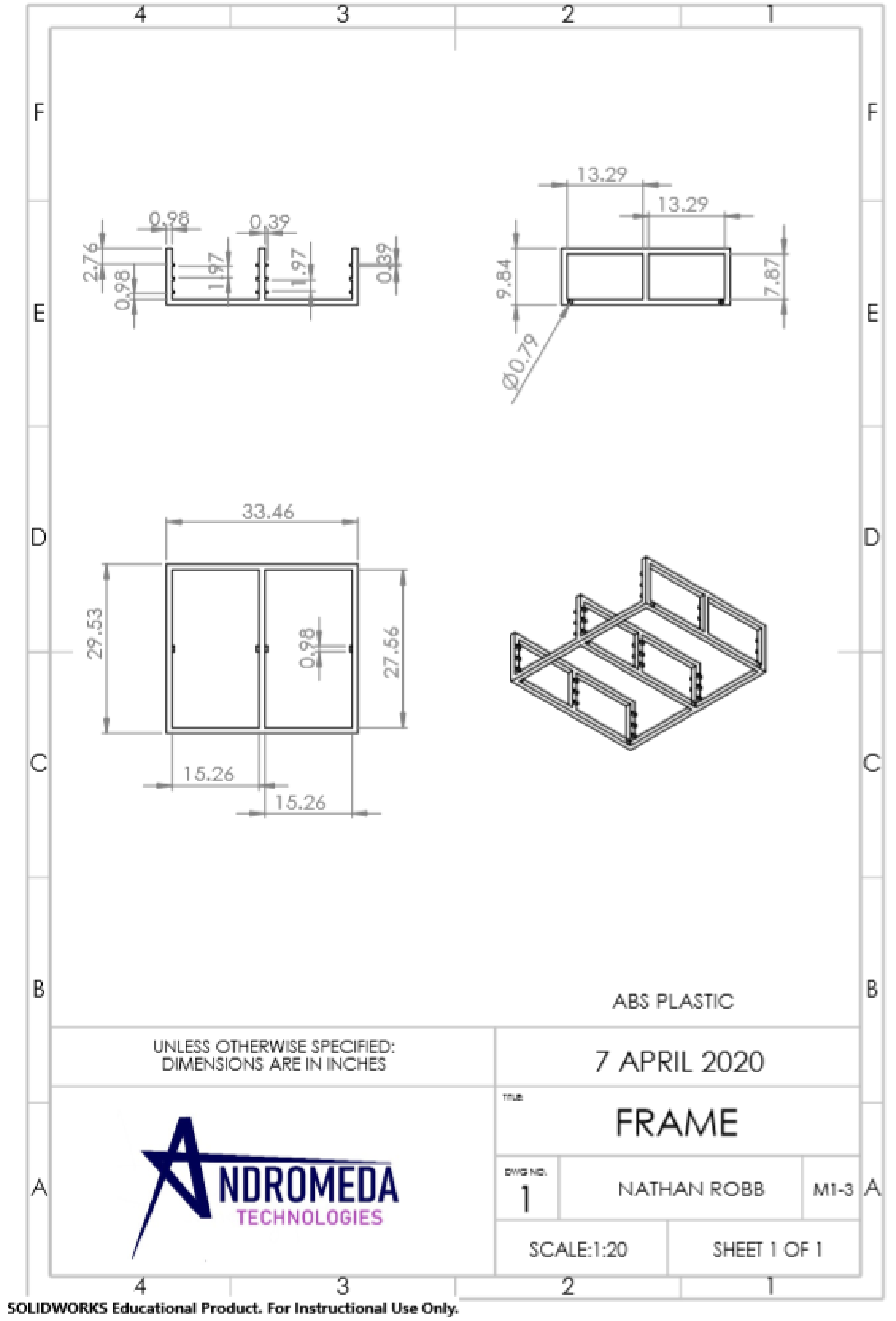
Appendix Q is the CAD model as the primary design. It provided a visual of what the product in its current state would look like as assembled. Here the limitations of it can be seen in the springs and the rail system.

Appendix R: Solidworks Drawing for Handle



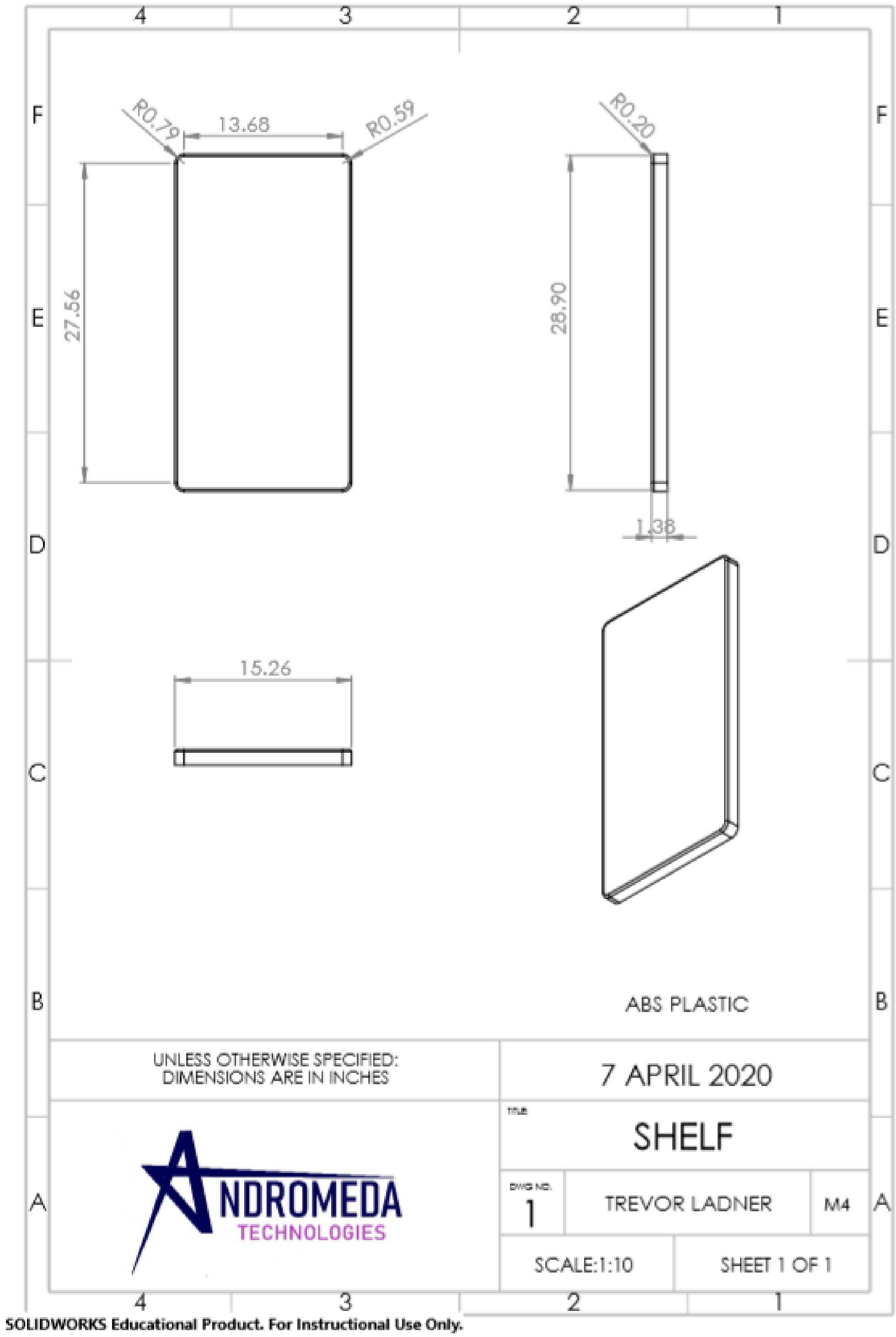
Appendix R is a part drawing for the manufactured part handle. It showcases important dimensions and will be made from plastic. The tolerances will be 0.01” on all dimensions.

Appendix S: Solidworks Drawing for Frame



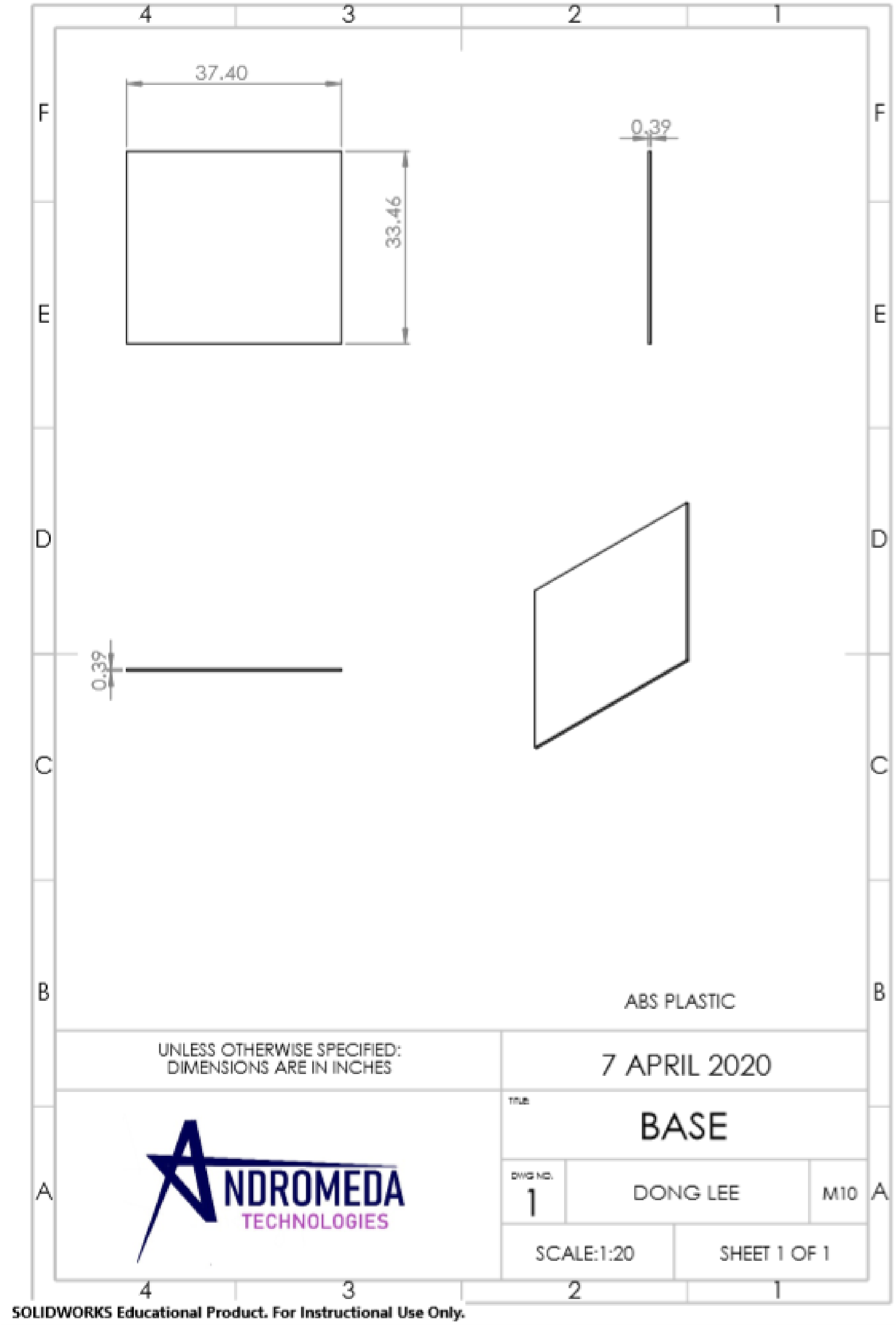
Appendix S is the CAD drawing for the primary frame. It features the dimensioning required for each of the parts of the frame. The tolerances used in this should 0.1".

Appendix T: Solidworks Drawing for Shelf



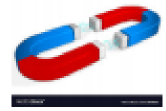
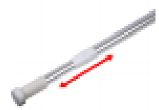
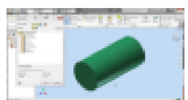
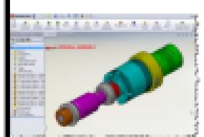
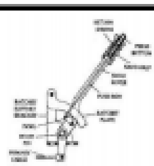
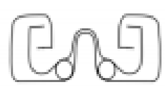
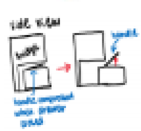
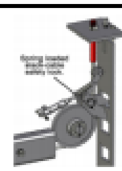
Appendix T is the CAD drawing for the shelf. The drawing features the dimensions required for the design with tolerances of 0.1”.

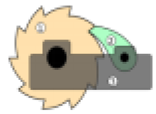
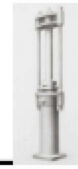
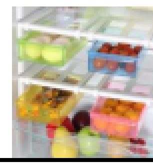
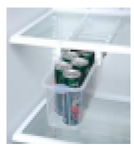
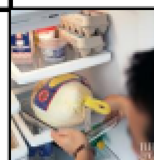
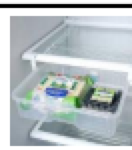
Appendix U: Solidworks Drawing for Base



Appendix U is the CAD drawing for the model of the solid base support and features the required dimensions for it. It features tolerances of 0.5”.

Appendix V: Morphological Chart used for the Generation of Concepts

		Solution			
	Sub-Function	**1**	**2**	**3**	**4**
A	Lock to Interior				
B	Resize mounting base				
C	Assemble device				
D	Unlock Primary Supports				
E	Provide lift assistance				
F	Lift and lower smoothly				
G	Provide Handle access assistance				
H	Provide customization options (locking heights)				

I	Prevent collapse / Safety support				
J	Provide sufficient support				
K	Prevent object fallout				
L	Support varying sized objects				
M	Visibility and easy access of storage contents				

Appendix V is the Morphological Chart that was created during the concept generation phase. The sub-functions were taken from the Function Decomposition diagram. Team members then brainstormed multiple solutions for each function by looking at current products as well as drawing their own designs. These were then used to generate multiple concepts by creating different combinations of the varying solutions.

Appendix W: Design for Assembly Worksheet 1

DESIGN FOR ASSEMBLY

INDIVIDUAL ASSEMBLY EVALUATION FOR Current Design

EVALUATED BY Trevor Ladner DATE 4/3/20

REVIEWED BY Andromeda Tech. DATE 4/14/20

TRIAL 01 02 03 04 05

						COMMENTS
OVERALL ASSEMBLY						
1 OVERALL PART COUNT MINIMIZED	○ POOR	○ FAIR	● GOOD	○ VERY GOOD	○ OUTSTANDING	
2 MINIMUM USE OF SEPARATE FASTENERS	○ POOR	● FAIR	○ GOOD	○ VERY GOOD	○ OUTSTANDING	
3 BASE PART WITH FIXTURING FEATURES (LOCATING SURFACES AND HOLES)	○ POOR	○ FAIR	● GOOD	○ VERY GOOD	○ OUTSTANDING	
4 REPOSITIONING REQUIRED DURING ASSEMBLY SEQUENCE	○ TWO OR MORE REPOSITIONS		○ REPOSITION ONCE		● NO REPOSITIONING	
5 ASSEMBLY SEQUENCE EFFICIENCY	○ POOR	○ FAIR	● GOOD	○ VERY GOOD	○ OUTSTANDING	
PART RETRIEVAL						
6 CHARACTERISTICS THAT COMPLICATE HANDLING (TANGLING, NESTING, FLEXIBILITY) HAVE BEEN AVOIDED	○ NO PARTS	○ FEW PARTS	○ SOME PARTS	● MOST PARTS	○ ALL PARTS	
7 PARTS HAVE BEEN DESIGNED FOR SPECIFIC FEED APPROACH (BULK, STRIP, MAGAZINE)	○	○	○	○	●	
PART HANDLING						
8 PARTS WITH END-TO-END SYMMETRY	○ NO PARTS	○ FEW PARTS	○ SOME PARTS	● MOST PARTS	○ ALL PARTS	
9 PARTS WITH SYMMETRY ABOUT THE AXIS OF INSERTION	○	○	●	○	○	
10 WHERE SYMMETRY IS NOT POSSIBLE PARTS ARE CLEARLY ASYMMETRIC	○	○	○	○	●	
PART MATING						
11 STRAIGHT LINE MOTIONS OF ASSEMBLY	○ NO PARTS	○ FEW PARTS	○ SOME PARTS	○ MOST PARTS	● ALL PARTS	
12 CHAMFERS AND FEATURES THAT FACILIATE INSERTION AND SELF-ALIGNMENT	○	○	○	●	○	
13 MAXIMUM PART ACCESSIBILITY	○	○	○	●	○	

4	TOTAL X 8	32
4	TOTAL X 6	24
4	TOTAL X 4	16
1	TOTAL X 2	2
0	TOTAL X 0	0
	TOTAL SCORE	74

NOTE:
EVALUATION SCORE TO BE USED ONLY TO COMPARE ONE ASSEMBLY TO ALTERNATE DESIGNS OF THE *SAME* ASSEMBLY

Appendix W is the first trial of the DFA worksheet for the primary design concept. This was completed by Trevor Ladner. It returned an admirable score of 74 overall and featured no ratings in the lowest category.

Appendix X: Design for Assembly Worksheet 2

DESIGN FOR ASSEMBLY
INDIVIDUAL ASSEMBLY EVALUATION FOR Freezer Lift Insert

EVALUATED BY Nathan Robb DATE 4/3/20
REVIEWED BY Andromeda Technology DATE 4/3/20
TRIAL 01 02 03 04 05

						COMMENTS
OVERALL ASSEMBLY						
1 OVERALL PART COUNT MINIMIZED	○ POOR	○ FAIR	● GOOD	○ VERY GOOD	○ OUTSTANDING	
2 MINIMUM USE OF SEPARATE FASTENERS	○ POOR	○ FAIR	○ GOOD	● VERY GOOD	○ OUTSTANDING	
3 BASE PART WITH FIXTURING FEATURES (LOCATING SURFACES AND HOLES)	○ POOR	○ FAIR	○ GOOD	● VERY GOOD	○ OUTSTANDING	
4 REPOSITIONING REQUIRED DURING ASSEMBLY SEQUENCE	○ TWO OR MORE REPOSITIONS		● REPOSITION ONCE		○ NO REPOSITIONING	
5 ASSEMBLY SEQUENCE EFFICIENCY	○ POOR	○ FAIR	○ GOOD	● VERY GOOD	○ OUTSTANDING	
PART RETRIEVAL						
6 CHARACTERISTICS THAT COMPLICATE HANDLING (TANGLING, NESTING, FLEXIBILITY) HAVE BEEN AVOIDED	○ NO PARTS	○ FEW PARTS	○ SOME PARTS	● MOST PARTS	○ ALL PARTS	
7 PARTS HAVE BEEN DESIGNED FOR SPECIFIC FEED APPROACH (BULK, STRIP, MAGAZINE)	○	○	●	○	○	
PART HANDLING						
8 PARTS WITH END-TO-END SYMMETRY	○ NO PARTS	○ FEW PARTS	○ SOME PARTS	● MOST PARTS	○ ALL PARTS	
9 PARTS WITH SYMMETRY ABOUT THE AXIS OF INSERTION	○	○	●	○	○	
10 WHERE SYMMETRY IS NOT POSSIBLE PARTS ARE CLEARLY ASYMMETRIC	○	○	○	●	○	
PART MATING						
11 STRAIGHT LINE MOTIONS OF ASSEMBLY	○ NO PARTS	○ FEW PARTS	○ SOME PARTS	○ MOST PARTS	● ALL PARTS	
12 CHAMFERS AND FEATURES THAT FACILIATE INSERTION AND SELF-ALIGNMENT	○	○	○	●	○	
13 MAXIMUM PART ACCESSIBILITY	○	○	○	○	●	
NOTE: EVALUATION SCORE TO BE USED ONLY TO COMPARE ONE ASSEMBLY TO ALTERNATE DESIGNS OF THE *SAME* ASSEMBLY	0 TOTAL X 0	0 TOTAL X 2	4 TOTAL X 4	7 TOTAL X 6	2 TOTAL X 8	16 42 16 0 0
					TOTAL SCORE	74

Appendix X features the second trial of the DFA worksheet for the current primary design. It was completed by Nathan Robb. This also features an overall score of 74, but with different alignments. It also featured none in the lowest category.

Appendix Y: Design for Assembly Worksheet 3

DESIGN FOR ASSEMBLY
INDIVIDUAL ASSEMBLY EVALUATION FOR Lower Freezer Lift Insert

EVALUATED BY Christina Yu DATE 4/4/2020
REVIEWED BY Andromeda Technologies DATE 4/4/2020
TRIAL 01 02 03 04 05

OVERALL ASSEMBLY						*COMMENTS*
1 OVERALL PART COUNT MINIMIZED	○ POOR	○ FAIR	○ GOOD	● VERY GOOD	○ OUTSTANDING	
2 MINIMUM USE OF SEPARATE FASTENERS	○ POOR	○ FAIR	○ GOOD	● VERY GOOD	○ OUTSTANDING	
3 BASE PART WITH FIXTURING FEATURES (LOCATING SURFACES AND HOLES)	○ POOR	○ FAIR	● GOOD	○ VERY GOOD	○ OUTSTANDING	
4 REPOSITIONING REQUIRED DURING ASSEMBLY SEQUENCE	○ TWO OR MORE REPOSITIONS		○ REPOSITION ONCE		● NO REPOSITIONING	
5 ASSEMBLY SEQUENCE EFFICIENCY	○ POOR	○ FAIR	● GOOD	○ VERY GOOD	○ OUTSTANDING	
PART RETRIEVAL						
6 CHARACTERISTICS THAT COMPLICATE HANDLING (TANGLING, NESTING, FLEXIBILITY) HAVE BEEN AVOIDED	○ NO PARTS	○ FEW PARTS	○ SOME PARTS	○ MOST PARTS	● ALL PARTS	rigid parts
7 PARTS HAVE BEEN DESIGNED FOR SPECIFIC FEED APPROACH (BULK, STRIP, MAGAZINE)	○	○	○	●	○	
PART HANDLING						
8 PARTS WITH END-TO-END SYMMETRY	○ NO PARTS	○ FEW PARTS	○ SOME PARTS	● MOST PARTS	○ ALL PARTS	
9 PARTS WITH SYMMETRY ABOUT THE AXIS OF INSERTION	○	○	●	○	○	
10 WHERE SYMMETRY IS NOT POSSIBLE PARTS ARE CLEARLY ASYMMETRIC	●	○	○	○	○	
PART MATING						
11 STRAIGHT LINE MOTIONS OF ASSEMBLY	○ NO PARTS	○ FEW PARTS	○ SOME PARTS	● MOST PARTS	○ ALL PARTS	
12 CHAMFERS AND FEATURES THAT FACILIATE INSERTION AND SELF-ALIGNMENT	○	○	○	●	○	
13 MAXIMUM PART ACCESSIBILITY	○	○	○	●	○	

NOTE:
EVALUATION SCORE TO BE USED ONLY TO COMPARE ONE ASSEMBLY TO ALTERNATE DESIGNS OF THE *SAME* ASSEMBLY

2	TOTAL X 8	16
7	TOTAL X 6	42
3	TOTAL X 4	12
0	TOTAL X 2	0
1	TOTAL X 0	0
	TOTAL SCORE	70

Appendix Y features the third trial of the DFA worksheet for the current primary design. It was completed by Christina Yu. This had an overall score of 70 which is relatively close to the scores in the first two. It featured 1 in the lowest category.

Appendix Z: Design for Assembly Worksheet 4

DESIGN FOR ASSEMBLY
INDIVIDUAL ASSEMBLY EVALUATION FOR Current design

EVALUATED BY Donghyun Lee DATE 4/3/20
REVIEWED BY Andromeda tech DATE 4/3/20
TRIAL 01 02 03 04 05

						COMMENTS
OVERALL ASSEMBLY						
1 OVERALL PART COUNT MINIMIZED	○ POOR	● FAIR	○ GOOD	○ VERY GOOD	○ OUTSTANDING	
2 MINIMUM USE OF SEPARATE FASTENERS	○ POOR	○ FAIR	● GOOD	○ VERY GOOD	○ OUTSTANDING	
3 BASE PART WITH FIXTURING FEATURES (LOCATING SURFACES AND HOLES)	○ POOR	○ FAIR	○ GOOD	● VERY GOOD	○ OUTSTANDING	
4 REPOSITIONING REQUIRED DURING ASSEMBLY SEQUENCE	○ TWO OR MORE REPOSITIONS		● REPOSITION ONCE		○ NO REPOSITIONING	
5 ASSEMBLY SEQUENCE EFFICIENCY	○ POOR	○ FAIR	○ GOOD	● VERY GOOD	○ OUTSTANDING	
PART RETRIEVAL						
6 CHARACTERISTICS THAT COMPLICATE HANDLING (TANGLING, NESTING, FLEXIBILITY) HAVE BEEN AVOIDED	○ NO PARTS	○ FEW PARTS	● SOME PARTS	○ MOST PARTS	○ ALL PARTS	
7 PARTS HAVE BEEN DESIGNED FOR SPECIFIC FEED APPROACH (BULK, STRIP, MAGAZINE)	○	○	○	●	○	
PART HANDLING						
8 PARTS WITH END-TO-END SYMMETRY	○ NO PARTS	○ FEW PARTS	● SOME PARTS	○ MOST PARTS	○ ALL PARTS	
9 PARTS WITH SYMMETRY ABOUT THE AXIS OF INSERTION	○	○	○	●	○	
10 WHERE SYMMETRY IS NOT POSSIBLE PARTS ARE CLEARLY ASYMMETRIC	○	○	○	●	○	
PART MATING						
11 STRAIGHT LINE MOTIONS OF ASSEMBLY	○ NO PARTS	○ FEW PARTS	○ SOME PARTS	○ MOST PARTS	● ALL PARTS	
12 CHAMFERS AND FEATURES THAT FACILIATE INSERTION AND SELF-ALIGNMENT	○	○	○	●	○	
13 MAXIMUM PART ACCESSIBILITY	○	○	○	●	○	

NOTE:
EVALUATION SCORE TO BE USED ONLY TO COMPARE ONE ASSEMBLY TO ALTERNATE DESIGNS OF THE *SAME* ASSEMBLY

1	TOTAL X 8	8
7	TOTAL X 6	42
4	TOTAL X 4	16
1	TOTAL X 2	2
0	TOTAL X 0	0
	TOTAL SCORE	66

Appendix Z was the fourth trial of the DFA worksheet completed for the primary concept. It was completed by Dong Lee. The overall score was a 66, the lowest score given, but is still in the same ballpark. It also featured nothing in the lowest category.

Appendix AA: Design for Assembly Worksheet, Design with No Size Adjustments

DESIGN FOR ASSEMBLY
INDIVIDUAL ASSEMBLY EVALUATION FOR Design with no size adjustments
EVALUATED BY Donghyun Lee DATE 4/3/20
REVIEWED BY Andromeda tech DATE 4/3/20
TRIAL 01 02 03 04 05

OVERALL ASSEMBLY						*COMMENTS*
1 OVERALL PART COUNT MINIMIZED	○ POOR	○ FAIR	○ GOOD	● VERY GOOD	○ OUTSTANDING	
2 MINIMUM USE OF SEPARATE FASTENERS	○ POOR	○ FAIR	● GOOD	○ VERY GOOD	○ OUTSTANDING	
3 BASE PART WITH FIXTURING FEATURES (LOCATING SURFACES AND HOLES)	○ POOR	○ FAIR	○ GOOD	● VERY GOOD	○ OUTSTANDING	
4 REPOSITIONING REQUIRED DURING ASSEMBLY SEQUENCE	○ TWO OR MORE REPOSITIONS		○ REPOSITION ONCE		● NO REPOSITIONING	
5 ASSEMBLY SEQUENCE EFFICIENCY	○ POOR	○ FAIR	○ GOOD	● VERY GOOD	○ OUTSTANDING	
PART RETRIEVAL						
6 CHARACTERISTICS THAT COMPLICATE HANDLING (TANGLING, NESTING, FLEXIBILITY) HAVE BEEN AVOIDED	○ NO PARTS	○ FEW PARTS	○ SOME PARTS	● MOST PARTS	○ ALL PARTS	
7 PARTS HAVE BEEN DESIGNED FOR SPECIFIC FEED APPROACH (BULK, STRIP, MAGAZINE)	○	●	○	○	○	
PART HANDLING						
8 PARTS WITH END-TO-END SYMMETRY	○ NO PARTS	○ FEW PARTS	○ SOME PARTS	● MOST PARTS	○ ALL PARTS	
9 PARTS WITH SYMMETRY ABOUT THE AXIS OF INSERTION	○	○	●	○	○	
10 WHERE SYMMETRY IS NOT POSSIBLE PARTS ARE CLEARLY ASYMMETRIC	○	○	○	●	○	
PART MATING						
11 STRAIGHT LINE MOTIONS OF ASSEMBLY	○ NO PARTS	○ FEW PARTS	○ SOME PARTS	○ MOST PARTS	● ALL PARTS	
12 CHAMFERS AND FEATURES THAT FACILIATE INSERTION AND SELF-ALIGNMENT	○	○	○	●	○	
13 MAXIMUM PART ACCESSIBILITY	○	○	○	●	○	

NOTE:
EVALUATION SCORE TO BE USED ONLY TO COMPARE ONE ASSEMBLY TO ALTERNATE DESIGNS OF THE *SAME* ASSEMBLY

2	TOTAL X 8	16
8	TOTAL X 6	48
2	TOTAL X 4	8
1	TOTAL X 2	2
0	TOTAL X 0	0
	TOTAL SCORE	74

Appendix AA is the DFA worksheet completed with a modification created to the design for which the design cannot be adjusted to the size of the freezer it is in. It scored an overall 74 and was completed by Dong Lee.

Appendix AB: Design for Assembly Worksheet using only Snap Fasteners

DESIGN FOR ASSEMBLY
INDIVIDUAL ASSEMBLY EVALUATION FOR No Fasteners, snap assembly

EVALUATED BY Trevor Ladner DATE 4/4/20
REVIEWED BY Andromeda Tan DATE 4/4/20
TRIAL 01 02 03 04 05

OVERALL ASSEMBLY						*COMMENTS*
1 OVERALL PART COUNT MINIMIZED	○ POOR	○ FAIR	○ GOOD	○ VERY GOOD	● OUTSTANDING	
2 MINIMUM USE OF SEPARATE FASTENERS	○ POOR	○ FAIR	○ GOOD	○ VERY GOOD	● OUTSTANDING	
3 BASE PART WITH FIXTURING FEATURES (LOCATING SURFACES AND HOLES)	○ POOR	● FAIR	○ GOOD	○ VERY GOOD	○ OUTSTANDING	
4 REPOSITIONING REQUIRED DURING ASSEMBLY SEQUENCE	● TWO OR MORE REPOSITIONS		○ REPOSITION ONCE		○ NO REPOSITIONING	
5 ASSEMBLY SEQUENCE EFFICIENCY	○ POOR	● FAIR	○ GOOD	○ VERY GOOD	○ OUTSTANDING	
PART RETRIEVAL						
6 CHARACTERISTICS THAT COMPLICATE HANDLING (TANGLING, NESTING, FLEXIBILITY) HAVE BEEN AVOIDED	○ NO PARTS	○ FEW PARTS	○ SOME PARTS	● MOST PARTS	○ ALL PARTS	
7 PARTS HAVE BEEN DESIGNED FOR SPECIFIC FEED APPROACH (BULK, STRIP, MAGAZINE)	○	○	○	●	○	
PART HANDLING						
8 PARTS WITH END-TO-END SYMMETRY	○ NO PARTS	○ FEW PARTS	○ SOME PARTS	● MOST PARTS	○ ALL PARTS	
9 PARTS WITH SYMMETRY ABOUT THE AXIS OF INSERTION	○	○	●	○	○	
10 WHERE SYMMETRY IS NOT POSSIBLE PARTS ARE CLEARLY ASYMMETRIC	○	○	○	●	○	
PART MATING						
11 STRAIGHT LINE MOTIONS OF ASSEMBLY	○ NO PARTS	● FEW PARTS	○ SOME PARTS	○ MOST PARTS	○ ALL PARTS	
12 CHAMFERS AND FEATURES THAT FACILIATE INSERTION AND SELF-ALIGNMENT	○	○	●	○	○	
13 MAXIMUM PART ACCESSIBILITY	○	○	●	○	○	

NOTE:
EVALUATION SCORE TO BE USED ONLY TO COMPARE ONE ASSEMBLY TO ALTERNATE DESIGNS OF THE *SAME* ASSEMBLY

2	TOTAL X 8	16
4	TOTAL X 6	24
3	TOTAL X 4	12
3	TOTAL X 2	6
1	TOTAL X 0	0
	TOTAL SCORE	58

Appendix AB was the DFA worksheet completed for the modification to the design in which all fasteners were replaced with snapping fasteners. It was completed by Trevor Ladner and scored an overall 58.

Appendix AC: Design for Assembly Worksheet with Scissorlift

DESIGN FOR ASSEMBLY INDIVIDUAL ASSEMBLY EVALUATION FOR	Freezer Lift Insert with Scissor Lift Replacement		EVALUATED BY Nathan Robb		DATE 4/4/20	
			REVIEWED BY Andromeda Technology		DATE 4/4/20	
			TRIAL 01 02 03 04 05			
OVERALL ASSEMBLY						*COMMENTS*
1 OVERALL PART COUNT MINIMIZED	○ POOR	○ FAIR	● GOOD	○ VERY GOOD	○ OUTSTANDING	
2 MINIMUM USE OF SEPARATE FASTENERS	○ POOR	○ FAIR	● GOOD	○ VERY GOOD	○ OUTSTANDING	
3 BASE PART WITH FIXTURING FEATURES (LOCATING SURFACES AND HOLES)	○ POOR	○ FAIR	○ GOOD	● VERY GOOD	○ OUTSTANDING	
4 REPOSITIONING REQUIRED DURING ASSEMBLY SEQUENCE	○ TWO OR MORE REPOSITIONS		● REPOSITION ONCE		○ NO REPOSITIONING	
5 ASSEMBLY SEQUENCE EFFICIENCY	○ POOR	○ FAIR	● GOOD	○ VERY GOOD	○ OUTSTANDING	
PART RETRIEVAL						
6 CHARACTERISTICS THAT COMPLICATE HANDLING (TANGLING, NESTING, FLEXIBILITY) HAVE BEEN AVOIDED	○ NO PARTS	○ FEW PARTS	● SOME PARTS	○ MOST PARTS	○ ALL PARTS	
7 PARTS HAVE BEEN DESIGNED FOR SPECIFIC FEED APPROACH (BULK, STRIP, MAGAZINE)	○	●	○	○	○	
PART HANDLING						
8 PARTS WITH END-TO-END SYMMETRY	○ NO PARTS	○ FEW PARTS	○ SOME PARTS	● MOST PARTS	○ ALL PARTS	
9 PARTS WITH SYMMETRY ABOUT THE AXIS OF INSERTION	○	○	●	○	○	
10 WHERE SYMMETRY IS NOT POSSIBLE PARTS ARE CLEARLY ASYMMETRIC	○	○	○	○	●	
PART MATING						
11 STRAIGHT LINE MOTIONS OF ASSEMBLY	○ NO PARTS	○ FEW PARTS	○ SOME PARTS	● MOST PARTS	○ ALL PARTS	
12 CHAMFERS AND FEATURES THAT FACILIATE INSERTION AND SELF-ALIGNMENT	○	○	●	○	○	
13 MAXIMUM PART ACCESSIBILITY	○	○	○	●	○	
NOTE: EVALUATION SCORE TO BE USED ONLY TO COMPARE ONE ASSEMBLY TO ALTERNATE DESIGNS OF THE *SAME* ASSEMBLY	0 TOTAL X 0	1 TOTAL X 2	7 TOTAL X 4	4 TOTAL X 6	1 TOTAL X 8	8
						24
						28
						2
						0
					TOTAL SCORE	62

Appendix AC was the DFA worksheet completed for the design with a scissor lift used in place of the guided rail system. This returned an overall score of 62 and was completed by Nathan Robb.

Appendix AD: Design for Assembly Worksheet with Frame produced as 1 Part

DESIGN FOR ASSEMBLY
INDIVIDUAL ASSEMBLY EVALUATION FOR Freezer Lift Insert w/ frame as 1 part

EVALUATED BY Christina Yu DATE 4/4/2020
REVIEWED BY Andromeda Technologies DATE 4/4/2020
TRIAL 01 02 03 04 05

OVERALL ASSEMBLY						*COMMENTS*
1 OVERALL PART COUNT MINIMIZED	○ POOR	○ FAIR	○ GOOD	○ VERY GOOD	● OUTSTANDING	
2 MINIMUM USE OF SEPARATE FASTENERS	○ POOR	○ FAIR	○ GOOD	● VERY GOOD	○ OUTSTANDING	
3 BASE PART WITH FIXTURING FEATURES (LOCATING SURFACES AND HOLES)	○ POOR	○ FAIR	● GOOD	○ VERY GOOD	○ OUTSTANDING	
4 REPOSITIONING REQUIRED DURING ASSEMBLY SEQUENCE	○ TWO OR MORE REPOSITIONS		○ REPOSITION ONCE		● NO REPOSITIONING	
5 ASSEMBLY SEQUENCE EFFICIENCY	○ POOR	○ FAIR	○ GOOD	● VERY GOOD	○ OUTSTANDING	
PART RETRIEVAL						
6 CHARACTERISTICS THAT COMPLICATE HANDLING (TANGLING, NESTING, FLEXIBILITY) HAVE BEEN AVOIDED	○ NO PARTS	○ FEW PARTS	○ SOME PARTS	● MOST PARTS	○ ALL PARTS	
7 PARTS HAVE BEEN DESIGNED FOR SPECIFIC FEED APPROACH (BULK, STRIP, MAGAZINE)	○	○	○	●	○	
PART HANDLING						
8 PARTS WITH END-TO-END SYMMETRY	○ NO PARTS	○ FEW PARTS	○ SOME PARTS	● MOST PARTS	○ ALL PARTS	
9 PARTS WITH SYMMETRY ABOUT THE AXIS OF INSERTION	○	○	●	○	○	
10 WHERE SYMMETRY IS NOT POSSIBLE PARTS ARE CLEARLY ASYMMETRIC	○	○	○	●	○	
PART MATING						
11 STRAIGHT LINE MOTIONS OF ASSEMBLY	○ NO PARTS	○ FEW PARTS	○ SOME PARTS	○ MOST PARTS	● ALL PARTS	
12 CHAMFERS AND FEATURES THAT FACILIATE INSERTION AND SELF-ALIGNMENT	○	○	○	●	○	
13 MAXIMUM PART ACCESSIBILITY	○	○	●	○	○	

Count	Multiplier	Score
3	TOTAL X 8	24
7	TOTAL X 6	42
3	TOTAL X 4	12
0	TOTAL X 2	0
0	TOTAL X 0	0
	TOTAL SCORE	78

NOTE:
EVALUATION SCORE TO BE USED ONLY TO COMPARE ONE ASSEMBLY TO ALTERNATE DESIGNS OF THE *SAME* ASSEMBLY

Appendix AD was the DFA worksheet completed for the design if the frame were manufactured as one part rather than multiple and plastic welded together. It scored an overall 78 and was completed by Christina Yu. This is the highest scoring DFA; however, the design was not used because of the cost to produce the frame like that.