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Cart Loader

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Cart Loader

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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Cart Loader

By

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SENIOR DESIGN PROJECT REPORT

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ABSTRACT

For this senior design project, the team partnered with a startup, Dishcraft Robotics, to design and create a device that would decrease the time it takes to unload and load their products in and out of a truck. The team's design, Cart Loader, consists of an aluminum structure that is able to hold their products. Outfitted with a rail system on the truck and the liftgate, the Cart Loader can move onto the liftgate and roll inside the truck, where the products can then be rolled off the Cart Loader. There was extensive finite element analysis done to ensure that the structure could handle the loads of the products. The Cart Loader can withstand loads of up to 1500 lbs with a factor of safety of 1.82. Even without the physical truck, testing was done on the Cart Loader. The Cart Loader ended up reducing the loading time from 60 minutes to 27.1 minutes. In addition, the Cart Loader accomplished the customer's goals of a device that secures their products, is easy to use, and carries a large portion of their products in one load.

Keywords: Dishcraft Robotics, Cart Loader, dishcart, liftgate,

truck loading, FEA

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Chapter 1: Introduction

1.1 Partner Organization: Dishcraft Robotics

The team has been tasked with finding a more efficient way to load and unload a box-truck. More specifically, the team will be partnering with a company called Dishcraft Robotics, a San Carlos, CA-based company that provides a dish cleaning service to cafeterias and dining halls with an emphasis on sustainability. After the dishes are used, Dishcraft picks them up in a box-truck and returns them to the San Carlos facility to be washed.

Dishcraft Robotics has designed and manufactured their own line of custom dish-cleaning robots. These robots are able to save considerable amounts of time, money, and water through an automated washing process that filters and recycles the used dish water. The idea is that companies hosting large scale dining operations can spare themselves the expense of purchasing and maintaining dishwashing equipment (or using paper/plastic ware) and instead hire Dishcraft to carry out any necessary dish cleaning process.

1.2 Problem Statement

One of the biggest challenges faced by Dishcraft has to do with transporting the dishes to and from specified locations. The transportation life-cycle includes driving clean dishes to a client location, dropping them off, and then picking up the dirty wares after use. After the dishes are picked up, they are brought back to a facility where they are washed using an advanced water and waste efficient robotic system. Under their current system, Dishcraft utilizes dishcarts (dishcarts and carts will be used interchangeably throughout this paper) that each hold approximately 150 lbs of dishes. These carts are roughly 15"x 15" at the base and around 3' tall. Up to 60 of these carts are contained in the cargo area of the truck at any given time. Currently, the company uses a standard lift gate to load or unload the carts. Unloading or loading all dishcarts, takes approximately one hour. It is also a hazardous process due to the possibility of one of the dishcarts inadvertently falling off of the lift gate. The team's project goal is to design a system that will drastically reduce the amount of time it takes to load or unload the box-truck while also securing the carts throughout the operation.

1.3 Review of Existing Products and Literature

To begin solving Dishcraft's logistical problem, the team researched existing products to gain insight into possible solution methods. This served to determine if a viable solution already existed and if that solution was applicable. An ancillary benefit to researching existing solutions was that the current solutions could serve as a benchmark upon which the team's final design could be compared. Also of great importance was research into the mechanics of liftgates and liftgate hydraulics. This research allowed for a greater understanding of how the current liftgate system operates and how the team could potentially alter its operation if necessary.

1.3.1 Hydraulics and Liftgate Research

The team's first and foremost task was to gain insight into the operation and control of lift gates and lift gate hydraulics. This knowledge was a baseline necessity for the successful implementation of the team's "Cart Loader." An academic lab report, "Hydraulic and pneumatic control laboratory" [1], provided useful information on hydraulic systems and flow control valves. Information on flow control valves was acquired to gain insight into whether or not a lift gate's speed could be precisely controlled for the team's project [1]. From this report it was determined that flow control, and thus lift speed, could be altered.

After gaining insight into flow control valves, research proceeded into in-depth concepts regarding liftgates. Specifically, the Maxon TE-20 liftgate was researched in depth. This lift gate was chosen to be researched because it is currently used on the company's box-truck. The load capacity of the lift gate was engineered to be 2000 lbs [2]. Other important information regarding the operation and control was also gathered. This information revealed to the team that all loads at or close to 2,000 lbs needed to be centered on the liftgate at a specific point. This knowledge was essential to later design efforts.

An early idea that the team had was to incorporate a hydraulic system into the design solution. This idea led to more research into the procurement and implementation of hydraulic cylinders. A few devices were selected that would allow for the expansion of the liftgate surface-area to include a large 'tray-like' device that would lower down all of the carts at once. It involved using a hydraulic system that included a Vevor pump [3] and a set of hydraulic cylinders from Northern Hydraulic [4]. The team had considered using a fifth wheel landing gear, but none of them had long enough stroke lengths for the team's applications. Instead the hydraulic system was initially selected. However, after speaking with the truck driver at Dishcraft, it was determined that using a 'tray' with hydraulic cylinders for vertical movement was not feasible due to size constraints.

1.3.2 Conveyor Belt Research

In a research article, Zeng et al [5] addressed the need to create a more accurate model for conveyor belt operation for non-uniform bulk materials.. This is important for the team's project, especially since customers have a variety of materials they would place onto a potential design solution involving a conveyor belt. According to the article, the non-uniform distribution of weight can affect the traction of the conveyor belt and the speed. If the conveyor belt design is selected, the equations in the aforementioned article will be useful to determine if or when loss of traction or speed will occur due to varied distribution loading.

It is notable that for the team's project a number of simplifications can be made to the equations in the article. For their research, Zeng et al [5] estimated how traction and speed are affected by a distribution of rocks on a conveyor belt. Whereas for the team's design, the weight of objects placed on the belt will be known and critical load cases will be able to be analyzed. Critical loading cases include two scenarios: a highly uniform load and a large point load.

Chapter 2: Customer Needs and Product Specifications

2.1 Customer Needs

In order to create a product that would satisfy the potential market, the needs of three companies were analyzed. To do this, interviews were conducted with Dishcraft Robotics, Funflicks, and Bon Appetit. From these interviews, the needs of each company and their level of importance were ascertained and are listed in Appendix A Table A.1. However, as the product is truly for Dishcraft's use, the customer needs from Dishcraft will be of premiere importance and all other needs will be identified as latent needs that Dishcraft did not consider.

There were a couple of takeaways that were gathered from Dishcraft. To unload a full truck of 60 dishcarts (using the truck's liftgate) it takes the Dishcraft driver approx one hour. With Dishcraft's current process, one operator can handle one to two carts per lift gate cycle and two operators can handle eight carts per lift gate cycle. As shown in Figure 2.1 there is a process that the driver follows. First, the driver rolls one to two carts from inside the truck to the lift gate. He then locks one wheel brake per cart and has the cart bumpers align side by side. The lift gate is then lowered using an operating switch. His other hand is used to safely secure the dishcarts. Upon reaching the apex of the truck, the wheel brakes are unlocked and the carts are rolled off. This process is repeated about 29-59 more times.

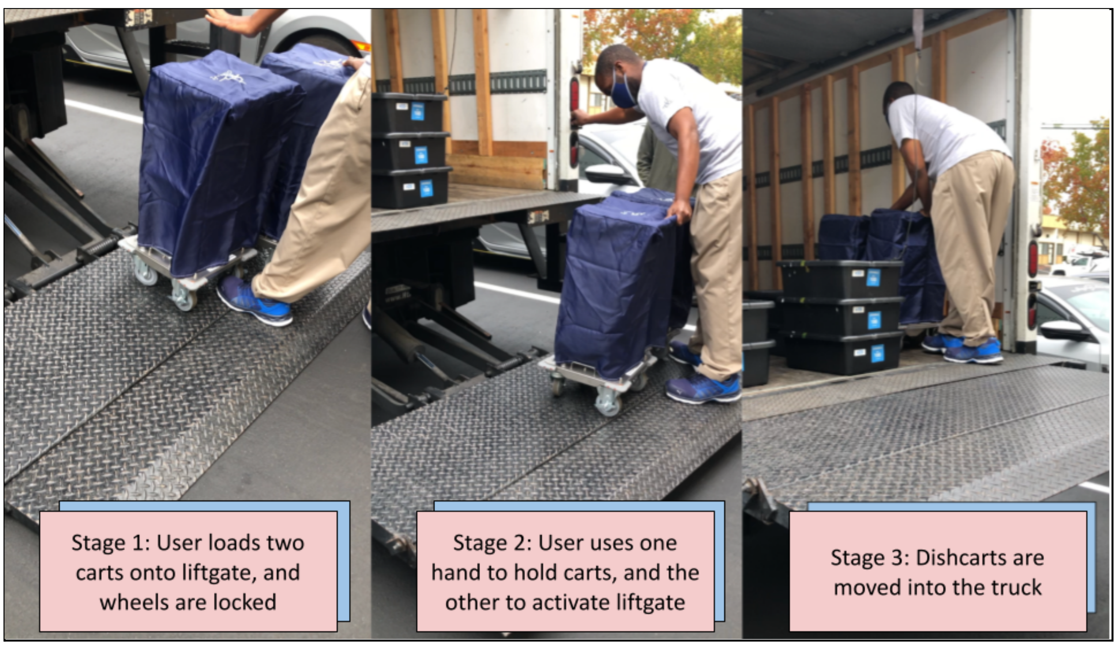


Figure 2.1. Procedure for loading dishcarts onto the truck

After the interview with Dishcraft's driver and product manager, the team began to contemplate how the design needed to accomodate slopes and space constraints. Accounting for slopes includes considering inclines, declines, and flat surfaces. The space behind the truck is limited to four feet in certain situations, therefore space constraints also need to be considered so that the driver can maneuver efficiently behind the truck with the device. This is important because the lift gate, itself, takes up three feet of space. This decreased the number of potential solutions that the team considered.

The next potential customer, Funflicks, is an outdoor moving company that transports several heavy, cumbersome products for their service. The time they currently spend unloading a truck to set up a movie scene can be upwards of an hour even with four or more people helping to unload. That said, they are a small business and don't have extra resources to spend on a several thousand dollar unloading equipment. Thus, the ideal solution for them is a low cost solution that doesn't take up much space.

The final potential customer, Bon Appetit, is an on site restaurant company that makes meals for Santa Clara students and faculty. Employee safety is the number one concern for the operations company. As such, a Cart Loader that would increase the security of the food and increase the safety of the workers is a logical investment. The current daily process involves workers unloading food shipments from Bon Appetit to Benson. The average unloading process takes about one and a half hours. Due to safety concerns, the process has recently increased by approximately 30-45 minutes because the workers cannot lift anything over 25 lbs. The company could benefit from a new unloading system which will save time.

2.2 Product Specifications

In order to make it easier to analyze the designs that the team came up with, the customer needs were converted into design metrics. Using these metrics, each of the created designs could be analyzed on how well they met the given product specifications. The metrics are listed in Appendix B, Table B.1.

2.3 Benchmarking

In addition to product specifications, benchmarking of existing products was carried out to compare and contrast performance levels. The most crucial product that the team benchmarked was the Maxon Tuk-A-Way GPT-3 Liftgate which is the type of liftgate that Dishcraft was using for its operations. Benchmarking allowed the team to predict how their design solution stacked up against other potential products. Quantitative results from the benchmarking analysis can be found in Appendix B, Table B.2.

Chapter 3: Preliminary Design Ideas and Selection Matrices

3.1 Concept Sketches and Ideas

For the concept generation portion of the project, each team member brainstormed and developed a design idea. For each of these ideas, the team members made basic sketches of the overall design and critical subsystems. These sketches included details about how the system operates, and how the design effectively solves the given problem. The sketches were constrained to the design parameters given to the team by Dishcraft Robotics. In addition to the sketches, each team member developed a basic SolidWorks model. Depicted below are five basic concept ideas, developed by each of the team members: (a) Cart Roller, (b) Cart Pusher, (c) Cart Rails, (d) Cart Ramp, (e) Cart Clamp.

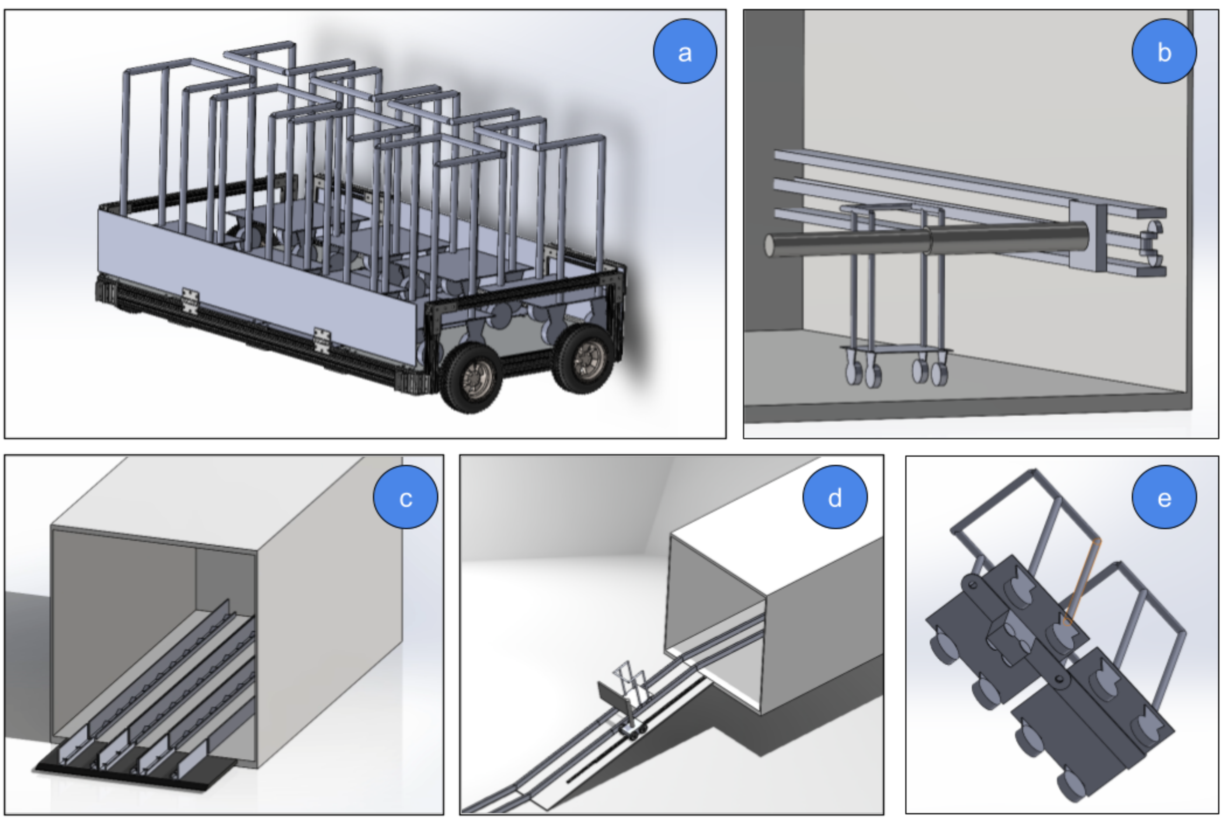


Figure 3.1. Five initial conceptual designs considered in critical design review

The Cart Roller serves as a platform that can ferry eight to ten dishcarts to and from the back of a box-truck in a larger batch. This concept would secure the carts while moving more dishcarts in one trip. The Cart Roller is free to move into a truck, out of a truck, onto the liftgate, and even into a building. The SolidWorks model is shown as image “a” in Figure 3.1.

The Cart Pusher is a robotic telescoping arm that can extend, contract, and move along the length of the truck via a belt system. Its purpose is to automate the loading inside of the truck. As the carts are loaded onto the liftgate, the telescoping arm extends to reach the furthest cart and then the arm moves itself and subsequently the carts to the back of the truck. Two sets of arms will be utilized on the truck, one on either side of the truck, where both arms would be controlled by one control system. The SolidWorks model is shown as image “b” in Figure 3.1.

The Cart Rail concept uses a series of rails within the truck to move the carts to and from the liftgate. The rails simultaneously secure the carts to the truck and prevent unwanted rolling while on slopes. This concept would involve physically attaching rails to both the bed of the box-truck as well as the liftgate. The rail system would contain a locking mechanism such that the carts can only move one direction without an external force acting upon the locking mechanism. So loading the carts requires no external force, but unloading does. Thus, the carts are secure during transportation, and easy to load/unload safely. The idea behind the Cart Rail was based on an understanding that the speed of operation was the primary goal. The speed was hindered, in large part, by the insecurity of the carts during liftgate operations. Therefore, solving the cart insecurity issue would, in part, solve the speed problem. The SolidWorks model is shown as image “c” in Figure 3.1.

The Cart Ramp idea is designed to be used regardless of a liftgate being present on the truck. This design idea relies on a motorized (by a linear actuator) rail system within the truck, so the user can simply push the dishcarts onto the rail, where it will then be automatically moved to the front of the truck. Then at the front of the truck as a sensor is triggered the cart falls onto a rolling door which guides the dishcart to the ground. Finally, the door swings open allowing the cart to be released onto another motorized rail system on the ground. This entire operation would provide a more automated solution and would then be repeated requiring minimum user input. The SolidWorks model is shown as image “d” in Figure 3.1.

The Cart Clamp concept connects individual dishcarts together using a clamp system. The purpose is to move multiple carts when one cart is pushed. The operation is for the row of clamped carts to be brought to the lift gate and then lowered down. After the carts are lowered down, they are then rolled to their final destination using a powered device. The SolidWorks model is shown as image “e” in Figure 3.1.

3.2 Selection Matrix Introduction

Before making a final design selection, the team first decided on the most critical criteria the design needed to meet to successfully address the customer needs. After identifying these key criteria, weights were assigned to judge the importance of different product specs relative to each other. Table 3.1 shows the ten selection criteria the team deemed most appropriate along with their corresponding weights. The team deemed "secures carts during operation" and "speed" as being the most essential to fulfilling the customer needs and product specifications with the highest weights of "20" each.

Table 3.1 Important criteria used in selection matrix based upon customer needs

	Selection Criteria to Accomplish Customer Needs	Weights
A	Not reliant on physically attaching things to truck	10
B	Ease of use for the user	15
C	Build difficulty	5
D	Cost to build	5
E	Cart capacity	10
F	Secures carts during operation	20
G	Space taken up behind truck	7
H	Speed	20
I	Adaptability for other uses	5
J	Space taken up in truck	3

3.3 Design Selection

The team used two selection matrices to find the best potential design. The first selection matrix was based on the team's five individual ideas (Table 3.2). After the first selection matrix, it was determined that there were flaws in each of the designs that could be improved with a combination of multiple team members' ideas. Therefore the second selection matrix was a combination selection matrix, combining these ideas based on different aspects from the first five ideas that were complementary (Table 3.3). These scores were ranked democratically based on averaging each of the team members' assigned value. Values were assigned based on the assessment of each of the conceptual designs. It should be noted that these selection matrices refer to 1 as the best score and 5 as the worst score. It should also be noted that the current Dishcraft liftgate process is also included (as a control) to analyze how well each design improves upon the current process.

The selection matrix process yielded a clear winner (lowest score of 171.25). This design was a combination of two of the team members' ideas - the Cart Roller with an integrated rail system. From here on out this design will be called the "Cart Loader". The Cart Loader is an aggregate of the best aspects of two of the team member's designs.

The basic function of this design is that it is a powered platform that ferries carts too and from the back of the truck. When the cart reaches the lift gate, it locks into place. After it is locked in place, the user can then lower the liftgate to the ground and off load all of the carts.

Table 3.2 Selection matrix of individual ideas

Design Idea	A	B	C	D	E	F	G	H	I	J	Total	Total Weighted
Weights	10	15	5	5	10	20	7	20	5	3		
Current Dishcraft Liftgate	5	4	2	3	4	5	1	5	1	1	**31**	**390**
Cart Roller	1	2.4	1.6	1.9	1	3	1	1.5	1.1	1	**15.5**	**179**
Cart Clamp	1	3.5	1	1.1	1.3	4	1	1.9	1.5	1	**17.3**	**221.5**
Cart Ramp	5	1.7	3.4	2.8	2.5	1.5	2.3	2.5	2	2	**25.7**	**243.6**
Cart Rail	5	1.5	2.3	1.5	1.3	1	1	2.3	3.1	1.25	**20.25**	**196.75**
Cart Pusher	5	3	3.6	3.5	1.3	3.6	1	2.3	1.9	1.5	**26.7**	**282.5**

Table 3.3 Selection matrix of combined ideas

Design Idea	A	B	C	D	E	F	G	H	I	J	Total	Total Weighted
Roller Cart w/ Rails	5	1	2.75	3	1	1	1	1.5	1.5	1	**18.75**	**171.25**
Ramp Rails	5	1	3	2	2	1	2	2	2.5	2.5	**23**	**204**

Chapter 4: Design Modeling and Iteration

4.1 Software Package Selection and Coordination

Chapter 3 gave a thorough explanation of the selection process that the team used to reach a conceptual design idea. The next step was to iterate on the selected conceptual design until an adequate model emerged. This process was carried out almost entirely using a CAD software package. The team elected to use SolidWorks as the primary software package for modeling the design. SolidWorks has excellent 3-D modeling features and allows for importation of manufactured parts directly into the workspace. For instance, if a part from McMaster-Carr, a hardware supplier, was going to be used in the design, the team could download a CAD file for the part and pre-test the part for dimensional accuracy and fit. This sped up the design process immensely and allowed for the team to seamlessly integrate all necessary hardware components. It also prevented the team from purchasing hardware that did not fit, thus decreasing the amount of returns back to the supplier.

Coordination between different team members' design tasks was carried out using SolidWorks' Pack-And-Go feature. This was an essential part of the design process as it allowed team members to send updated 3-D model drafts to the entire team with ease. The Pack-And-Go feature allows a user to pack every component of their sub-assembly into a compressed zip folder and then send that zip folder to all the team members. The team members would then replace their current part folder with the new, updated part folder. The process seems tedious but ended up being the most effective way to keep the model iterations up-to-date.

4.2 Truck-Bed Measurement and Modeling

Before starting the design process, the team needed an accurate model of the truck used by Dishcraft to transport dishes to and from different locations. This step was absolutely crucial as it would prevent the team from building a device that did not fit properly in the rear of the truck bed. The team traveled to Dishcraft's HQ in San Carlos to take precise measurements of the rear of the truck. This process was repeated twice throughout the design process before any parts were purchased to ensure that the final design would fit precisely in the rear of the box-truck.

After the measurements were taken, the team created a SolidWorks model of the rear of the truck. This truck model became the basis for which the overall dimensions of the design were created. The truck bed model also served as a way for the team to begin creating a workflow model of how the user could effectively use the device to its maximum potential. This model was used throughout different design iterations, as will be shown in later sections.

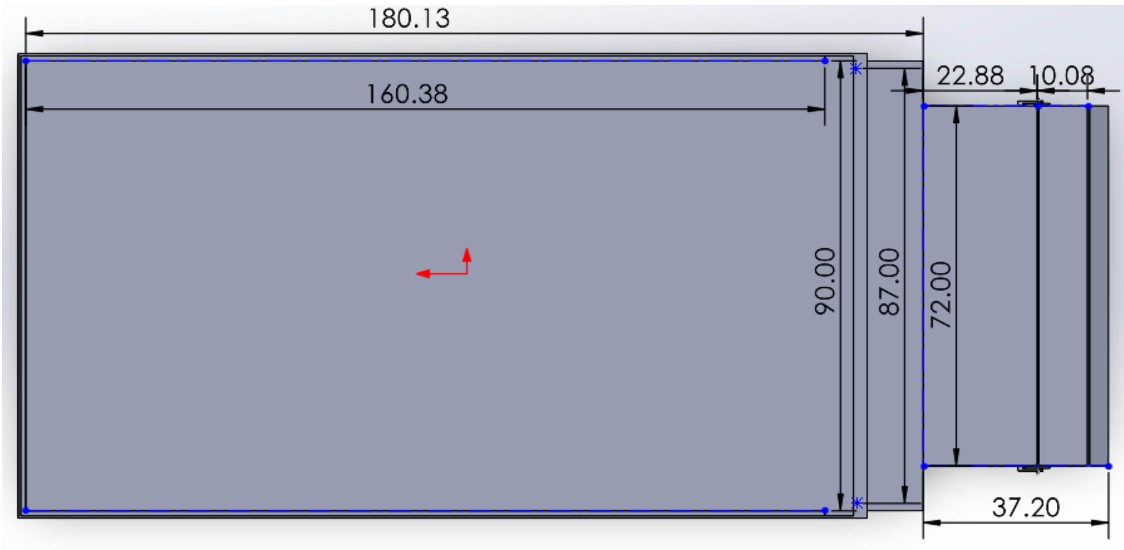


Figure 4.1. Dimensions of the box-truck bed. All dimensions given in inches

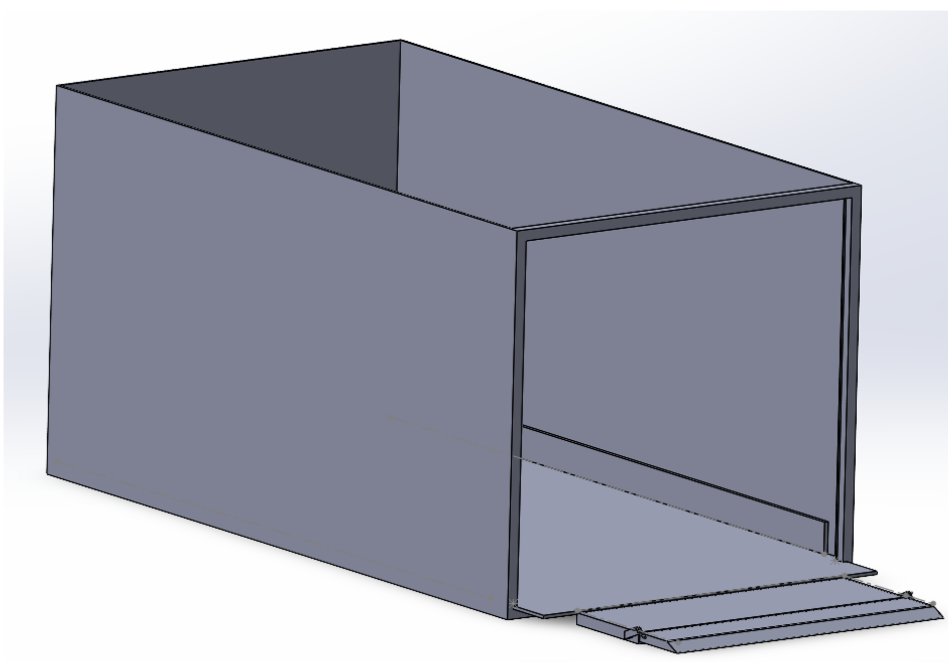


Figure 4.2. Isometric view of the truck bed with liftgate

4.3 Preliminary Materials Selection

Before diving into a detailed design effort, the team came to a consensus regarding how the final product should be constructed given the knowledge and tools available. Questions as to what sort of fabrication effort the team was capable of completing were discussed. The team considered a few key factors including cost, modularity, ease of construction, and strength of design.

A first consideration was to create the frame from steel or aluminum square tube. This square tubing would be cost effective and yield a high design strength. However, using these materials would require a considerable amount of welding. With minimal room for error both in design and budget, any mistake in welding could require large sections of the frame to be cut out and replaced.

Another consideration was to use T-Slotted framing rails or aluminum extrusions to create the base frame of the device. These extrusions allow for considerable modularity and are not nearly as prone to user error. They are also considerably strong and require no welding. The main downside is a high upfront cost.

After careful consideration, the team decided that T-Slotted aluminum extrusions would be used to create the frame. With this in mind, the team was able to begin modeling a prototype using CAD software. This prototype used T-Slot CAD models identical to those that would be purchased from online vendors. This allowed for a strikingly realistic computer simulation model to be constructed.

4.4 CAD Model Iterations

There were a total of six design iterations to reach a final configuration that was ready for construction. Each of these iterations brought the team closer to the final goal of a working Cart Loader. The main purpose of these preliminary iterations was to create a design that fit perfectly within the rear of the box-truck while also being large enough to carry ten dishcarts for each liftgate cycle. Another primary reason for so many of these iterations was that the team was ‘zeroing-in’ on the best possible design solution for the given constraints. The team was able to conduct many iterations in rapid succession due to the availability of pre-modeled hardware on websites like McMaster-Carr.

The first few iterations lacked depth and detail. Version 1 of the Cart Loader was simply a rolling platform made of aluminum extrusions. Version 1 had almost no hardware specifications and was purely a 'theoretical' model used throughout the selection matrix process. Revision 2 was akin to version 1 in many ways except that the hardware specifications were more thorough. Revision 2 only had the surface area to allow for 8 carts. Revisions 3, 4 & 5 were nearly identical in that they all had a base frame made of aluminum extrusions and were capable of carrying ten dishcarts. Hardware specifications were also nearly complete for Revisions 3, 4 & 5 and they met most of the geometric requirements. Throughout the iterative revision process, the team would frequently get close to finishing a design iteration and recognize a discrepancy or drawback with the current version. The beauty of 3D modeling is that iteration is fast, free and relatively straightforward.

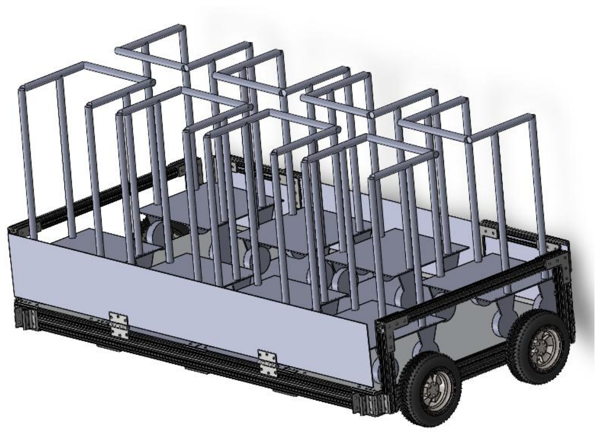


Figure 4.3. Cart Loader revision 2

Figure 4.4. Cart Loader revision 4

4.5 Pre-Simulation CAD Model

By the time the CAD modeling had reached its 6th iteration, the Cart Loader had achieved a high degree of constructability and dimensional accuracy. Revision 6 was the final, pre-simulation design that the team settled on. This final revision had many of the distinguishing characteristics of the five previous versions but included an incredible level of detail. This level of detail described the dimensions down to the thousands of an inch. The final CAD revision had enough surface area to hold 10 carts (or 9 carts and one person), weighed in at around 260 lbs (unloaded) and had overall dimensions of about 7' (width) by 3' (depth).

The main subcomponents of the Cart Loader included: a base frame of aluminum extrusions, an aluminum top sheet made of ⅛" 6061 T6, two hinged ramps also made of ⅛" 6061 T6, six caster bracket subsystems made of ¼" 6061 aluminum, and a 24V motor system used to power the device.

The secondary subcomponents of the design include all necessary parts to keep the Cart Loader in place throughout operation. These second set of parts are essentially a set of rails that attach to the truck and liftgate and constrain the Cart Loader within the back of the truck. These rails keep the Cart Loader straight during operation and also prevent the device from inadvertently rolling out of the truck.

Each of these subcomponents will undergo extensive FEA testing in subsequent chapters. After testing, any necessary modifications will be made and the Cart Loader will go through another round of iterations to ensure safety and reliability during operation. Figure 4.5 below illustrates the major sub-assemblies.

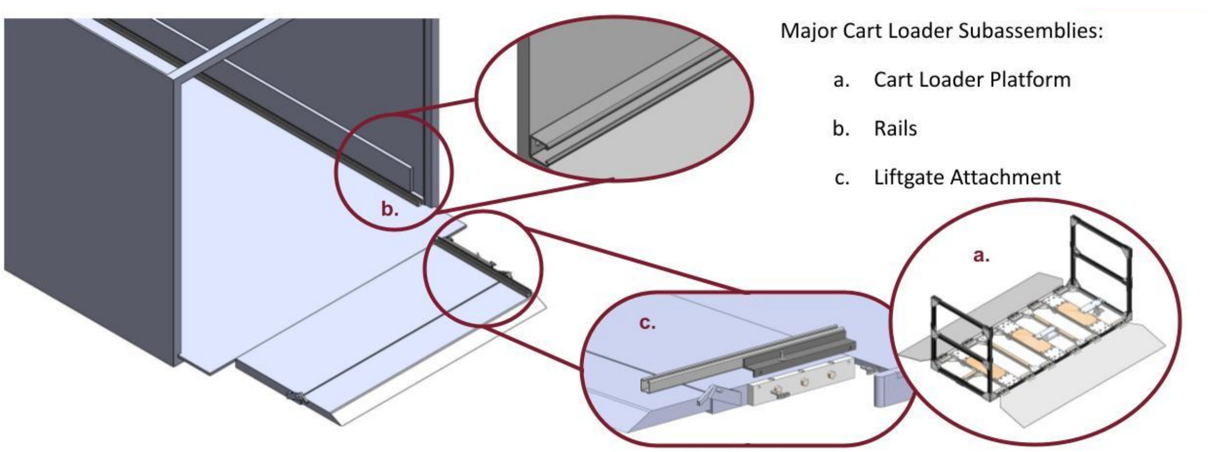


Figure 4.5. Cart Loader major sub-assemblies

4.6 Design Workflow

The design workflow model is essentially a set of instructions that describe how the Cart Loader is supposed to be used by the operator. Following the design workflow model allows for fast, safe operation of the device. Outlined below are the steps that should be followed to successfully operate the Cart Loader. Also included are various snapshots of a design workflow simulation that depicts exactly how the Cart Loader should be used.

Step one involves attaching the 'lift gate rail' to the lift gate. This rail prevents the Cart Loader from inadvertently rolling out of the truck and also maintains the Cart Loader's alignment. Step two first starts with lowering the two hinged ramps and then loading carts from the rear of the truck onto the Cart Loader platform. After the carts have been loaded onto the platform, step three is to lock the hinged ramps into an upright position with the user on top of the platform with the carts. Step four then proceeds with the user switching the motor controller to the 'on' position and allowing the Cart Loader to then make its way to the end of the lift gate where it will automatically lock into place. Step five instructs the operator to lower the lift gate to the ground and then unload all of the carts. The inverse process is followed for loading.

As will be shown in the testing section of chapter 8, this workflow model allows for 8-10 carts to be transported out of the truck for every lift gate operation. The current workflow model that Dishcraft Robotics uses only allows 1-2 carts to be transported out of the truck for every lift gate operation. The design solution depicted up to this point is expected to cut the loading time down from 1 hour for every 60 carts to a mere 30 minutes. This saves about two man hours per full truck (loading and unloading) per delivery trip.

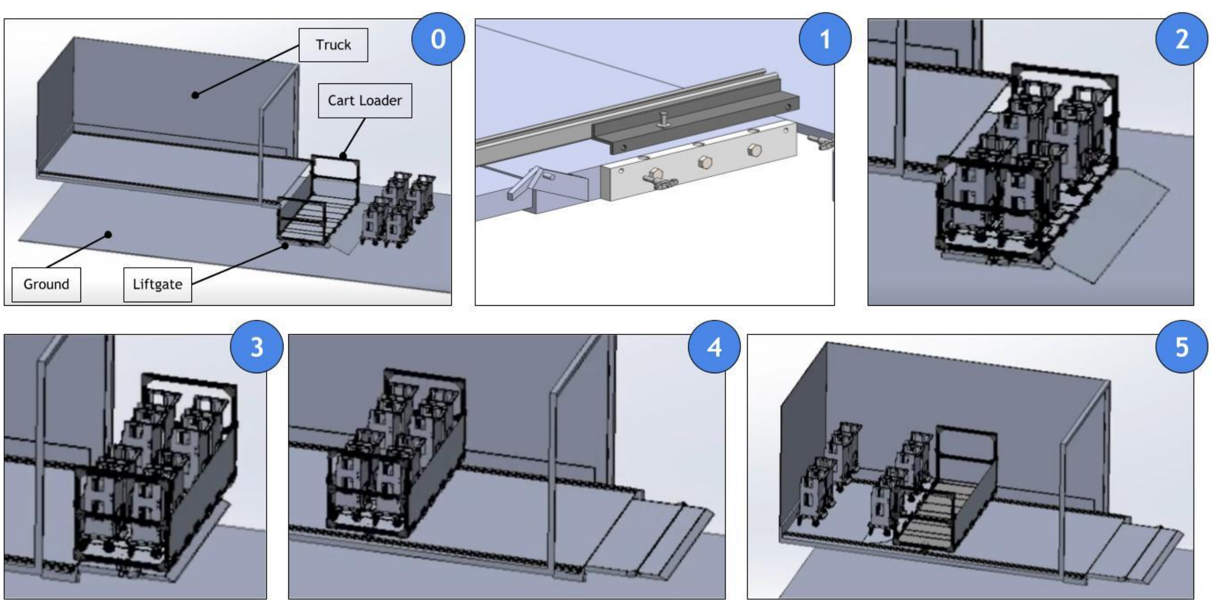


Figure 4.6. Workflow model

Chapter 5: Finite Element Analysis

5.1 FEA Introduction

In order to ensure the team's product could be used safely and reliably, an in-depth analysis of the possible failure modes of the Cart Loader system was conducted. The critical failure modes are associated with key subsystems of the design, as shown in Figure 5.1. These include the base structure of the frame, the top sheet that the dishcarts rest on, the ramp, and the latching mechanism. To evaluate the safety of these subsystems, the team used hand calculations and finite element simulations as the primary tools of the failure analysis. The hand calculations are used as a simple verification tool to ensure that the FEA software results are within the range of expected values. The FEA method is used on the more complex aspects of the geometry that would be near impossible to solve analytically.

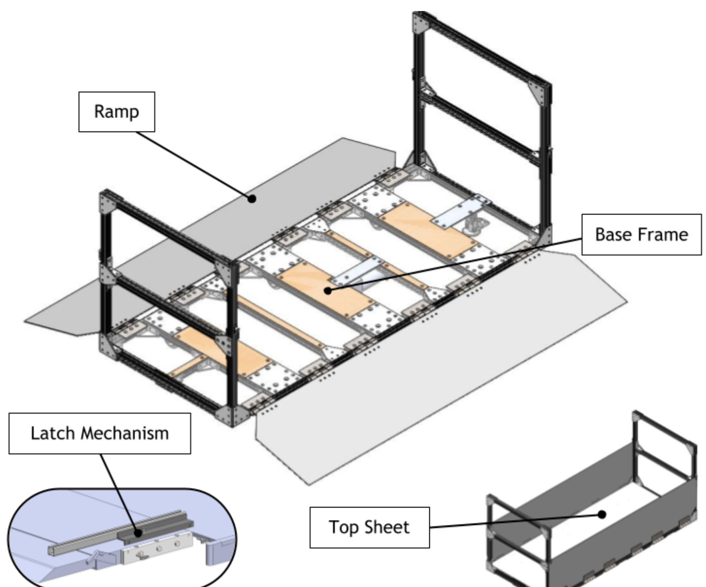


Figure 5.1. Critical subsystems identified and used for FEA

5.2 Software Packages

The primary FEA software used by the team was SolidWorks' Static Simulation package. This package gives a reasonably accurate approximation to how various components will perform under static loads. Another FEA software regime used by the team was Abaqus' Explicit

Dynamic package. This package allows the team to determine whether or not various components of the design will fail during the inevitability of dynamic impacts.

5.3 Equivalent Beam Explanation

In order to employ an FEA simulation on the base structure of the frame, the aluminum extrusions needed to be simplified. The key reason is that the cross-sectional geometry of the aluminum extrusion is quite complex which makes it impractical to use an FEA method on without running into computational limitations. In other words, the number of nodes necessary to carry out the FEA simulation would cause most computers to crash. Therefore, the 1.5”x1.5” T-Slotted aluminum extrusion was simplified into an equivalent beam of the same height and area moment of inertia.

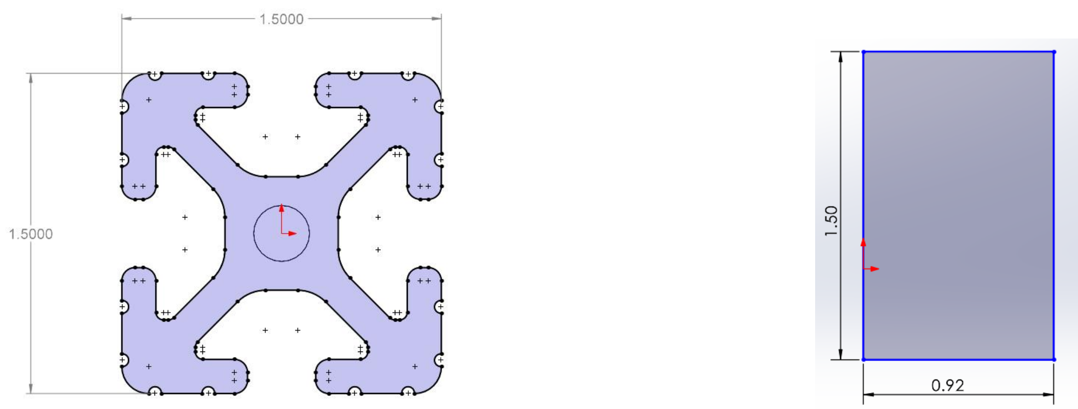


Figure 5.2. Aluminum extrusion simplification
(Left picture shows the actual cross section. Right picture shows a simplified cross section with the same inertia.)

A joint analytical and FEA test were employed to determine the viability of using this simplified model in determining an accurate stress. The joint test involved finding the bending stress of the beam under the same loading conditions and seeing if the simplified and actual beams gave the same results as compared to the analytical results.

The test was done on an 18” cantilever beam with a loading condition of 100 lbs of force applied at one end and the other end fixed in place. The results of the analytical test revealed a bending stress of 2.6 ksi at exactly 9 inches from the fixed end of the beam. This was determined using Equation 5.1 where σ is the bending stress. M is the moment and y is the distance between the center and top of the beam while I is its inertia.

$$\sigma = \frac{My}{I} \qquad \text{(Equation 5.1)}$$

Next, SolidWorks' Static FEA package was applied to both the aluminum extrusion beam and the equivalent beam to verify that the equivalent beam can be used for more complex FEA studies.

Table 5.1 FEA beam simplification verification

Method:	Normal (Bending) Stress in Z Direction	% Error from analytical results
Analytical	2.596 ksi (9" from fixed end)	0.00%
FEA Equivalent Beam	2.597 ksi (9" from fixed end)	0.03%
FEA Aluminum Extrusion	2.639 ksi (9" from fixed end)	1.66%

As can be seen in Table 5.1, all three beams yielded near identical results. The stresses were calculated 9" away from the fixed end to avoid stress concentrations that SolidWorks' FEA package inevitably finds. These stress concentrations are due to sharp changes in the geometry of both the equivalent beam and the aluminum extrusion which can't be solved for analytically. From this verification process, the SolidWorks' Static Simulation Package was seen as agreeing well with analytical results. In addition, using an equivalent beam instead of the aluminum extrusion beam will still yield highly accurate results. Therefore, in order to complete the FEA simulation, all aluminum extrusions were simplified to rectangular beams.

5.4 Base Frame Simulation

Using the equivalent beam method from the previous section, loads were applied to the top of the base frame and a fixed support was added to each of the six caster brackets. The base frame FEA simulation shown below is for a load of 10 dishcarts. Each of these dishcarts was replaced by 4 point loads (one for each wheel). The FEA illustrates three loading scenarios. The first loading scenario is a total load of 830 lbf (20.75 lbf load per point). This represents the actual testing load. The second loading scenario is a total load of 1500 lbf (37.55 lbf load per point) this represents the maximum weight 10 dishcarts can hold (at 150lb per dishcart). The third loading scenario totaled 2725 lbf (68.125 lbf load per point). This load represents the rated capacity or the maximum load the seven wheels (six caster wheels and one motor wheel) can withstand before failure. See Figure 5.6 for the stress distributions for each simulated loading scenario.

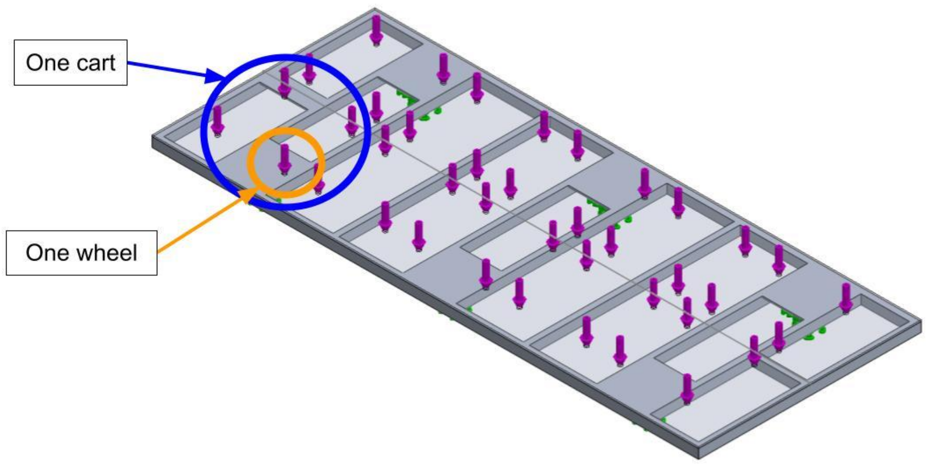


Figure 5.3. Base frame loading

Figure 5.4. Actual frame

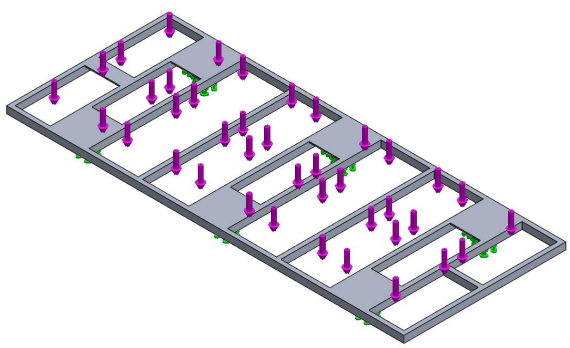
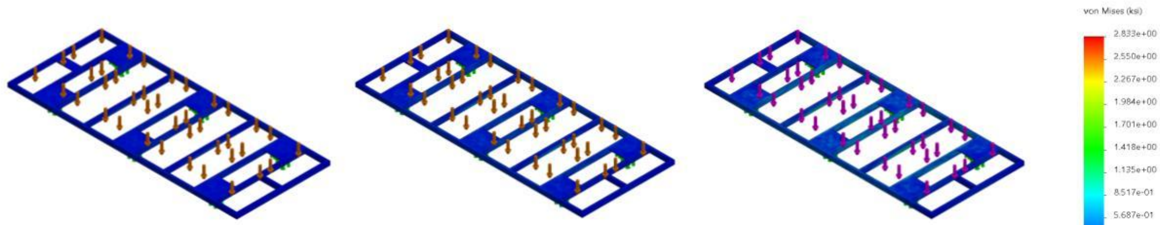


Figure 5.5. Equivalent frame



Total Load	830lb	1500lb	2725lb
Max Stress [ksi]	0.86	1.58	2.83
Max Displacement [mm]	0.1127	0.2083	0.3709

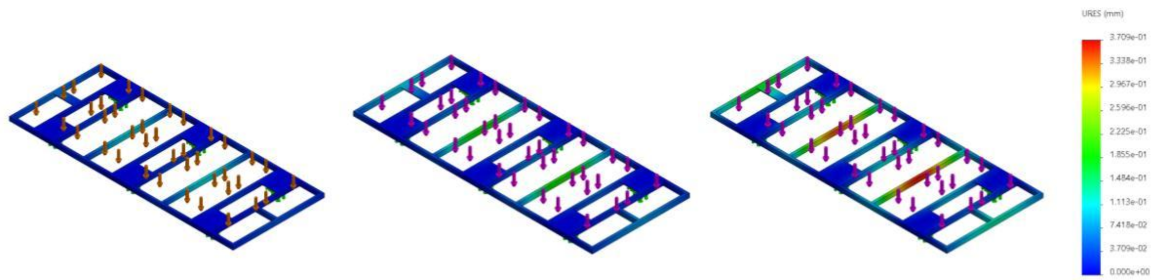


Figure 5.6. Equivalent frame FEA results

The results show that the frame is subjected to a maximum Von Mises stress of about 2.83 ksi. Of all of the components modeled in the frame FEA analysis, the one with the lowest yield strength was masonite at approximately 4 ksi. This means that a worst-case-scenario still yields a factor of safety of 2.53. Therefore the base frame passes the FEA test.

5.5 Top Sheet Simulation

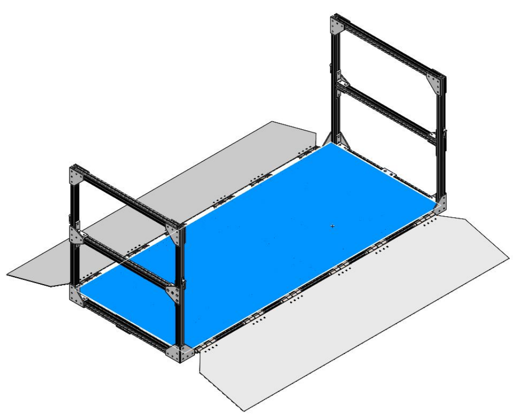


Figure 5.7. Top sheet subsystem

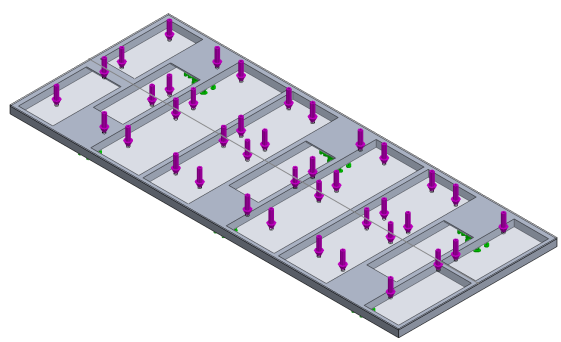
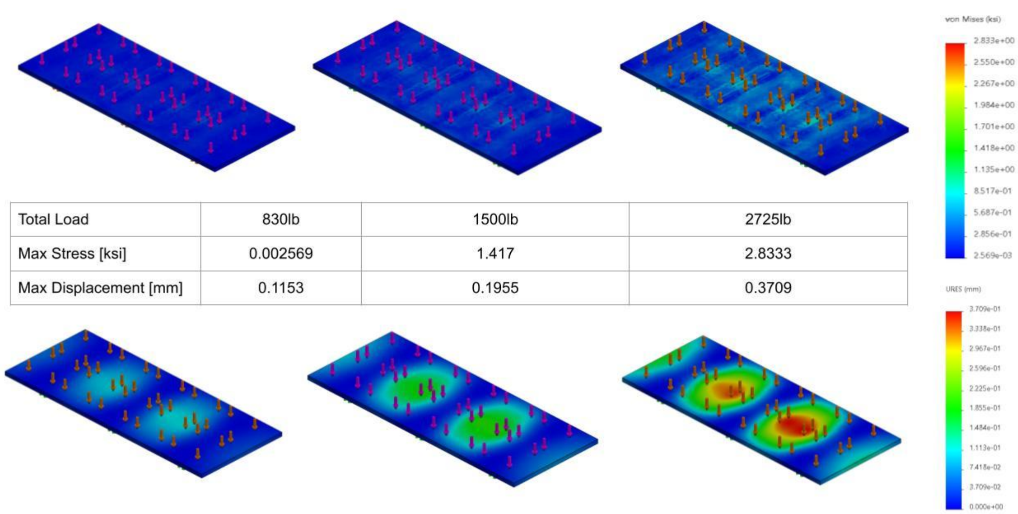


Figure 5.8. Top sheet loading

Similarly to how the frame FEA was verified by hand, the top sheet FEA was verified analytically to ensure the accuracy of the computer model. The aluminum top sheet is essentially just an 84”x36” metal sheet with a thickness of 0.125”. It is made of 3000 series aluminum. The verification results show a roughly 1.11% error between the FEA and the hand calculations for a simple set up. This result shows that the FEA can be used to estimate the performance of the aluminum sheet during actual use.

After hand verification, the aluminum top sheet was modeled using SolidWorks’ Static Simulation package to get an idea of its performance under the expected loading conditions.

The aluminum top sheet simulation resulted in a max stress of 2.83 ksi, yielding a factor of safety of 13.74. The max displacement was just under 0.4mm. These results were improved by adding a cross bar underneath the part of the top sheet that experienced the highest levels of stress and displacement.



Total Load	830lb	1500lb	2725lb
Max Stress [ksi]	0.002569	1.417	2.8333
Max Displacement [mm]	0.1153	0.1955	0.3709

Figure 5.9. Top sheet FEA results

5.6 Ramp Simulation

The hinged ramp is an 87”x 20” piece of 6061 T6 aluminum that has a thickness of ⅛”. Its primary purpose is to act as an inclined plane for the carts to roll on to when the Cart Loader is being either loaded or unloaded. Its secondary purpose is to keep the carts contained on the platform while it is moving back and forth. These two important purposes led the team to consider the ramp as a critical subsystem of the model. The team assumed that the hinged ramp would probably undergo a significant amount of stress due to the fact that every cart must be rolled onto the ramp before landing on the platform. It was also assumed that at any given time 2-3 people could potentially be standing on the ramp at once while loading the carts.

To successfully simulate the predicted loadings on the ramp, the team created a FEA method that would allow for different loading configurations to be tested. These loading configurations represented various places where people or carts could be standing on the ramp at any given time. After a few different configurations were tested, the team took the worst case scenario and created a factor of safety. The worst case loading was where 5, fully loaded, 150 lb carts were being loaded at one time. The FEA results for this loading showed a maximum Von Mises stress of 18.41 ksi and a factor of safety of 2.16. This factor of safety is more than acceptable and leaves room for error. Shown below are Figures 5.10 and 5.11 depicting the 'hinged ramp' critical subsystem as well as the stress distribution results.

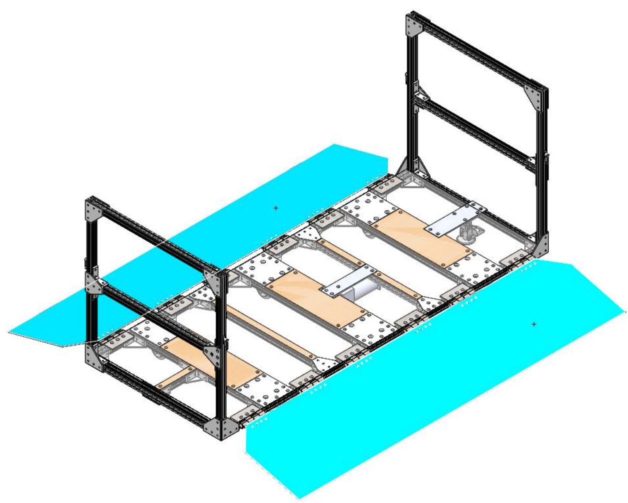


Figure 5.10. Hinged ramp subsystem

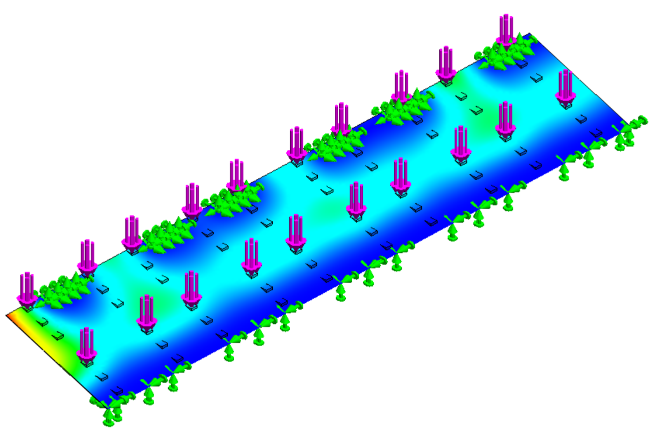


Figure 5.11. Hinged ramp FEA results

5.7 Latching Mechanism Dynamic Simulation

Another critical subsystem is the latch holder and the strike bolt which were designed to attach to the truck liftgate. This is critical in the sense that a dangerous situation can be created if the truck is on uneven ground. If the operator is loading carts onto the Cart Loader and he or she accidentally lets go, the Cart Loader will start moving and gaining velocity until the latch holder hits the strike bolt. This will cause the Cart Loader to fall off and potentially injure someone. To simulate this scenario an assumption of negligible friction between the Cart Loader and the ground was made since it has low friction casters, as well as an assumption that the rotational kinetic energy of the wheels was negligible and therefore could be neglected. Therefore, to understand this scenario, the velocity of the Cart Loader when it reached the strike bolt had to be determined. The dynamics of the motion were calculated and are shown below.

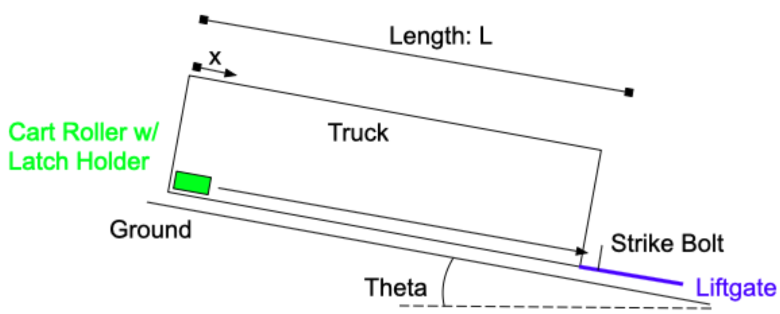


Figure 5.12. Dynamic collision drawing

$$v_f = \sqrt{2gLsin(\theta)} = \sqrt{2 * 9.81 * 4.7 * sin(10^{\circ})} = 4 \text{ m/s} \qquad \text{(Equation 5.2)}$$

As seen in Equation 5.2, the Cart Loader will end up colliding at the strike bolt at a velocity of 4 m/s. Doing a dynamic simulation with the latch holder going at 4,000 mm/s led to numerical errors as the deformation ended up being too large. However, dynamic analysis was done with the latch holder colliding with the strike bolt at 900 mm/s while it carried a load of 1650 lbs which is about 750 kg. This change was made because it is highly unlikely that the Cart Loader would be used on ground with a slope greater than probably 5 degrees. In addition, an analytic solution to this problem was solved in order to determine whether the FEA was accurate.

For the analytic solution, the stresses at the contact point will be solved for. This is because at the contact point, an assumption can be made that the stresses are roughly axial in nature. In addition, the axial force can be determined by calculating the deceleration and multiplying it by the mass.

The acceleration is the derivative of velocity and this data can be extracted from Abaqus. As seen in Figure 5.13, the velocity can be approximated as a straight line between 4 and 6 milliseconds. In this period, the deceleration is approximately the slope of the velocity gradient which is $-\ 178 m/s^2$. It should be noted that this acceleration value is not the acceleration of gravity (obviously). It is instead the predicted *deceleration* of the Cart Loader slamming into the latching mechanism.

$$a\ = \frac{dv}{dt} = \frac{248-604}{0.006-0.004}\left(10^{-3}\right) =-\ 178\, m/s^2 \qquad \text{(Equation 5.3)}$$

The contact area was simply the width of the latch, 2 mm, multiplied by the length of the bolt in contact with the latch holder. This length was hard to tell from the simulation but was around 30-50% of the front area of the bolt which ended up being 4.2 mm to 7 mm. Now all the information was there to calculate the stresses at the contact area. The stress ended up being a range of 9.5 GPa to 15.9 GPa, according to the analytical results. This is clearly in excess of any conceivable material. Therefore, the team concluded that a braking system would need to be added in order to slow the Cart Loader in case of excess velocity.

$$\frac{750}{7*2} *\ 178\ = \frac{m}{A}\frac{dv}{dt} \leq\ \sigma\ \leq \frac{m}{A}\frac{dv}{dt} = \frac{750}{4.2*2} *\ 178 \qquad \text{(Equation 5.4)}$$

$$9.5\ \text{GPa} \leq\ \sigma\ \leq 15.9\ \text{GPa} \qquad \text{(Equation 5.5)}$$

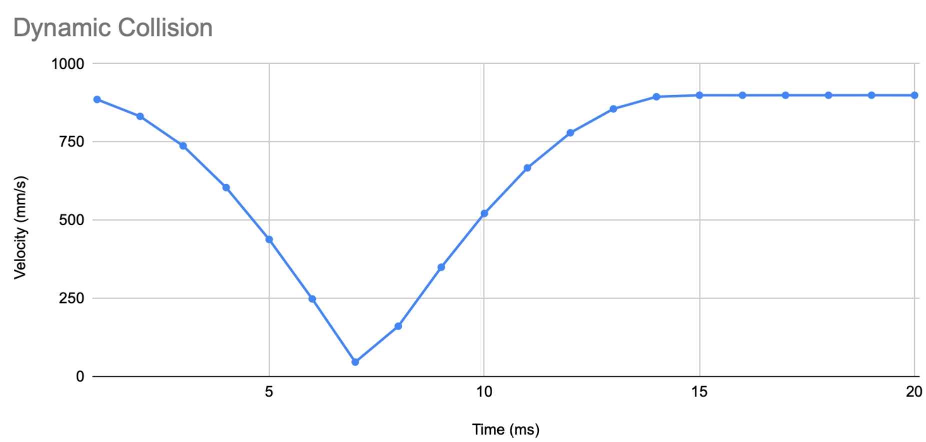


Figure 5.13. Velocity of the Cart Loader as it collides with the strike bolt

A preliminary FEA simulation is shown in Figure 5.14. As shown in Figure 5.14, there was significant complex geometry connected to the latch holder that wasn't near the contact point and didn't offer structural support. The same held true for the strike bolt. These complex geometries were removed to reduce the number of meshes and to make sure a simulation could be run for the whole collision.

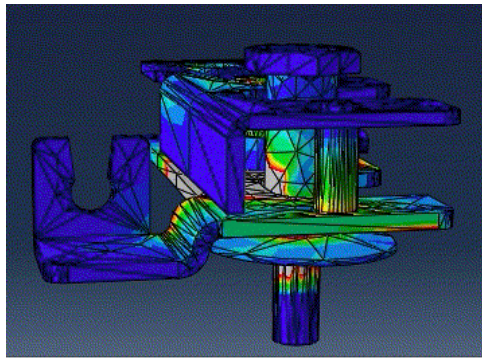


Figure 5.14. Preliminary collision with complex geometry

The FEA dynamic simulation was set up in a particular manner. The strike bolt's end was fixed and the latch holder was going at it at 900 mm/s. As a result of the rails, the latch holder was fixed to only go in one direction. The weight of the Cart Loader was attached by extruding a flat piece at the end of the latch holder and changing that flat piece's density to make it weigh approximately 750 kg.

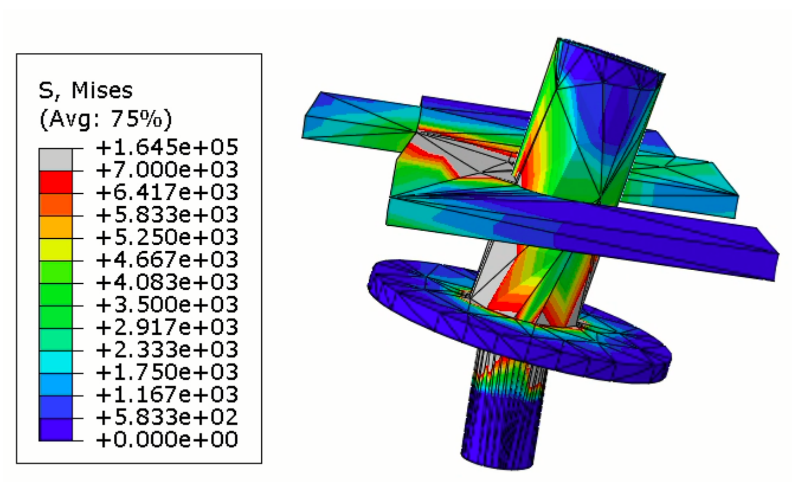


Figure 5.15. Von mises stress of simplified dynamic collision at 5 m/s

As seen in Figure 5.15, the strike bolt underwent significant deformation at 5 m/s. The maximum stress was 160 GPa which is greater than 215 MPa which is the yield strength of the strike bolt.

From the FEA dynamic simulation, the stress at the contact point ended up being 12.6 GPa which is within the range of 9.5 GPa and 15.9 GPa predicted from the analytic solution. Both these numbers point to the fact that the strike bolt will not be able to handle dynamic collision without plastically deforming.

In conclusion, a dangerous situation can develop when the Cart Loader starts rolling and then collides with the strike bolt. The dynamic analysis revealed that the strike bolt will plastically deform when the Cart Loader is going at 0.9 m/s. This means it will definitely deform when the Cart Loader goes at it at 4 m/s. Therefore, a design change needed to be made to solve this problem.

In order to solve this problem, the velocity of the Cart Loader needed to be reduced before it hit the strike bolt. One way to do this was to create a device that applied brakes when the Cart Loader reached a certain velocity. An incremental rotary encoder can be attached to the Cart Loader and its rotation will be fixed with one of the caster wheels. By connecting this encoder to Arduino, a simple program can be created to determine the position and velocity of the Cart Loader in the truck. When it reaches a certain velocity near the strike bolt, the Arduino can command the brakes to be applied. When the operator gets to the liftgate, he or she can only slowly push the Cart Loader to the strike bolt. This will ensure that there won't be a dynamic collision. The velocity of the Cart Loader anywhere in the truck could also be limited too.

5.8 Simulation Design Iterations Based on FEA

Based on the results of the preliminary FEA on the Cart Loader, the team concluded that an important change was necessary. It was discovered that the base frame did not have quite enough surface area to successfully support the top sheet under a full load. This was evidenced by excessive deflection in the central areas of the sheet. Even though the yield strength was not reached, a high level of deflection is undesirable for a component that is meant to support up to 1,500 lbs of materials. To reduce this deflection, the team devised a plan to add two extra cross-beams to the middle of the frame. It was assumed that these two cross-beams would be capable of supporting a large portion of the load and prevent the top sheet from deflecting during normal operating conditions. In Figure 5.16, modifications made to the base frame are shown.

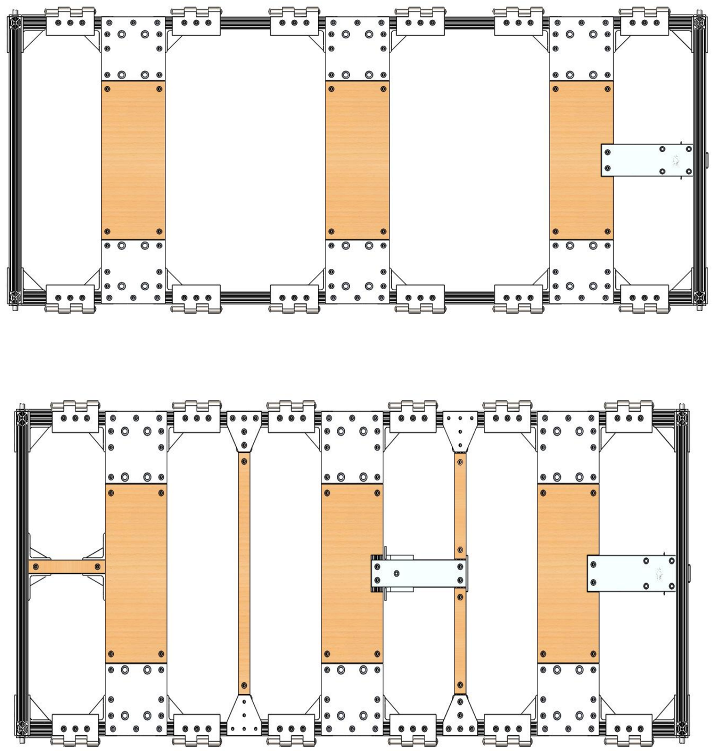


Figure 5.16. Cart Loader cross-beam iterations

Adding the cross beams reduced the deflection to a manageable 0.1955 mm. This amount of deflection is essentially negligible and means that the carts will roll on a flat surface throughout operation. It also means reduced stress concentrations at the contact points between the base frame and the top sheet. This simple modification costs less than $100 which is well within the allocated extra budget for the project (see budgeting, section 6.3).

5.9 Key Results and Safety Factors

The FEA simulations (and subsequent design iterations) led the team to a high level of confidence that the Cart Loader would operate successfully under the prescribed conditions. All of the simulated subsystems passed the initial analysis with only one subsystem requiring significant iteration. Ensuring that all critical components were capable of withstanding the predicted loading was probably the most crucial part of the entire project.

The Cart Loader is meant to be used day-in and day-out in real-world situations. These situations sometimes require moving up to 1,500 lbs of materials. There is a serious risk of injury if any of the major components fail during operation. The team mitigated this risk by hand calculating some of the loading cases and then comparing them to FEA results. This ensured that the simulation accurately predicted real-life conditions. In addition to double checking the FEA, each subsystem simulation was attempted by different team members independently. The results were then compared. This reduced the likelihood of a mistake being made during the setup of the simulation.

The last step was for the team to compute the factors of safety for each of the subsystems. A factor of safety essentially dictates how far a design is from its yield point. The ideal factor of safety the team decided on was at least 2. This means that the worst case loading (1,500 lbs) could be doubled and still theoretically not yield. This factor of safety provides a large margin or error for accidental drops and unsuspecting impacts throughout daily operation. The frame subsystem yielded a F.O.S of 2.53. The top sheet subsystem yielded a F.O.S of 28.15. It should be noted that the top sheet was a part of the design iteration described in section 5.8. In most cases, a high factor of safety would be an indication of over engineering. However, the point of creating a stronger base for the top sheet was to reduce deflection, not stress. Therefore, the design iteration described in section 5.8 drastically increased the factor of safety more than necessary but also decreased the overall deflection, which was the point. Last but not least, the hinged ramp showed a factor of safety of 2.16. These results proved to the team that the Cart Loader should operate safely and effectively under the prescribed loading conditions.

Chapter 6: Budgeting, and Purchasing

6.1 Budget Overview

The total allocated budget for the entire project was $4,000. Out of the total amount, $2,500 was supplied by the SCU School of Engineering and the remainder came from the Frugal Innovation Hub (FIH) who were facilitating the relationship between the SCU design team and Dishcraft Robotics. The base frame was expected to be the most expensive and time consuming part of the project. Therefore, over half of the total budget was immediately spent on the base frame of the Cart Loader to facilitate a faster construction time. After purchasing the base frame, the team moved on to acquiring the next most crucial part of the project - the large aluminum top sheet and hinged ramps. All three of these parts had to be specially ordered from a custom sheet metal shop in Redwood City, CA. The total cost of these 3 pieces was around $650. The remainder of the budget was spent on hardware, aluminum blanks (for making brackets), caster wheels, and electrical supplies (for motorizing the Cart Loader).

All purchased and unpurchased items were kept in a spreadsheet. This spreadsheet served as a parts list as well as a preliminary budget. This preliminary budget allowed the team to predict whether or not the project would exceed the total available cash. The team was able to make adjustments to certain parts in order to stay under budget. The team was also able to acquire several parts from the SCU machine lab. These parts were free for the team to use and saved valuable resources.

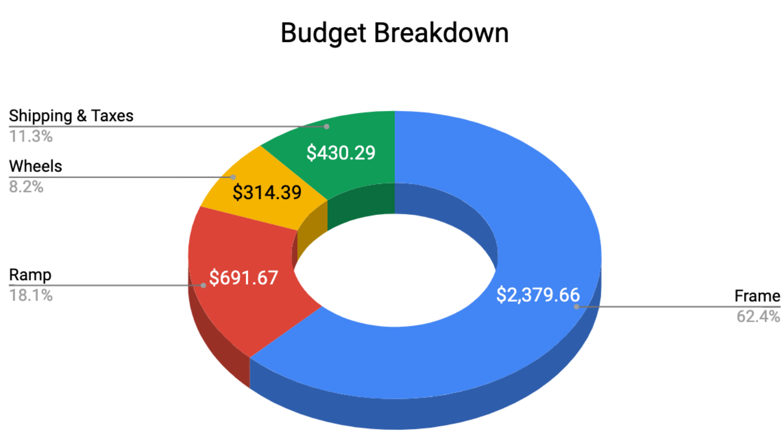


Figure 6.1. Budget breakdown by parts relative to sub-assembly

Table 6.1 Budget breakdown of all parts

Parts	Cost	Sub-Assembly	Total
Aluminum T Frame	$678.62	Frame	$3,816.01
Fasteners	$926.08	Frame	
Hardware	$272.59	Frame	
Caster Bracket Aluminum 6061 Blanks	$118.14	Frame	
Aluminum Sheet	$308.75	Frame	
Zinc-Steel Floor Lock	$66.28	Frame	
End caps	$9.20	Frame	
Steel Hinges w/o Holes	$382.92	Ramp	
Aluminum Sheet	$308.75	Ramp	
Casters	$208.50	Wheel	
Motor Wheels	$62.87	Wheel	
Machine Key	$5.03	Wheel	
Battery	$37.99	Wheel	
Shipping & Taxes	$430.29	Shipping & Taxes	

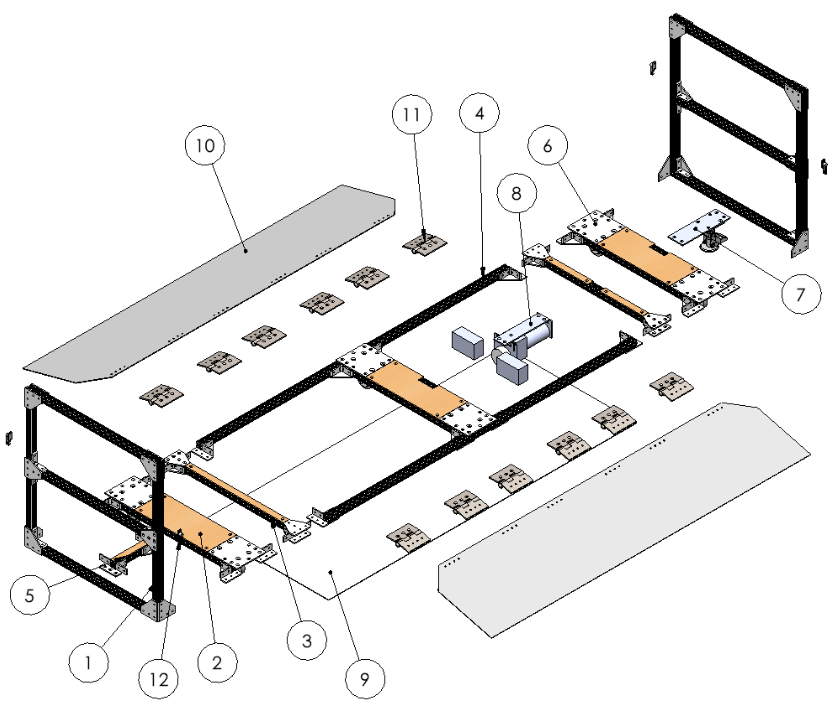
6.2 Part Purchasing and Ordering

Part purchasing and ordering occurred as portions of the design were completed in SolidWorks. On January 20, 2022, the aluminum extrusions were finalized as the main structural component of the base frame. As such they were ordered utilizing Quartzy, an ordering platform that allows students to submit purchasing requests for the school to approve and execute. The full part list of all orders is located below in Appendix E. Almost the entirety of the project parts were ordered from the online retailer McMaster-Carr.

Chapter 7: Construction

7.1 Overall Assembly

The CAD model of the overall assembly is shown in Figure 7.1. The team decided that individual subsystems would be constructed separately and then combined to form the overall assembly. The overall assembly is shown as an exploded view in order to accurately depict all of the subsystems and how they are meant to fit together. A table is included in Figure 7.1 which lists the name of the subsystems. The team constructed the Cart Loader in a manner identical to the exploded view in Figure 7.1. Inherent difficulties arose while trying to fit the subassemblies together and the entire process took at least 16 man hours. However, the nature of the assembly allows for a tremendous amount of adaptability and modularity. In fact, the Cart Loader could easily be adapted to different overall dimensions if necessary.



Part #	Part Name
1	Side Section Assy
2	Cross Section A Assy
3	Cross Section B Assy
4	Cross Section C Assy
5	Cross Section D Assy
6	Caster Bracket Assy
7	Foot Brake Assy
8	Motor Assy
9	Top Sheet
10	Ramp
11	Hinge
12	Latch

Figure 7.1. Overall Cart Loader assembly

7.2 Subsystem Assembly

Shown below are part drawings of the various subsystem assemblies. Having a greater number of subsystems allowed the team to troubleshoot potential issues before combining parts into a larger assembly. This drastically reduced the time necessary to complete the construction phase of the project.

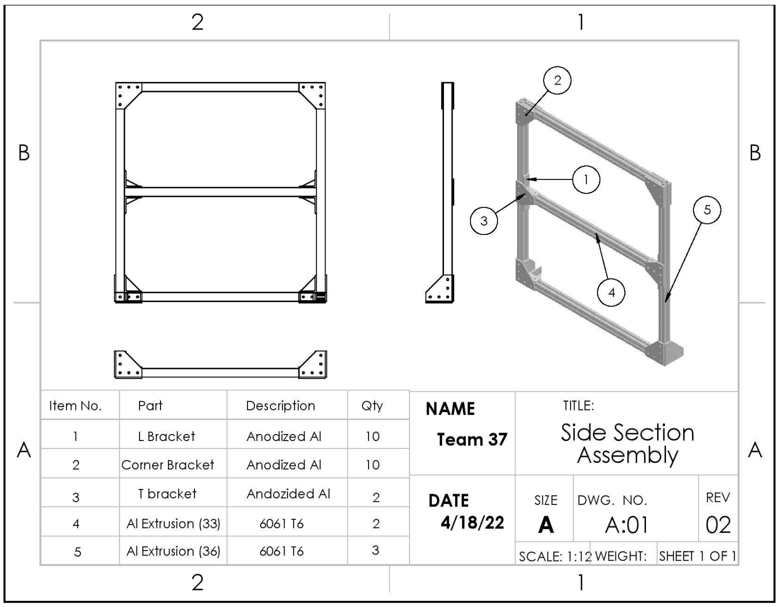


Figure 7.2. Side section sub-assembly drawing

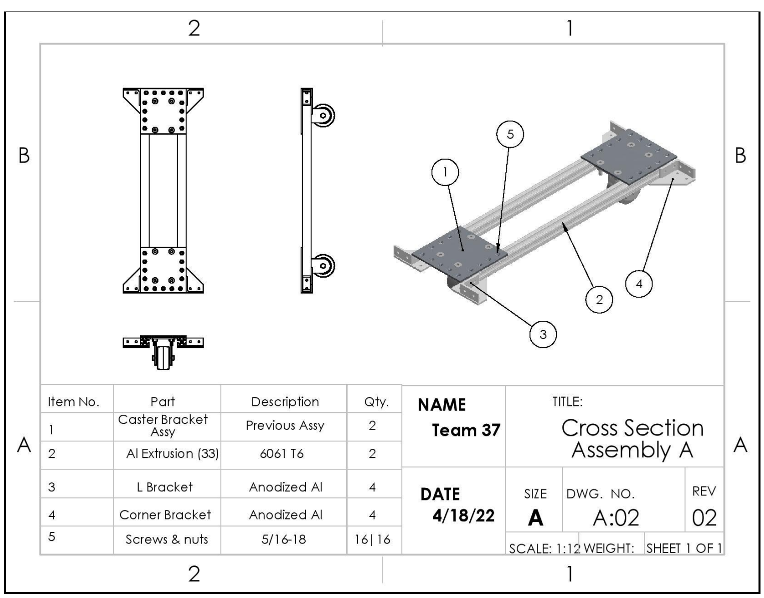
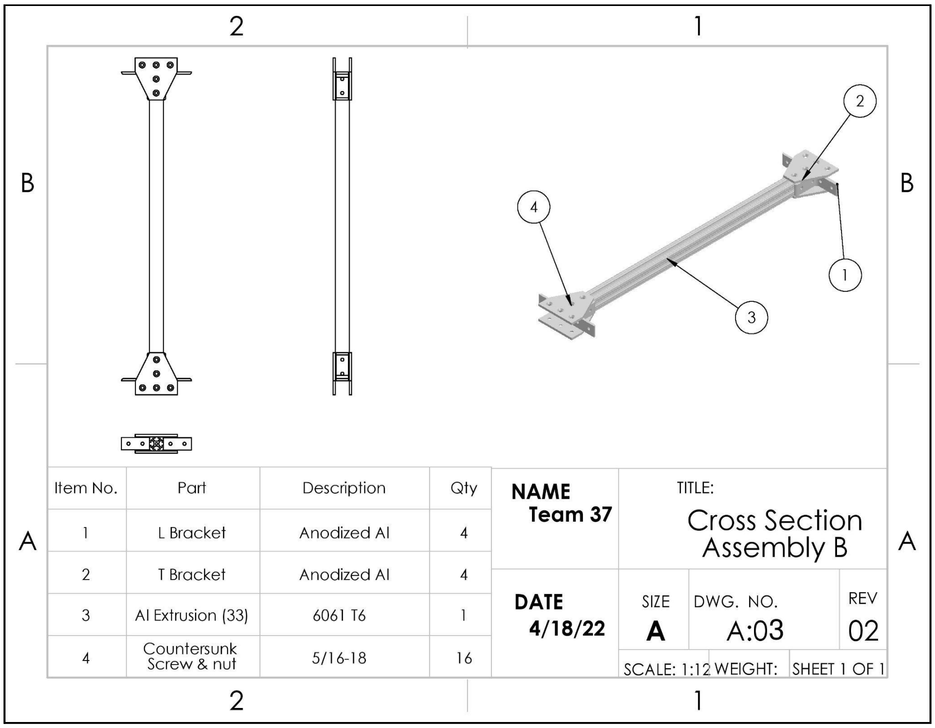
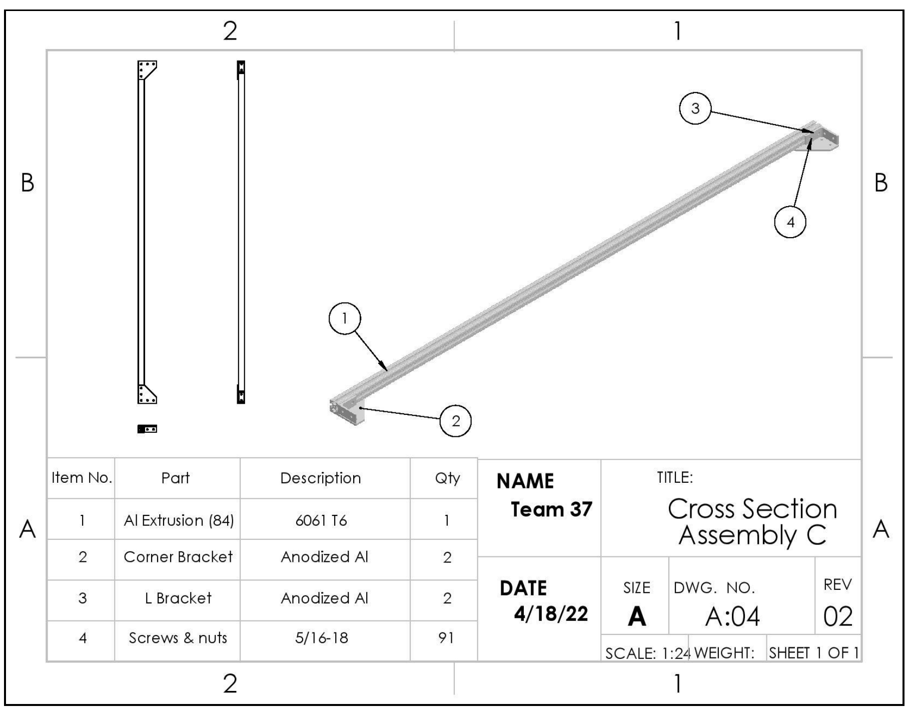


Figure 7.3. Cross section assembly A sub-assembly drawing



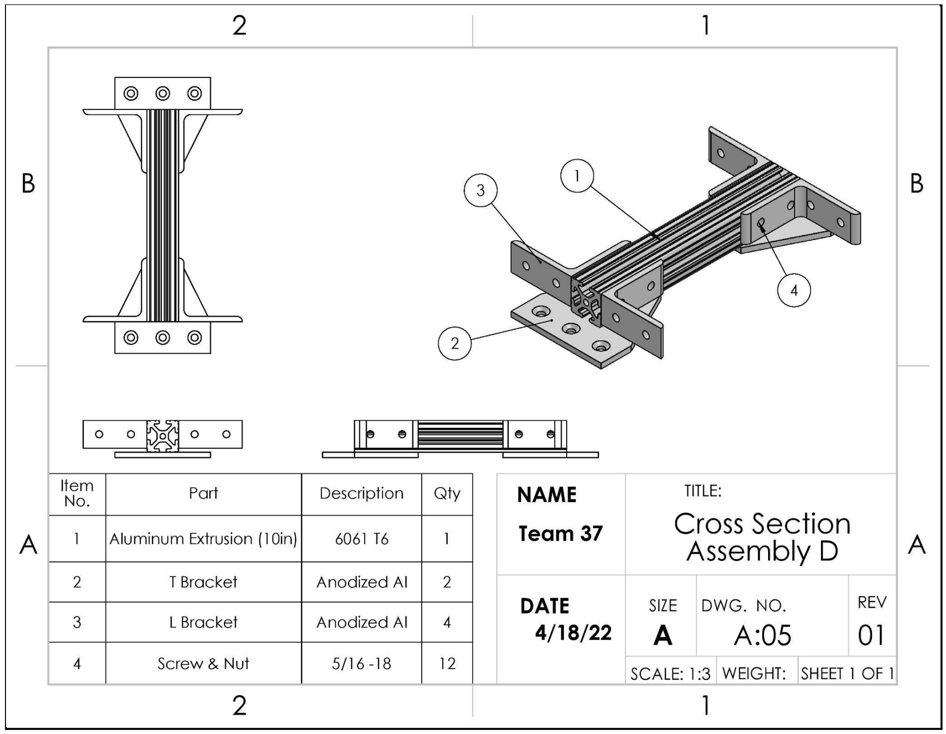
Item No.	Part	Description	Qty
1	L Bracket	Anodized Al	4
2	T Bracket	Anodized Al	4
3	Al Extrusion (33)	6061 T6	1
4	Countersunk Screw & nut	5/16-18	16

Figure 7.4. Cross section assembly B sub-assembly drawing



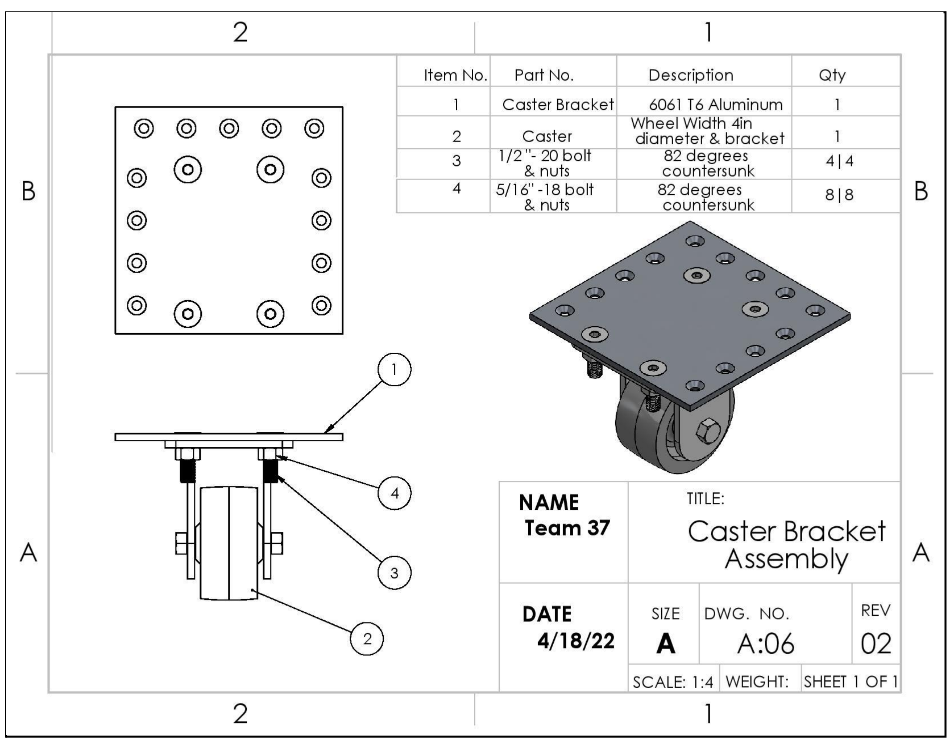
Item No.	Part	Description	Qty
1	Al Extrusion (84)	6061 T6	1
2	Corner Bracket	Anodized Al	2
3	L Bracket	Anodized Al	2
4	Screws & nuts	5/16-18	91

Figure 7.5. Cross section assembly C sub-assembly drawing



Item No.	Part	Description	Qty
1	Aluminum Extrusion (10in)	6061 T6	1
2	T Bracket	Anodized Al	2
3	L Bracket	Anodized Al	4
4	Screw & Nut	5/16 -18	12

Figure 7.6. Cross section assembly D sub-assembly drawing



Item No.	Part No.	Description	Qty
1	Caster Bracket	6061 T6 Aluminum	1
2	Caster	Wheel Width 4in diameter & bracket	1
3	1/2"- 20 bolt & nuts	82 degrees countersunk	4|4
4	5/16" -18 bolt & nuts	82 degrees countersunk	8|8

Figure 7.7. Caster bracket sub-assembly drawing

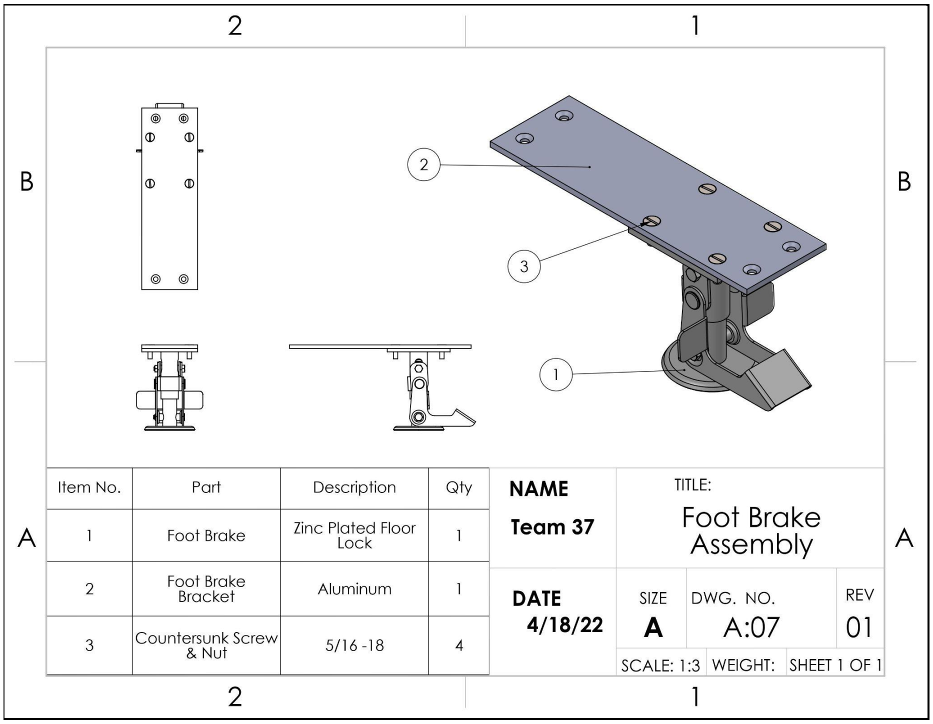


Figure 7.8. Foot brake sub-assembly drawing

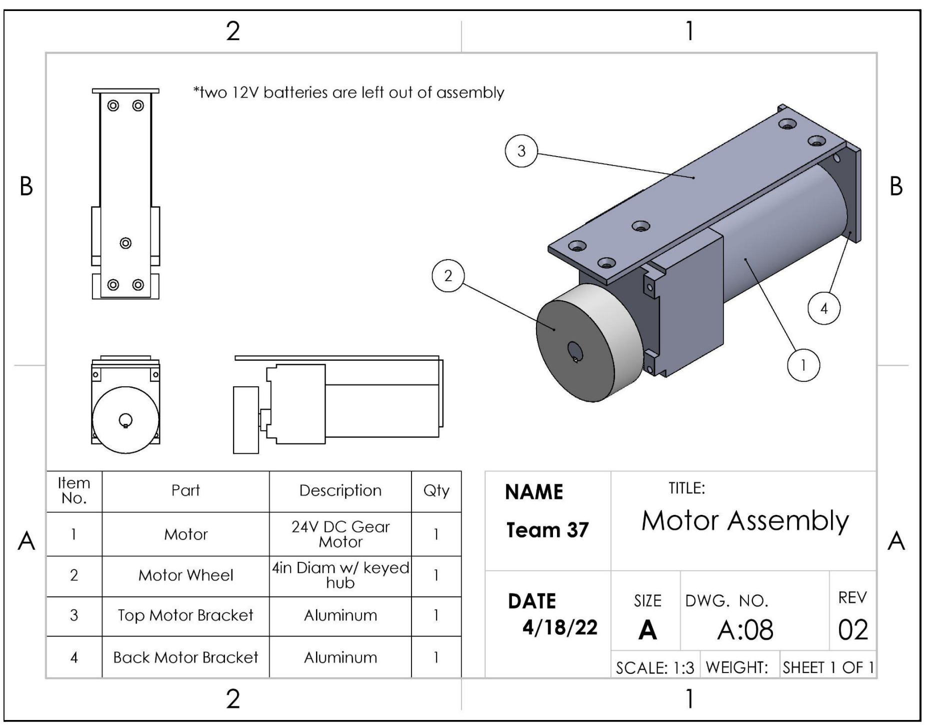


Figure 7.9. Motor sub-assembly drawing

It's important to note that the aluminum extrusion cross section subsystems shown above are shown without the masonite for better view of the sub-assemblies. The masonite acts as a structural support so that the top sheet has a flat, even surface to rest upon.

While the aluminum extrusion sub-assemblies shown in Figures 7.2 through 7.6 are critical in building the Cart Loader frame, just as important are the foot brake and motor sub-assemblies shown in Figures 7.8 and 7.9. The foot brake, or floor lock, serves as a safety locking mechanism (in the absence of a latching mechanism). The motor sub-assembly consists of a DC gear motor, a four inch diameter keyed wheel, and two brackets to align the motor/wheel and attach it to the Cart Loader frame. The motorized wheel is powered by two 12V batteries, and allows for the Cart Loader to move in both directions (forward and backward). Testing was done with the motorized wheel, and it was found that the motor had no trouble moving the prescribed testing loads.

7.3 Drawings of Machined Parts

Before beginning the machining process, part drawings were created depicting various dimensions. These drawings were created using the SolidWorks drawing software package and were used directly with the programmable milling machine to create an incredibly fast and efficient workflow model. Shown below is an example of a part drawing that depicts the necessary hole pattern for the steel hinges. These hinges were blank and had no bolt holes upon arrival. The team intentionally ordered hinges without a pre-drilled hole pattern so that a custom pattern could be machined. The entirety of the machined parts are included in Appendix F.

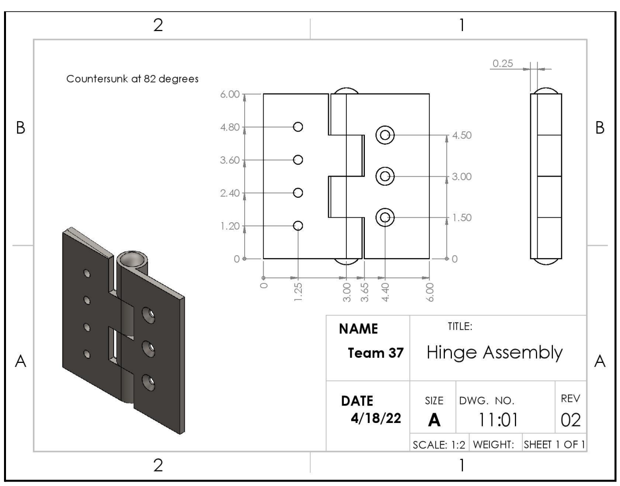


Figure 7.10. Hinge sub-assembly drawing

7.4 Machining and Fabrication

The machining portion of this project took place in SCU's machine lab. There, the team used a multitude of tools and techniques to create all of the necessary machined parts. The most widely used tool was the programmable milling machine. This machine allowed the team to drill and countersink all of the necessary brackets with a high level of speed and precision. The programmable features of the milling machine meant that a particular part could be loaded into the vise and the hole pattern could be drilled within minutes. This feature allowed the team to easily complete large batches of hinges and brackets with little effort.

All in all, there were over 30 individual parts that needed to be machined. The team was able to complete this large machining task in approximately only 20 man hours spanning a month. As parts were created, different sections of the Cart Loader were assembled and tested for fit. Due to the high degree of accuracy of the final SolidWorks model (revision 6), all of the machined parts worked properly on the first iteration. Therefore, not a single machined part was machined improperly or discarded.

Other equipment the team utilized included: sheet metal brakes, band saws, 3-D printers, and laser cutters. The combination of all of these tools allowed for a smooth assembly process that required little to no iteration. Shown below are the CAD models of all machined parts used by the team.

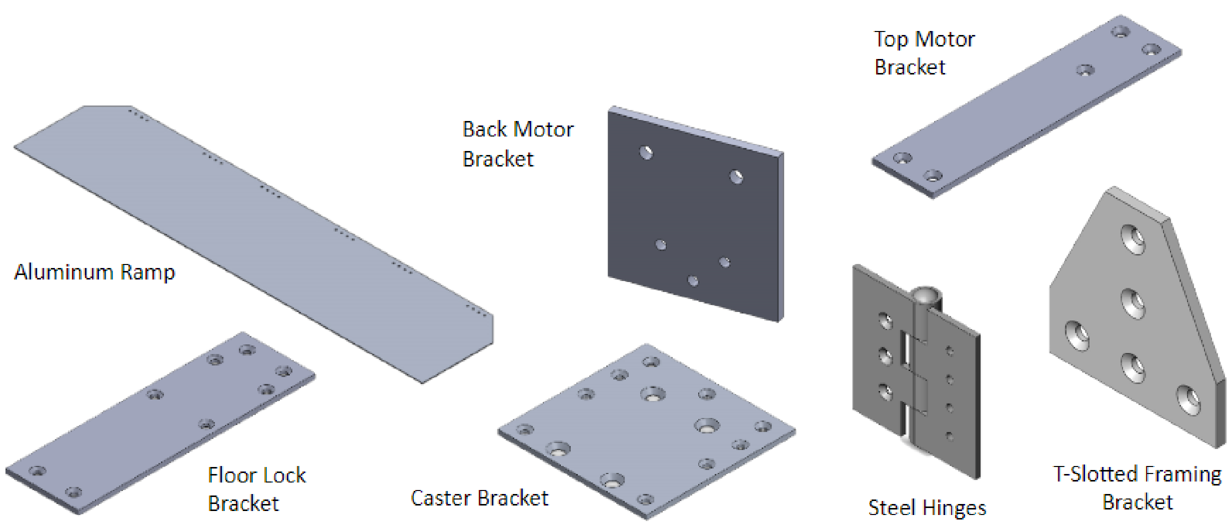


Figure 7.11. CAD models of all machined parts

7.5 Final Assembly Assessment

The final Cart Loader assembly was completed in May of 2022. Total construction time from start to finish was about 3 months. The team on average put in around 20 man hours per week until the project was complete. The final design weighed in at approximately 267 lbs and was easily capable of supporting the weight of ten dishcarts. Overall, the assembly was a success and performed exactly as predicted. The Cart Loader can even support the weight of several humans walking or jumping on the top platform area. The caster wheels also performed exceedingly well and rolled smoothly under high load conditions. Despite the overall success, there were two minor discrepancies. The first had to do with the gap between the hinged ramp and the top sheet. This gap made loading the carts more difficult and it took some practice to learn how to safely load a cart. The second had to do with deflection on the hinged ramp. This deflection was really only apparent when standing on the very edge of the ramp. Future design iterations should include greater support on the bottom of the hinged ramp. Shown below are pictures showcasing the team's final design.

Figure 7.12. Final assembly photographs

Chapter 8: Testing

8.1 Testing Set Up

Testing was done on the assembly to see how much time the design saves when compared to Dishcraft's current process. First, the process to load 60 carts onto the truck was determined, consisting of nine total tasks. These nine tasks would be repeated 7 times to load up eight carts at a time and then repeated an additional time to load up the remaining four carts. The nine tasks, 8 cart times and 60 carts times are shown in Table 8.1.

For task one and nine the liftgate times were measured during the Dishcraft interview. Six of the tasks (including task 1 and 9) would take the same time regardless of how many dishcarts are being moved. While for the other tasks (tasks 2,5,6), the time is proportional to how many dishcarts are being moved. To test tasks 2, 5, and 6, the time was first measured for moving 8 carts. Therefore, to achieve the total time of each task for 60 carts, each individual task was multiplied by 7.5. The total 60 cart time was then calculated by adding the time of tasks 2,5, and 6 to the total time of doing the other six tasks eight times.

The team didn't possess a physical truck. However, tape was used to outline the dimensions of the truck. So, the times for tasks three and eight were measured by loading and unloading the Cart Loader inside the taped region. To begin the process, a team member pushed the Cart Loader from one end of the tape to the other end. As seen in Table 8.1, the time was recorded to do each process separately. In order to determine an accurate average time for completing the loading and unloading, two different team members completed the process. One member did each task in a fast manner while the other did in a slow and leisurely manner. Then the time was averaged to get a realistic time for a delivery driver.

8.2 Testing Results

From all the testing, the estimated average time to load up 60 carts ended up being 27.1 minutes. Since the current process takes 60 minutes to load the carts, the design saves just over 30 minutes. This means that the entire process of delivering a full load of clean dishes to a client (this includes loading clean dishcarts at Dishcraft's facility and unloading them at a client location) and taking a full load of dirty dishes back to Dishcraft's facility (this includes loading dirty dishcarts at a client location and unloading them at a Dishcraft's facility) would save a bit more than two hours. If Dishcraft was fully up and functioning at a high level then they would complete the outlined process two times a day. This means the company might end up saving 1,460 man hours for a year. At $15 per hour, the company can reduce their payroll by $21,900 per year by utilizing a device and rail system that has a fixed cost of under $7,500.

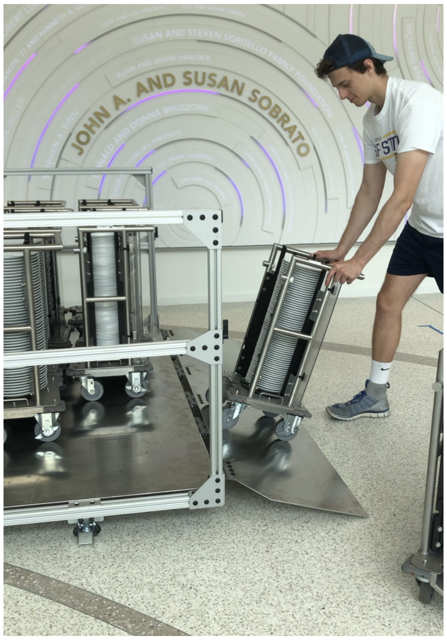


Figure 8.1. Testing of loading operation

Figure 8.2. Testing of motor wheel

Table 8.1 Testing results

Loading Tasks: 8 Carts	Fast Time (sec)	Slow Time (sec)	Average Time (sec)
1. Raise Liftgate	7	7	7
2. Load Carts on Cart Loader	34	67	50.5
3. Push Cart Loader	8	12	10
4. Raise/Lower Ramps	10	22	16
5. Unload Carts	29	47	38
6. Apply Cart Brakes	40	80	60
7. Pick Up Ramps	9	13	11
8. Move Cart Loader to Liftgate	8	12	10
9. Lower Liftgate	7	7	7
8 Cart Time	152	267	209.5
60 Carts Time	**19.4 minutes**	**34.8 minutes**	**27.1 minutes**

Chapter 9: Conclusion

9.1 Summary

The final design of the Cart Loader fulfilled all necessary customer needs and met the aforementioned product specifications. Testing was a success and showed that, on average, the device cut the load/unload times in half. In other words on a given work day, the Cart Loader would save two hours for every back and forth trip. This is a significant decrease in time, and would increase Dishcraft's throughput and allow the operator to complete more trips per day. The Cart Loader also demonstrated its ability to handle large loads of close to 1,000 pounds throughout the testing phase. There was no perceivable deflection on the frame during testing, and the caster wheels seamlessly supported the dishcarts.

As for key areas of improvement for future design iterations, first and foremost, the steel hinges used to attach the ramp to the frame were not only heavy but also created a large gap. This gap made loading the individual carts onto the device difficult. Hinges made of aluminum with smaller bolt profiles would easily fix this issue. Secondly, the hinged ramp experienced higher levels of deflection than had been anticipated by the simulations. This deflection did not affect the operation of the Cart Loader but could cause a fatigue stress failure. A simple solution would be to weld support beams underneath the ramp to help support the load. Another possible improvement is an updated motor and control system for future design iterations. This would mainly include controlling the rpm or speed of the motor so the dishcarts experience less movement in the free space of the Cart Loader, and the ease of being able to turn on and off the motor. Lastly, an improvement can be made in the suspension system which engages and disengages the motorized wheel from the ground. Currently, the Cart Loader's design has a spring between the motor and top motor bracket. However, the design does not include a method to control or engage the spring. Adding a controlling mechanism for the spring would raise and lower the motorized wheel off the ground. This would easily allow for the user to manually push the Cart Loader or automate the process by running the motor.

9.2 Ethical Considerations

This senior design project was undertaken to aid Dishcraft Robotics in their environmentally friendly dish washing operation. Dishcraft used an advanced robotic system that is water and waste efficient. This is important in a state like California where droughts are more prevalent and saving water is essential. Therefore, the aim of this project was to provide a time-saving product to an actual company that played a role in addressing this environmental problem in California.

Throughout working on this project, the team ended up learning what it means to be an ethical engineer. One thing that this project taught the team about the character of an engineer is that it consists of good teamwork. This senior design project entailed building a large and complex project which requires the entire team to synthesize many different fields in order to successfully make progress. The team realized that engineers need to have good teamwork and collaboration skills, so that the projects that benefit society can be completed in a timely manner. In addition, the team learned that one characteristic of an engineer is that he or she has respect for nature. This project's central purpose was to build a device for a startup that ends up saving water in the operation of washing dishes. Overall, the team realized the value in sustainability and how engineers can create and design devices that build a more sustainable world.

This project involves a significant amount of risk that needed to be considered as ethical engineers. The team had been tasked with unloading anywhere from 1,000-1,500 pounds of materials from the back of a box-truck, and then safely lowering these materials to the ground using a truck lift-gate. If any of the critical systems of the design failed, the operator could be severely injured or killed. As a team of engineers, there is an ethical duty to be absolutely sure that the final design can handle the loads throughout operation. Therefore, the ethical engineering challenge for this project was creating a design that is both reliable and safe.

9.3 Societal and Political Considerations

There are potential impacts that this senior design project can have on society as a whole. One of the minor but important impacts is that it reduces the hours that a delivery driver can work. Since the goal of this project is to reduce time to load trucks, the hours spent by a delivery driver might be reduced too. This means the project unintentionally yields negative economical ramifications for drivers in society. However, on the other hand, reducing time to load/unload can result in more time for the driver to do other work like, or can allow for companies to do business with clients in further locations. Another potential impact is positive. As mentioned earlier, the device would've helped Dishcraft in their mission to save water. This is positive for California since it historically struggles with droughts and society can as whole be better off when less water is used.

There are some political considerations that the team would have to consider with this project. This project wasn't a public project and it was intended for a private company, so there are no considerations stemming from that aspect. However, there are regulatory considerations from using the product. OSHA is a regulatory agency that is responsible for ensuring that workers in America have safe working conditions. In order to ensure that using this product wouldn't ever violate this, extensive finite element analysis was done to ensure its safety. In addition, the team decided that the driver would undergo safety training on this product to create a safe operation and workplace.

9.4 Future Plans

Unfortunately, in the middle of the team's design effort, Dishcraft Robotics failed to receive series B funding and went out of business. Despite this unfortunate news, the team continued forward with the project. The results of the testing phase of the design effort proved that for certain situations, the Cart Loader can significantly reduce the loading/unloading time of material from box-trucks. The team's design showed that for this particular situation, the Cart Loader can save at least two man hours for every round trip. With multiple trips per day, the time saved becomes even more significant. This report will serve as an excellent guide for future design efforts. There is ample information supplied here to equip a design team with the knowledge and skills to quickly and effectively design and implement a Cart Loader device.

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Appendix A: Customer Needs

Table A.1 Importance of each customer need

	Customer Needs (1 = worst, 5 = best)	Dishcraft Importance	FunFlicks Importance	Bon Appetit Importance
1	Carts are immobile on lift gate	4	2	3
2	Carts are immoblie while in truck	4	3	4
3	Carts that are loaded can't be sloped on lift gate/device	3	2	2
4	Carts are loaded/unloaded in a timely manner	5	4	4
5	Device can't consume too much space	5	3	4
6	There should be no damage to carts from using lift gate/device	4	4	4
7	There should be no accidents from using the lift gate/device.	4	4	4
8	Device is transportable	4	4	4
9	Device is adaptable for 'x' carts (IDed Latent)	2*	4	4
10	Device is workable on different size trucks	2	4	4
11	Device will last a long time	4	5	5
12	Device is easily accessible for repairs	4	4	4
13	Device does not rust in rain	5	3	5
14	Device is unaffected by dirt/debris	3	4	4
15	Device is cost effective	4	5	3
16	Device is structurally sound	5	5	5
17	Device is attached to the truck	4	3	3
18	The device has low estimated repairs per year	3	5	3
19	Device is easily operable	4	5	5
20	Device is aesthetically pleasing	3	1	1

Appendix B: Metrics

Table B.1 Customer metrics

Metric #	Need #s	Metric *LG = Lift Gate	Units	Marginal Value	Ideal Value
1	4	Time to Load a cart	sec/cart	<20	<8
2	4	Time to Unload a cart	sec/cart	<30	~6
3	8	Weight of Device	lb	200	<100
4		Volume Occupied by Device	m^3	<2	<1.5
5	15	Total Cost of Device	$	<5,000	<4000
6	1	Displacement of Carts in Device	cm	<2	<1
7	2	Displacement of Carts in Truck	cm	<5	<3
8	6,7	Probability of Accidents per 100 uses	#	<.5	<.1
9	9	Range of Cart sizes usable by Device	in	15	10
10	3	Grade of Carts on Device/LG	deg.	<5	3
11	5	Area of Device	in^2	36” x 72”	36” x 87.5”
12	13	Device’s Water Corrosion Resistance	N/A	Moderate	High
13	11,14	Device’s Overall Corrosion Resistance	N/A	Moderate	High
14	12	Time to Repair Device by a Mechanic	days	<10	<5
15	11	Number of years to failure	time	>7	>10
16	19	Time to learn Operation	min.	<60	<15
17	10	Range of usable truck lengths	m	4-6	4-8
18	20	Devices Aesthetics	N/A	Acceptable	Good

Table B.2 Benchmarking of existing products

Metric	Metric	Maxon Tuk-a-way GPT-3 LG	Large Ramp	Powered Conveyor
1	Time to Load a cart	20 sec/cart	46 sec/cart	50 sec/cart
2	Time to Unload a cart	20 sec/cart	41 sec/cart	50 sec/cart
3	Weight of Device	1,115 lbs	94 lbs	130 lbs
4	Volume Occupied by Device	2.69 m^3	2.71 m^3	2.71 m^3
5	Total Cost of Device	$8,000	$1,000	$2,000
6	Displacement of Carts in Device	8 c.m., 0.5 cm when held	0 cm	0 cm
7	Displacement of Carts in Truck	3 m	3 m	3 m
8	Probability of Accidents of Using Device/LG	1% accident per year	2% accident per year	9,000 accidents/year
9	Range of Cart sizes usable by Device	0.516 m	0.762 m	.61 in.
10	Grade of Carts on Device/LG	7.77 degrees	16.46 degrees	13.66 degrees
11	Area of Device	3 m^2	3.14 m^2	0.42 m^2
12	Device's Water Corrosion Resistance	High	High	Low
13	Device's Overall Corrosion Resistance	High	High	Moderate
14	Time to Repair Device by a Mechanic	2 days	1 days	7 days
15	Time to failure	10 years	10 years	5 years
16	Time to learn Operation	15 min.	5 min.	30 min.
17	Range of truck lengths for which the device can be used	0.9114 m	1.19 m	1.61 m
18	Devices Aesthetics	Good	Good	Poor

Appendix C: Preliminary Sketches & SolidWorks Models

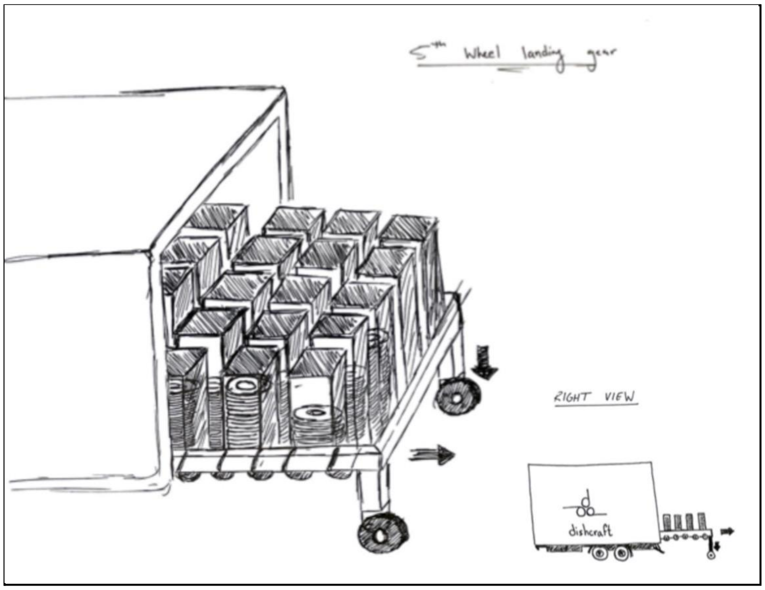

Figure C.1. Initial fifth wheel landing gear design sketch. A hydraulic slab which lies in the truck bed on several sets of rollers.

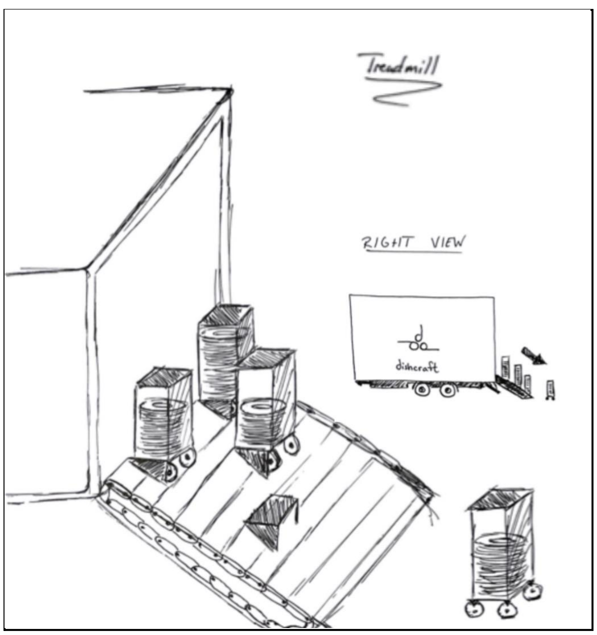

Figure C.2. Initial conveyor belt/treadmill design sketch. Carts are pushed on a moving conveyor belt and pushed into the truck via conveyor belt.

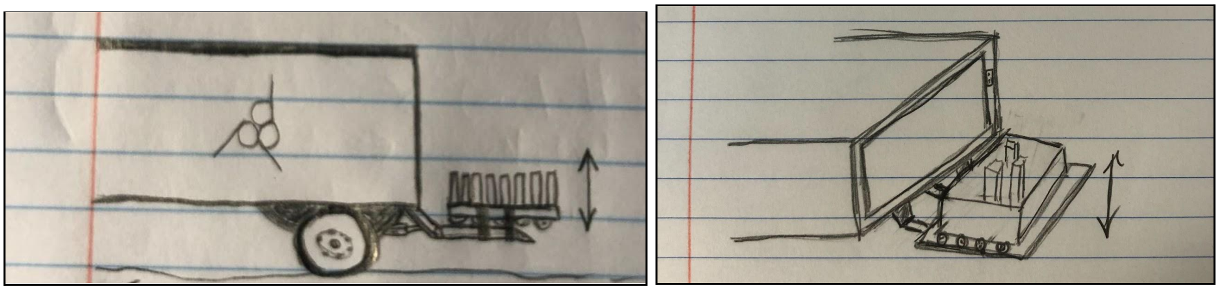

Figure C.3. Cart Roller sketches. Demonstrating motion of roller on liftgate

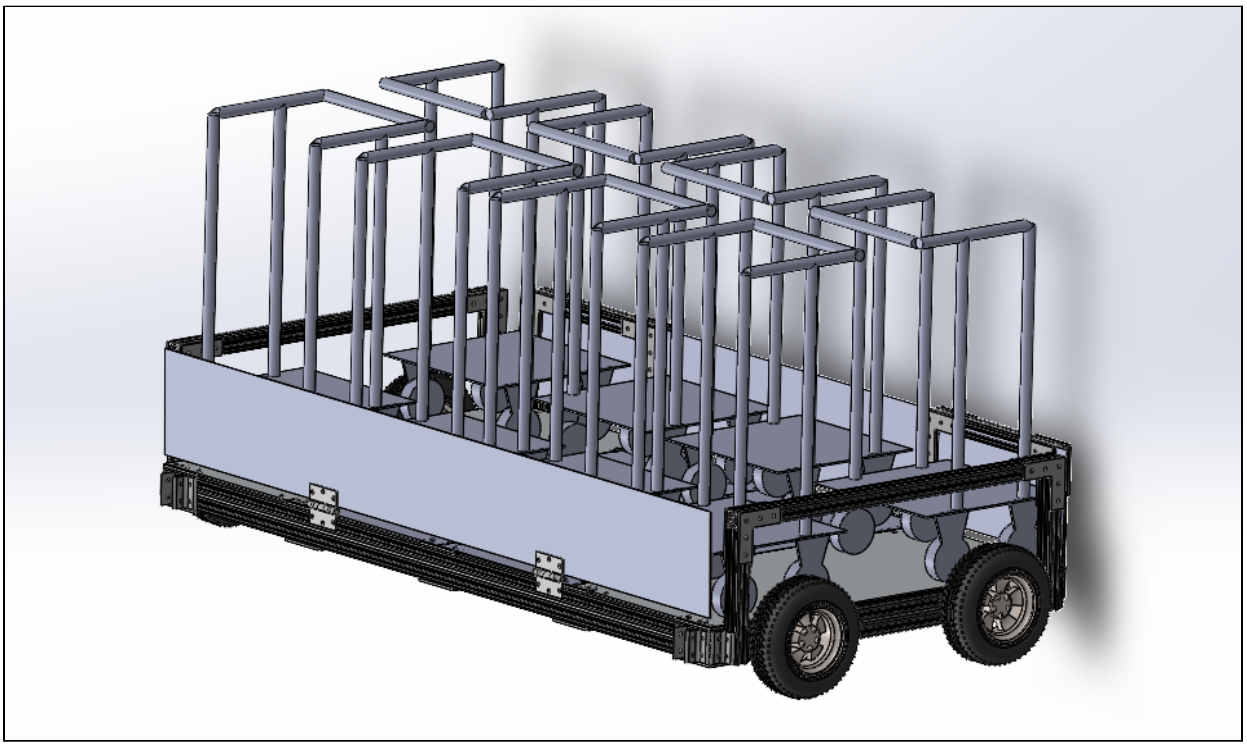

Figure C.4. Cart Roller SolidWorks model

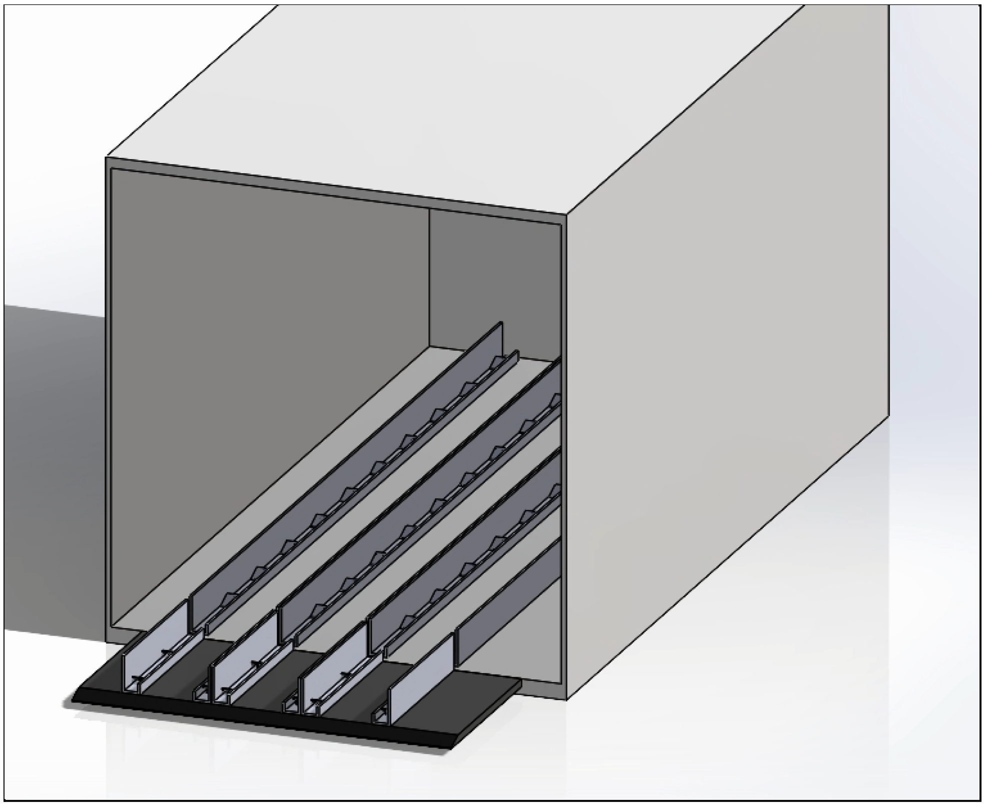

Figure C.5. Cart Rail SolidWorks model

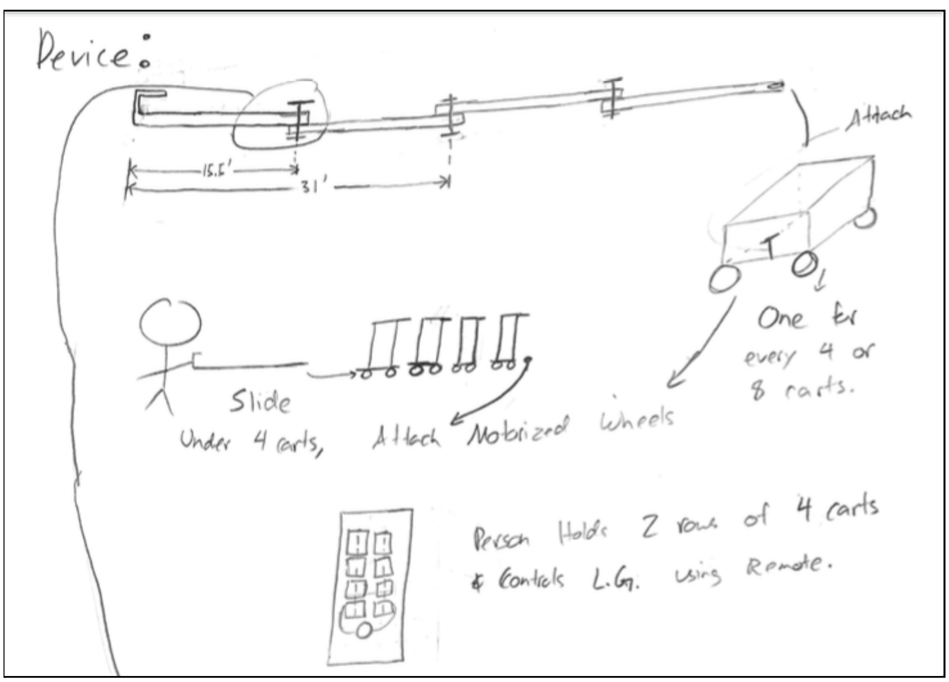

Figure C.6. Cart Clamp sketch

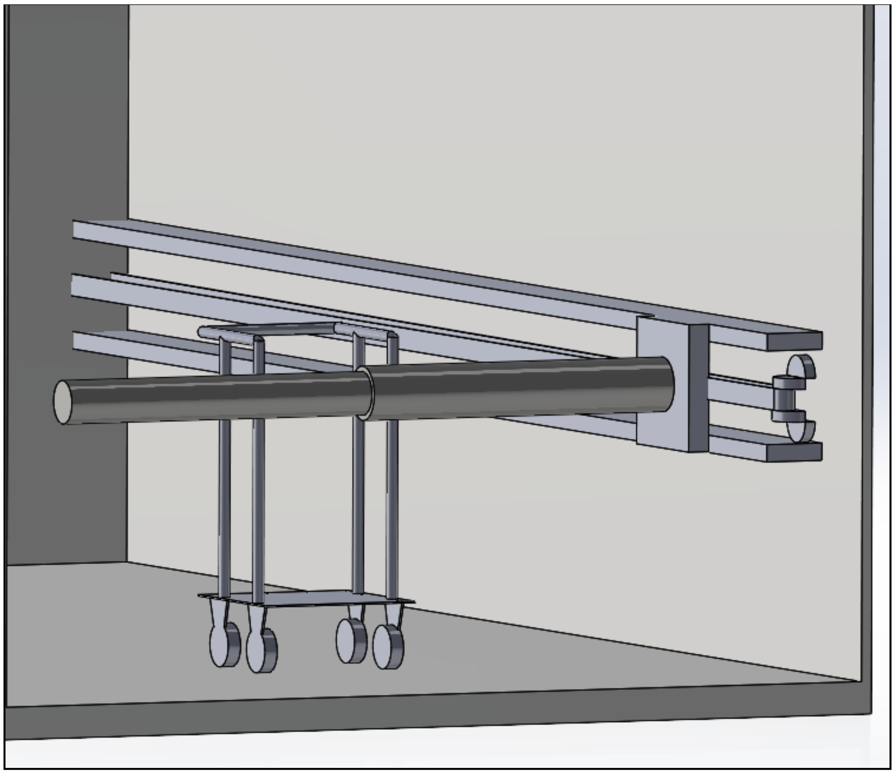

Figure C.7. Cart Pusher

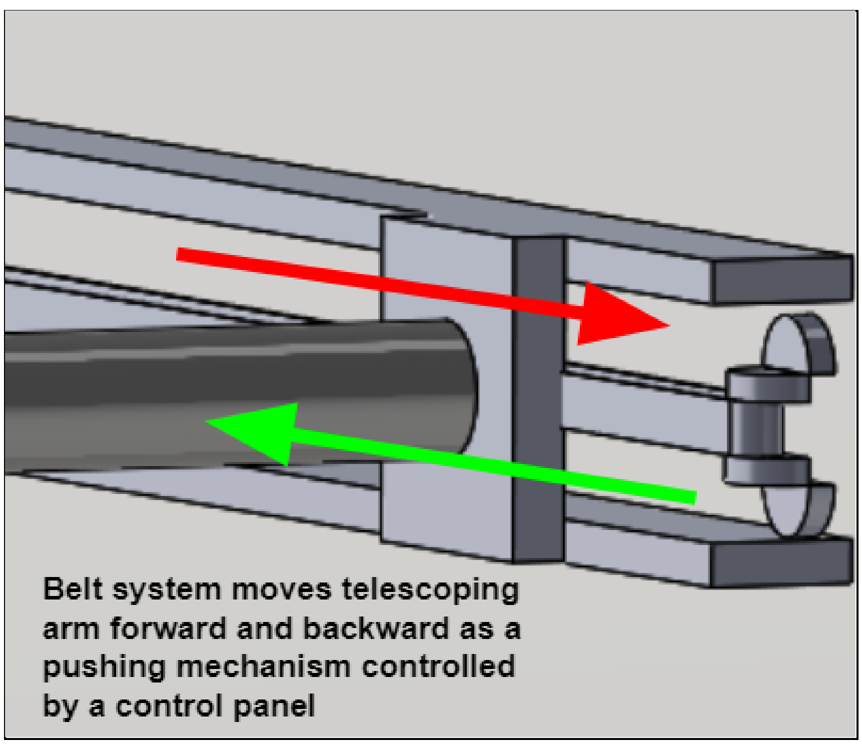

Figure C.8. Cart Pusher overview

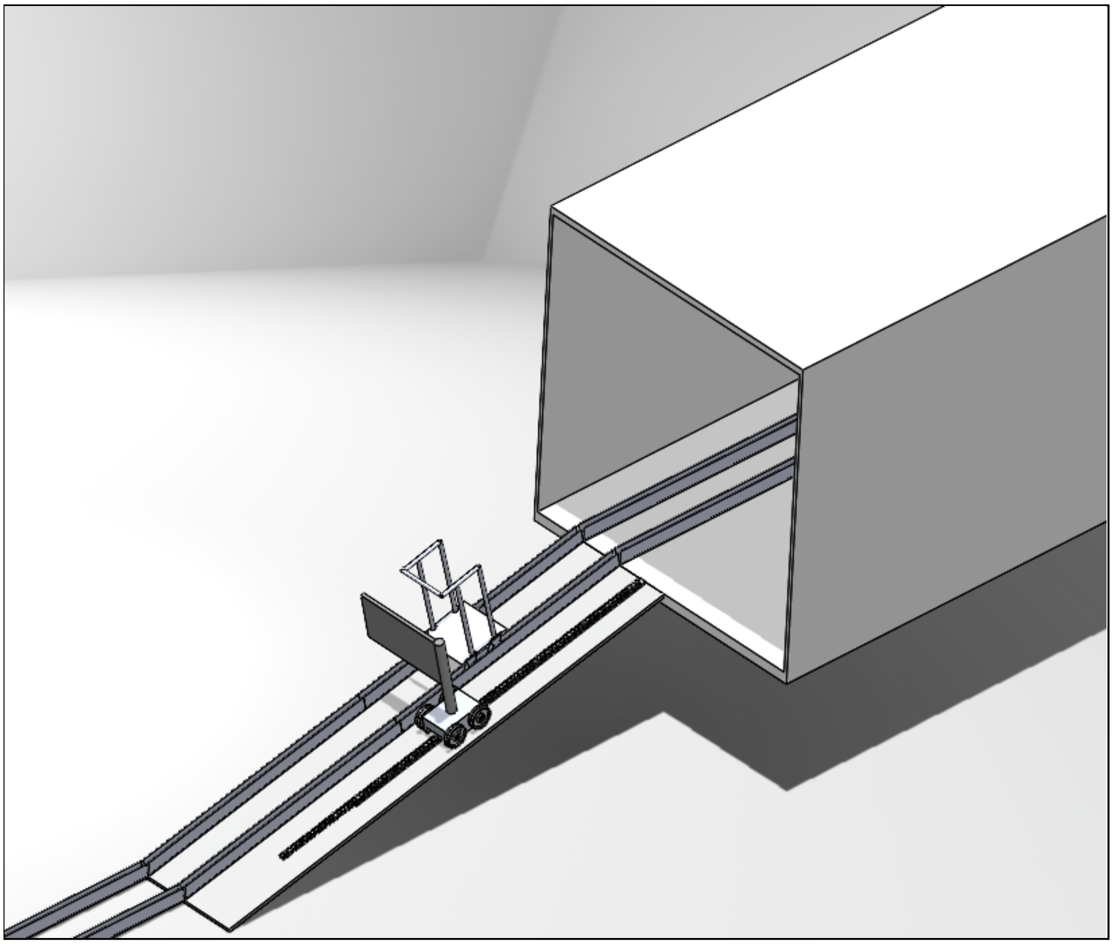

Figure C.9. Cart Ramp

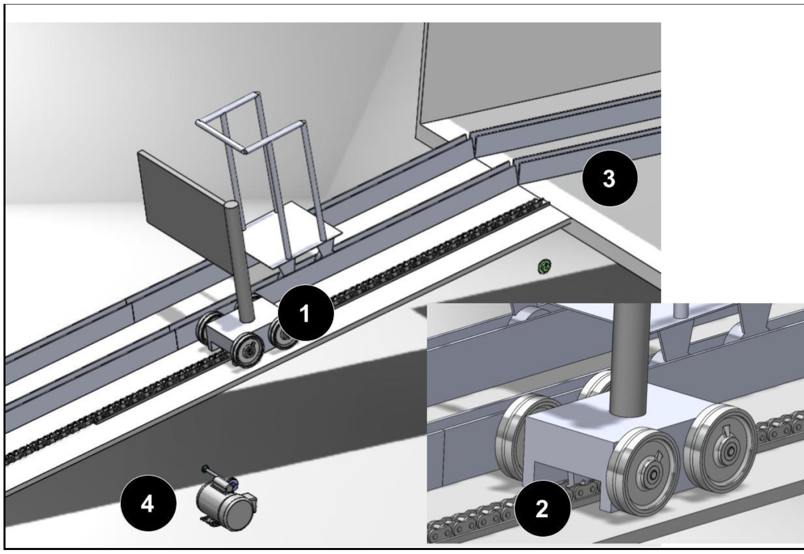

Figure C.10. Cart Ramp overview

Appendix D: Hand Calculations

Dynamic simulation calculations:

$$\sum F = ma = mgsin(\theta) \quad \text{(Equation D.1)}$$

$$a = gsin(\theta) \quad \text{(Equation D.2)}$$

$$v = gsin(\theta)t + v_0;\ v_0 = 0\ m/s \quad \text{(Equation D.3)}$$

$$x = 0.5gsin(\theta)t^2 \quad \text{(Equation D.4)}$$

$$L = 0.5gsin(\theta){t_f}^2 \Rightarrow t_f = \sqrt{\frac{2L}{gsin(\theta)}} \quad \text{(Equation D.5)}$$

Appendix E: Budget

Table E.1 Full itemized budget

Parts	Cost	Where Used	Date ordered	Subtotal of Order
Aluminum T Frame - 3 feet	$348.36	Frame	1/20/2022	$1,235.84
Aluminum T Frame - 8 feet	$133.40	Frame		
Aluminum T Frame Flat L Bracket	$375.48	Frame		
Aluminum T Frame L Corner Bracket	$208.60	Frame		
Shipping & Taxes	$170.00	Ship & Tax		
Aluminum T Frame - 3 feet	$196.86	Frame	2/9/2022	$1,087.22
Aluminum T-Slotted Brackets	$147.84	Frame		
Caster Bracket Aluminum 6061 Blanks	$118.14	Frame		
Steel Hinges w/o Holes	$382.92	Ramp		
Hex Nut Grade 5, 1/2"-20	$12.12	Frame		
Hex Nut Grade 5, 5/16"-18	$5.98	Frame		
Hex Flat Screw 5/16"-18	$54.72	Frame		
Hex Flat Screw 1/2"-20	$31.30	Frame		
Shipping & Taxes	$137.34	Ship & Tax		
Casters	$208.50	Wheel	2/18/2022	$242.82
Shipping & Taxes	$34.32	Ship & Tax		
Aluminum Top Plate	$308.75	Frame	2/14/2022	$617.50
Aluminum Top Plate	$308.75	Ramp		
Drop in nuts	$30.00	Frame	3/2/2022	$206.04
Drop in nuts	$35.60	Frame		

Zinc-Steel Floor Lock	$66.28	Frame		
Drop in nuts	$48.00	Frame		
Shipping & Taxes	$26.16	Ship & Tax		
T slot Framing	$15.00	Frame	4/12/2022	$168.48
T slot Framing	$8.86	Frame		
Multi Purpose 6061 Al	$30.70	Frame		
Screw on Latches	$62.60	Frame		
T slot Framing fasteners	$18.64	Frame		
Black oxide 8-18	$9.87	Frame		
Shipping & Taxes	$22.81	Ship & Tax		
Silver Tee Bracket	$24.64	Frame	4/20/22	$142.05
End caps	$9.20	Frame		
Drop in nuts	$45.00	Frame		
Polypropylene wheel	$4.87	Wheel		
corner bracket	$33.72	Frame		
Machine Key	$5.03	Wheel		
Shipping & Taxes	$19.59	Ship & Tax		
Motor wheel	$29.00	Wheel	4/20/22	$31.65
Shipping & Taxes	$2.65	Ship & Tax		
Motor Wheel (1)	$29.00	Wheel		$46.42
Shipping & Taxes	$17.42	Ship & Tax		
Battery	$37.99	Wheel	5/9/2022	$37.99
Total Cost				**$3,816.01**

Appendix F: Drawings of Machined Parts

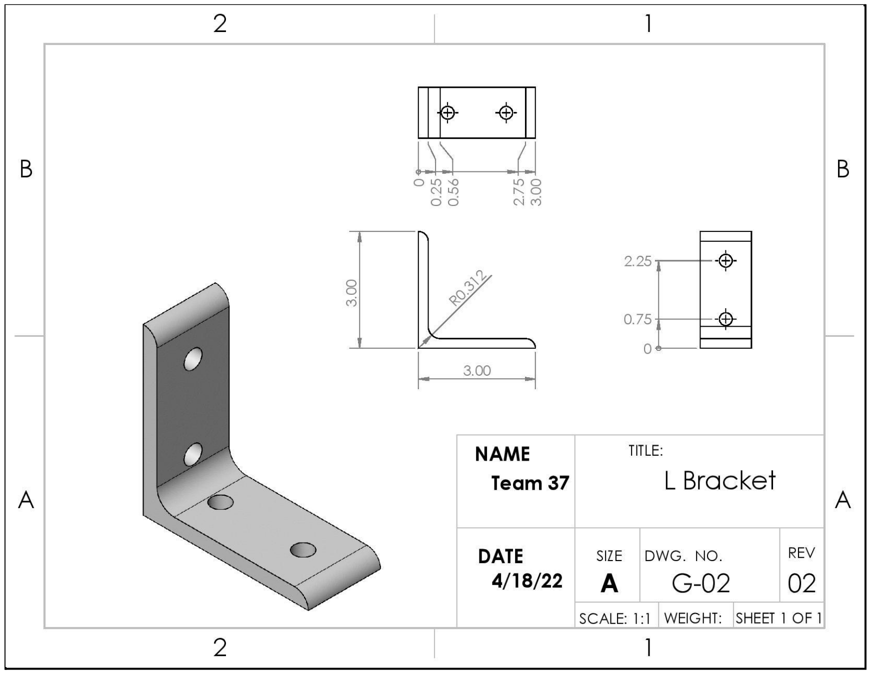

Figure F.1. L bracket drawing

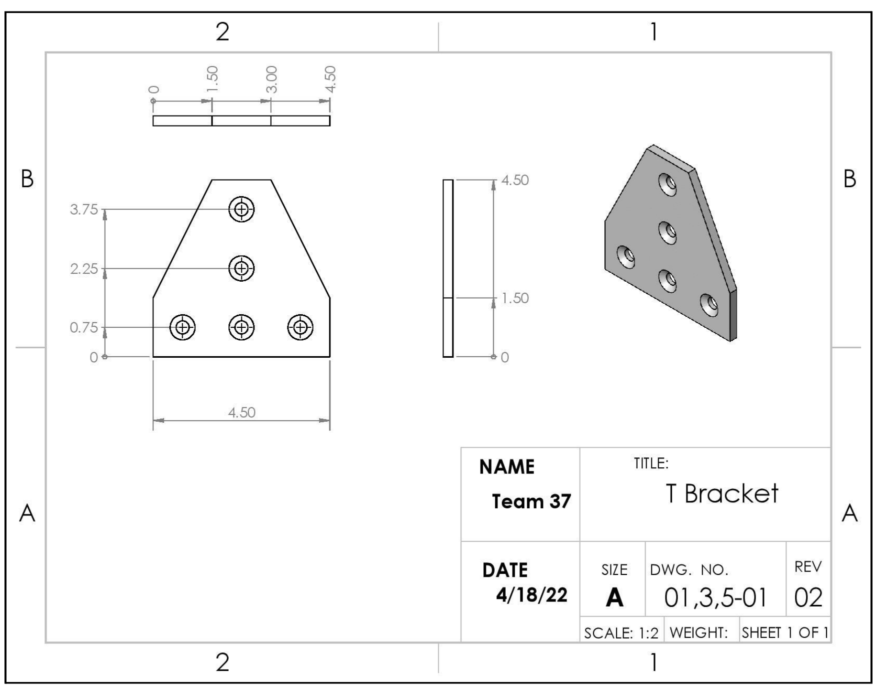

Figure F.2. T bracket drawing

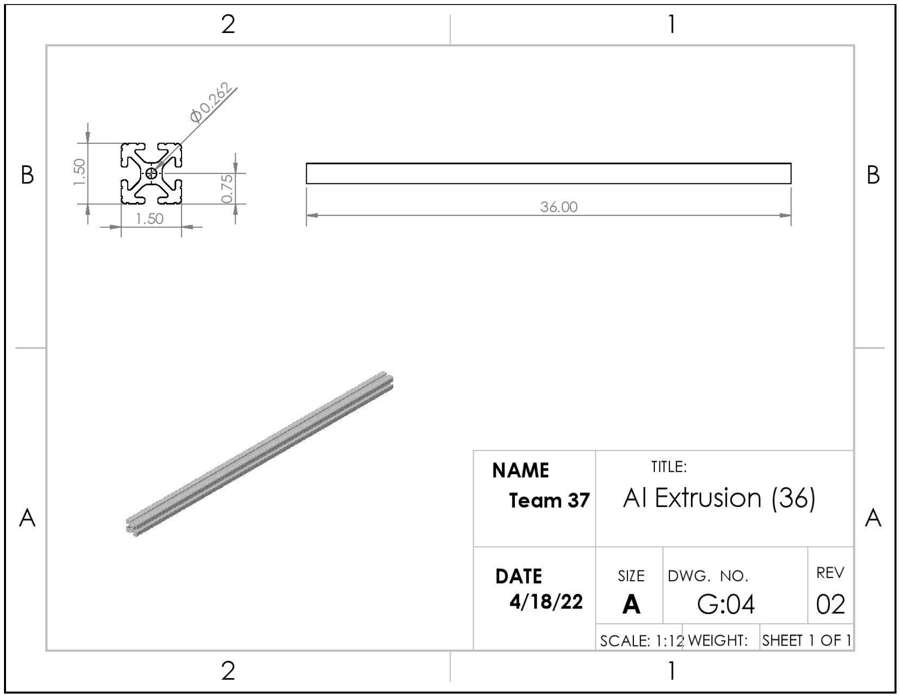

Figure F.3. Aluminum extrusion (36 in) drawing

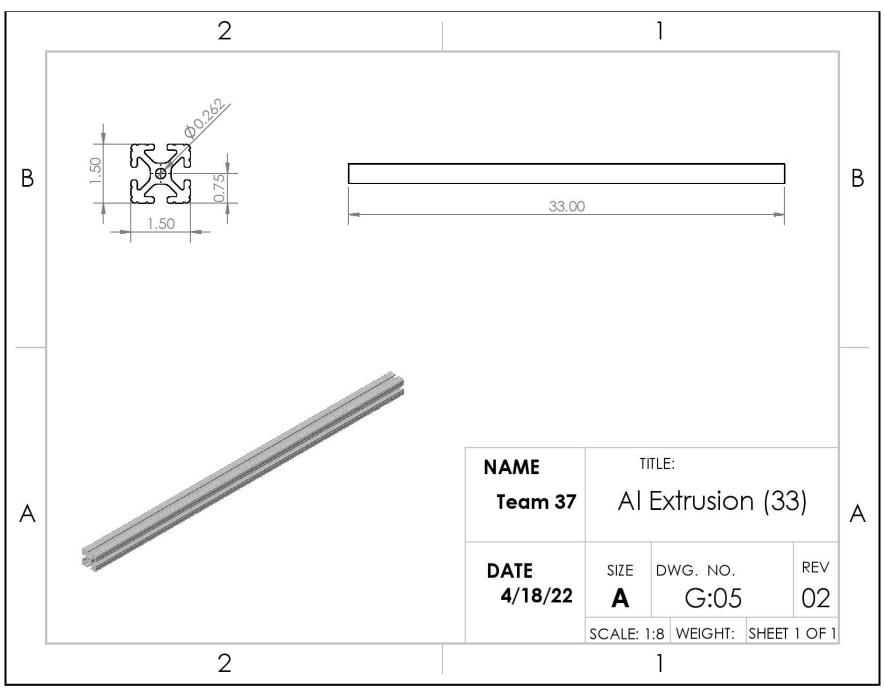

Figure F.4. Aluminum extrusion (33 in) drawing

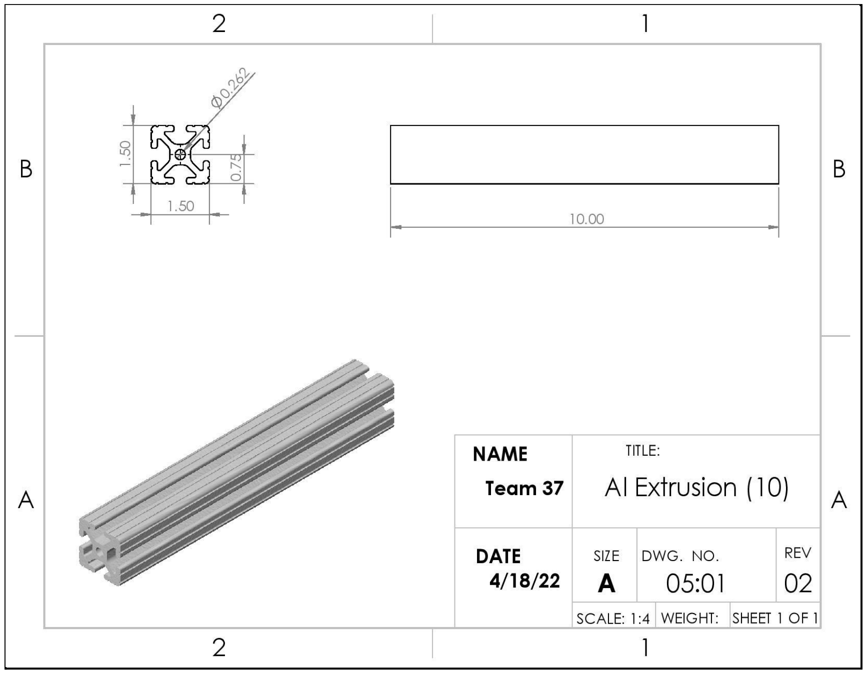

Figure F.5. Aluminum extrusion (10 in) drawing

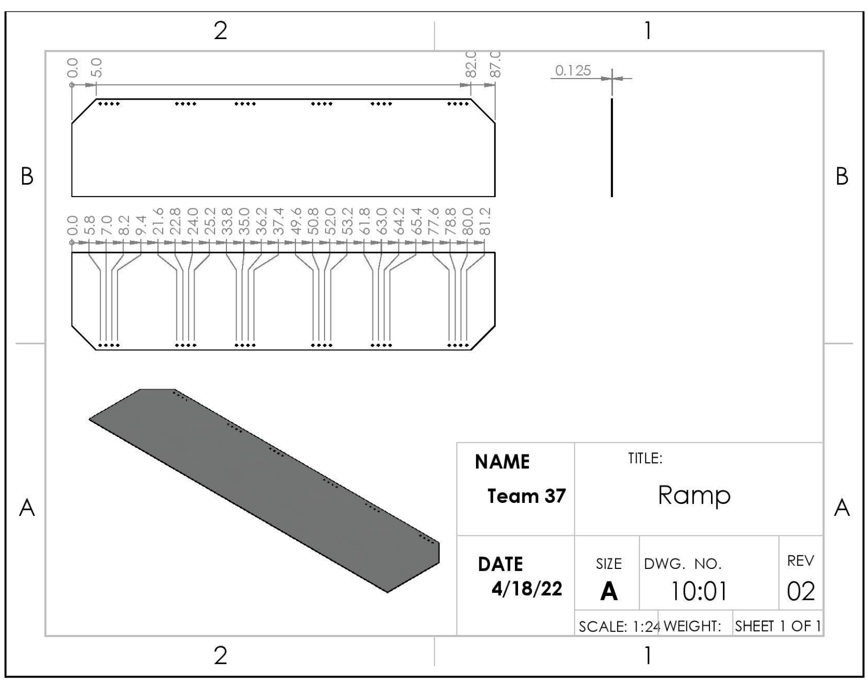

Figure F.6. Aluminum ramp drawing

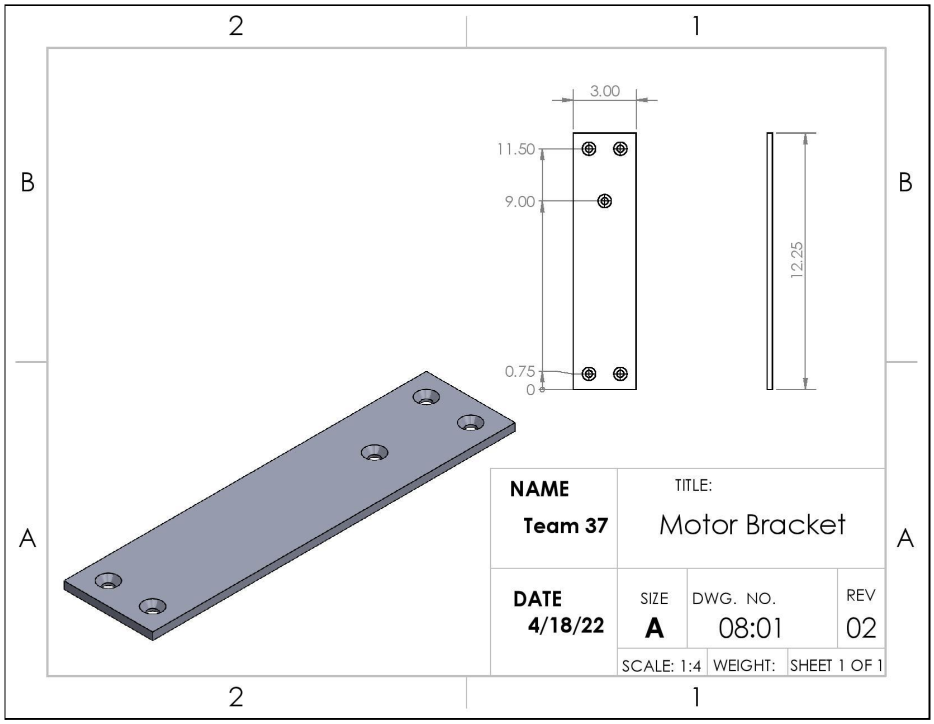

Figure F.7. Aluminum motor bracket drawing

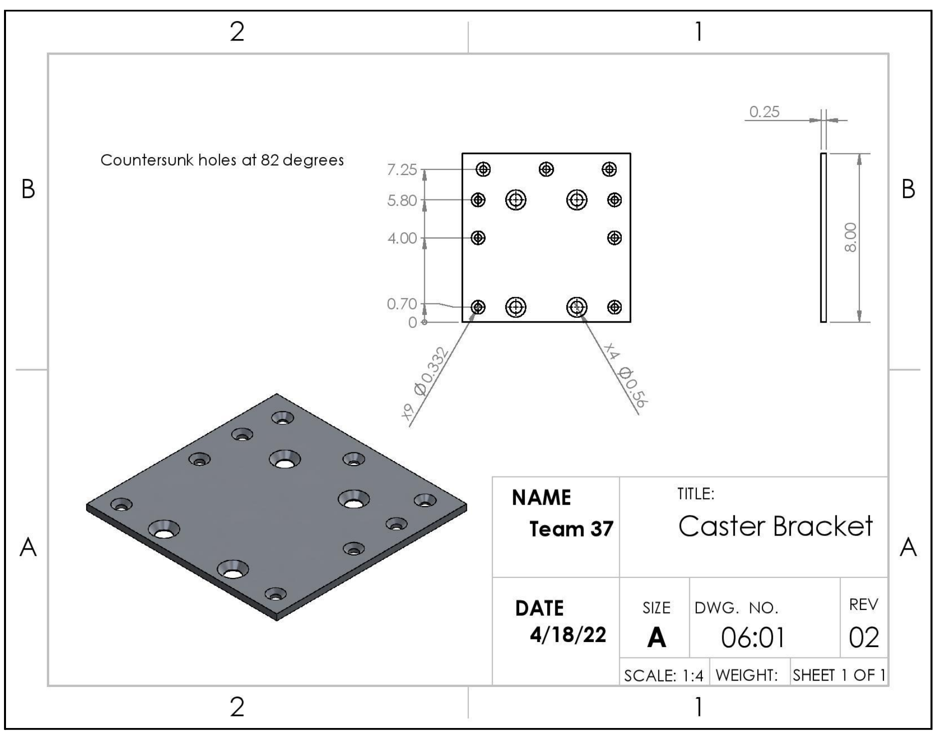

Figure F.8. Caster bracket drawing

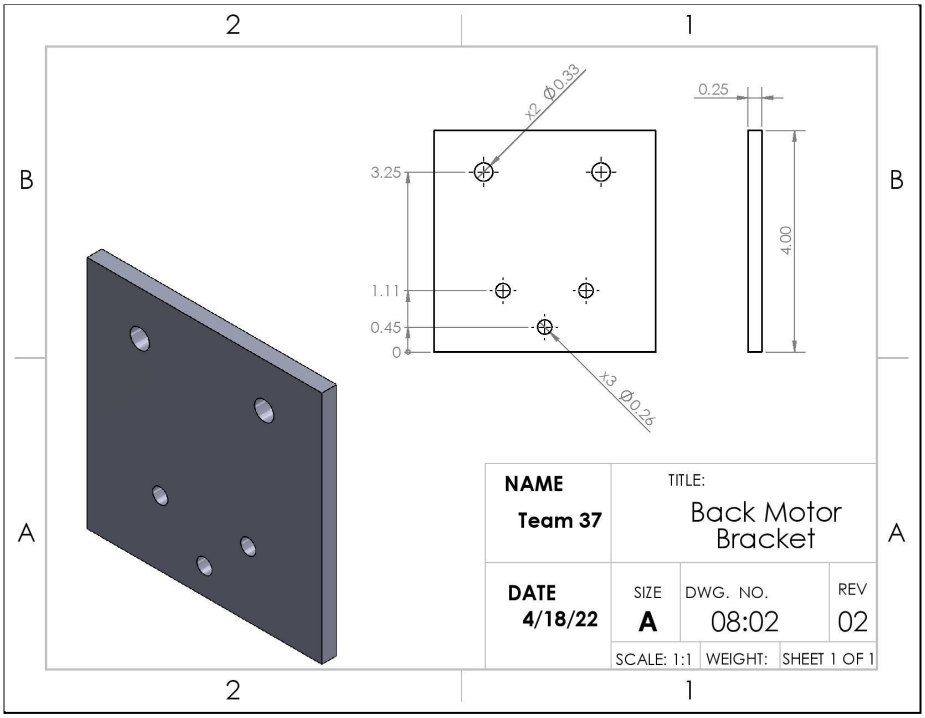

Figure F.9. Back motor bracket drawing

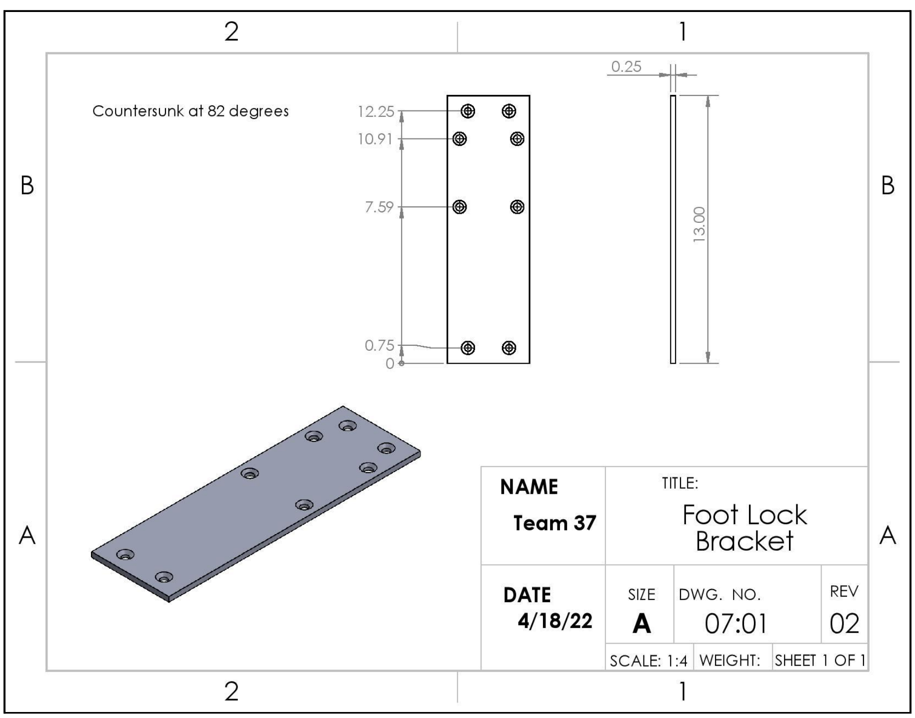

Figure F.10. Foot lock bracket drawing

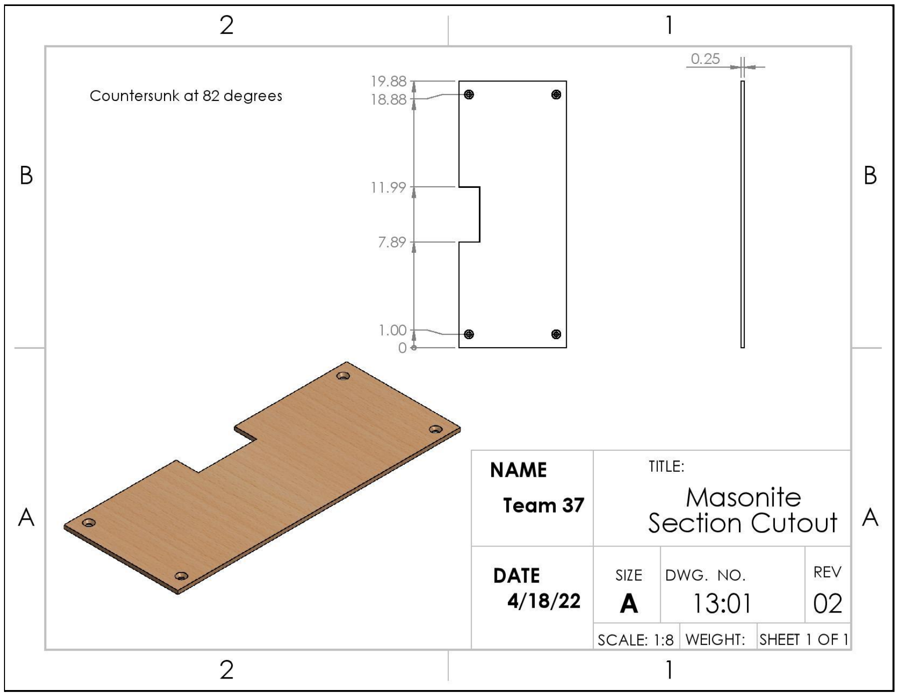

Figure F.11. Masonite section cutout drawing

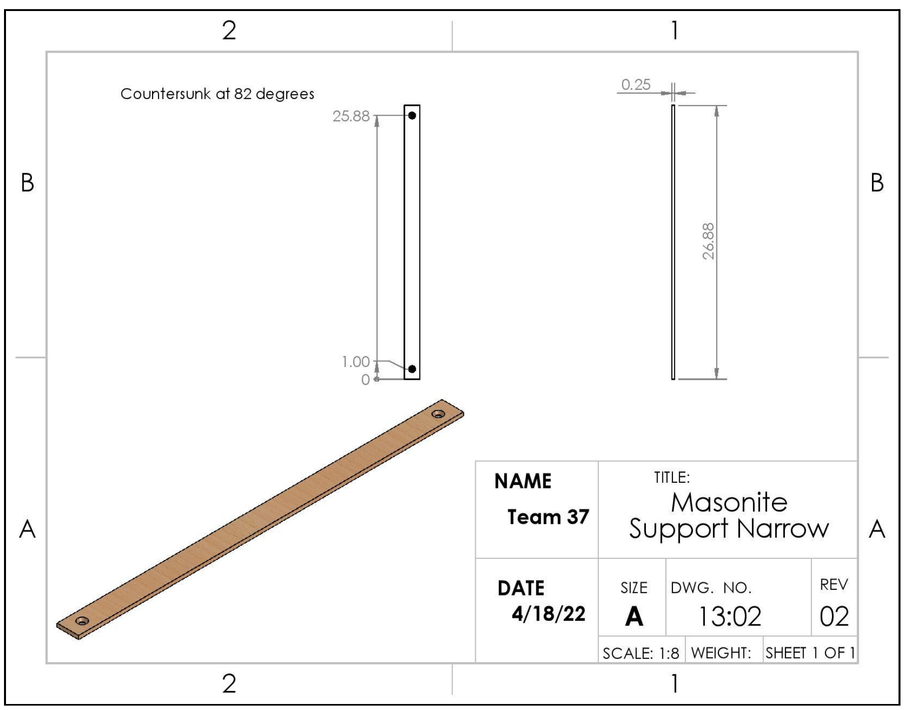

Figure F.12. Masonite section narrow drawing

Appendix G: Senior Design Conference Slides

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Senior Design Conference

Cart Loader

Hayelom Fitsum, Dalveer Grewal, Ishan Kumar, Sean McCauley, Nick O'Brien

Advisor: Dr. Robert Marks

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Agenda

1. **Engineering Design Process Overview**
2. **Introduction: Dishcraft Robotics**
   a. Project Purpose
   b. Understanding the Problem
   c. Customer Needs
3. **Concept Generation**
   a. Selection Matrix
   b. Design Process
4. **How it Works**
5. **Subsystems**
   a. Finite Element Analysis
6. **Build**
7. **Testing**
8. **Budget Analysis**
9. **Timeline**
10. **Future Plans**

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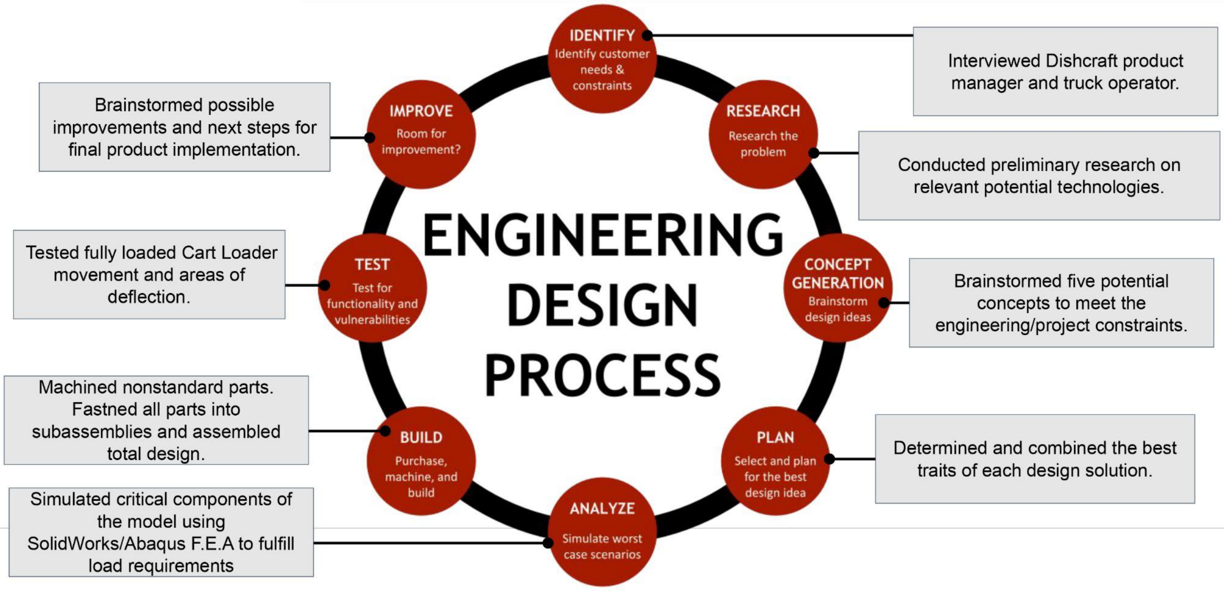

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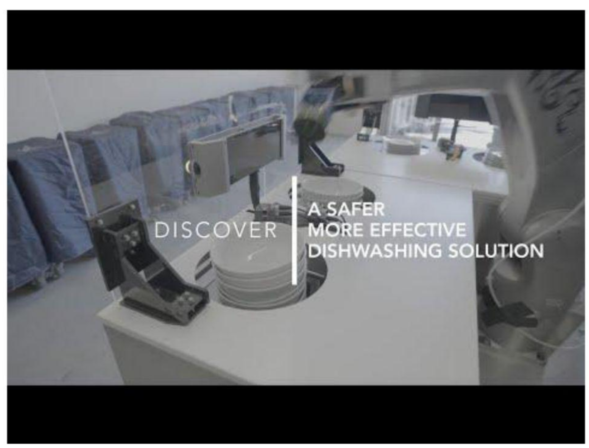
Introduction: Dishcraft Robotics

- Working with local startup: Dishcraft Robotics
    - Dish cleaning service to corporations or hotels
    - Operation:
        - Drop off clean dishes to client location
        - Pick dirty ones up after use
        - Clean dishes with automated robots

dishcraft



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Project Purpose: Understanding the Problem

- "Dishcarts"
  - Transport clean/dirty ceramic dishes
  - Each cart holds up to 150 lb of dishes
  - Up to 60 of these dishcarts are loaded into a truck at one time
- Currently, using the truck liftgate, it takes 1 hour to load or unload all 60 dishcarts.

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Project Purpose: Problem Statement

Dishcraft has tasked the SCU team with designing a device that will drastically reduce the time to load or unload their dishcarts from the back of a truck.

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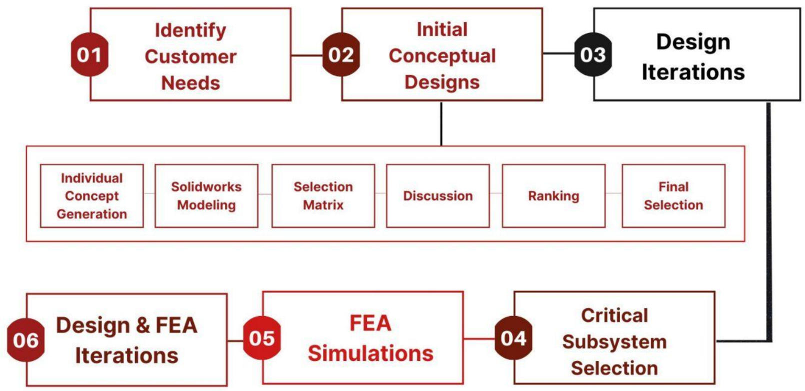
Cart Loader Design Process



Identifying Customer Needs

- Before beginning the conceptual design phase, the team went through an extensive process of identifying customer needs
- From customer needs, the team created detailed product specifications

Metric #	Need #	Metric	Units	Marginal Value	Ideal Value
1	4	Time to load cart	sec/cart	<20	<8
2	4	Time to unload cart	sec/cart	<25	<10
3	8	Weight of Device	lbf	250	200
4	-	Surface area	ft^2	12.5	16
5	15	Cost	$	<5,000	<4,000

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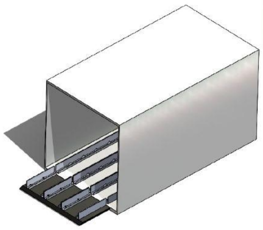
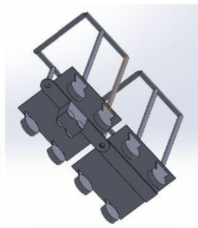
Five Initial Design Ideas

02 Initial Conceptual Designs

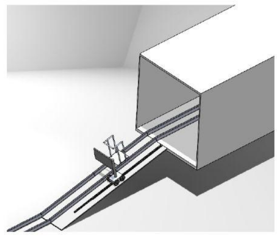
Individual Concept Generation | Solidworks Modeling



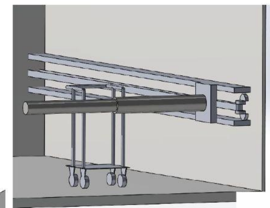
Cart Rail



Cart Clamp



Cart Ramp



Cart Pusher

Cart Roller

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Selection Matrix

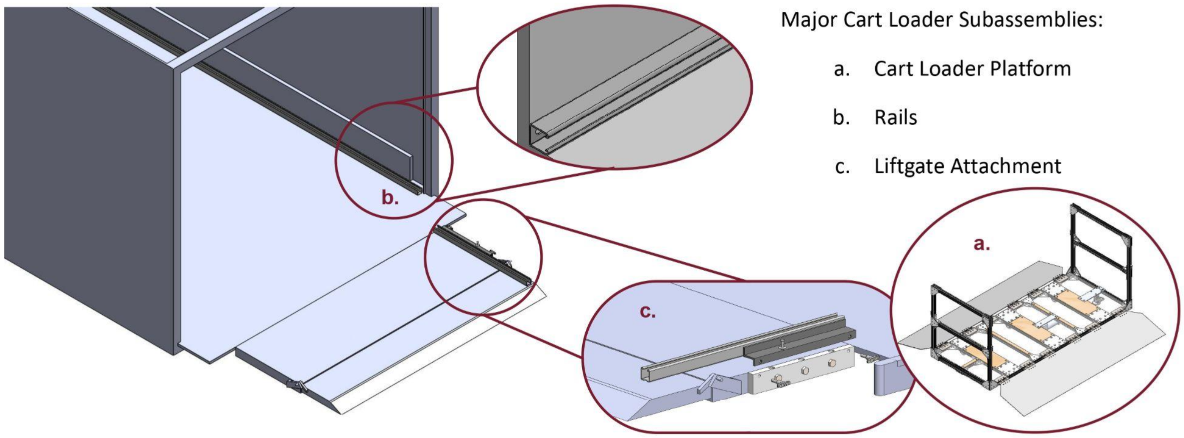
- 5 votes averaged/section - 1 is the best, 5 is the worst
- Each category is weighted
- Current product included to compare with new designs

Selection Matrix | Discussion | Ranking

Design Idea	Not reliant on physically attaching things to truck	Ease of Use for the user	Build Difficulty	Cost to Build	Cart capacity	Secures carts during operation	Space taken up BEHIND truck	Speed	Adaptability for other uses	Space taken up IN truck	Total Weighted
Weights	10	15	5	5	10	20	7	20	5	3	
Current Dishcraft Liftgate	5	4	2	3	4	5	1	5	1	1	**390**
Cart Roller	1	2.4	1.6	1.9	1	3	1	1.5	1.1	1	**179**
Cart Clamp	1	3.5	1	1.1	1.3	4	1	1.9	1.5	1	**221.5**
Cart Ramp	5	1.7	3.4	2.8	2.5	1.5	2.3	2.5	2	2	**243.6**
Cart Rail	5	1.5	2.3	1.5	1.3	1	1	2.3	3.1	1.25	**196.75**
Cart Pusher	5	3	3.6	3.5	1.3	3.6	1	2.3	1.9	1.5	**282.5**
Roller Cart & Rails	5	1	2.75	3	1	1	1	1.5	1.5	1	**171.25**
Ramp & Rails	5	1	3	2	2	1	2	2	2.5	2.5	**204**

Final Conceptual Design: Cart Loader

Final Selection



Major Cart Loader Subassemblies:

a. Cart Loader Platform
b. Rails
c. Liftgate Attachment

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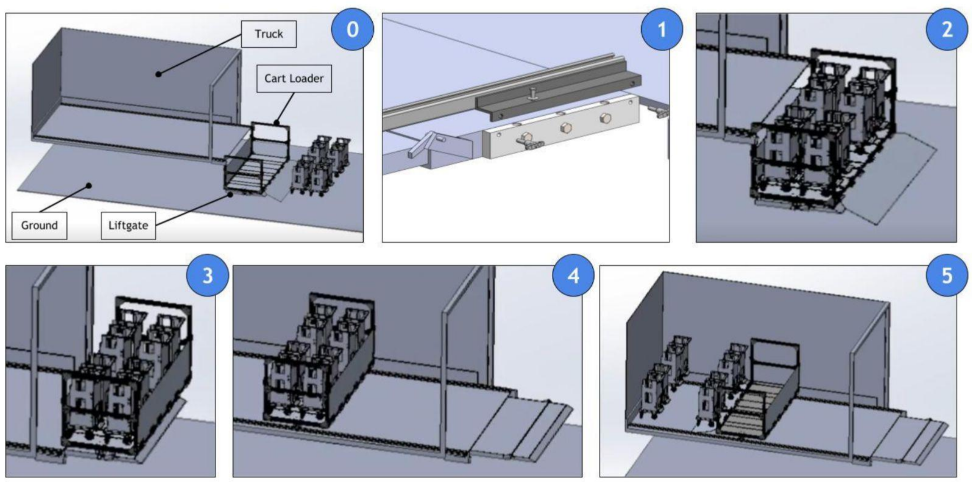
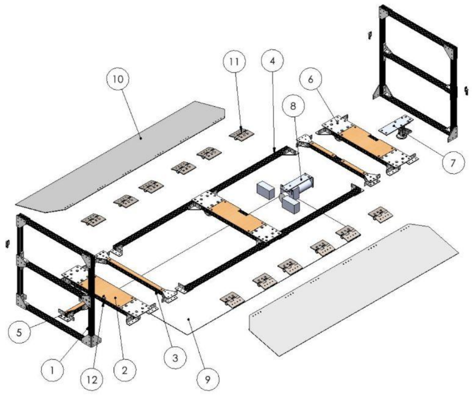
How it Works



Cart Loader: Critical Subsystem Modeling & Simulation



- Frame
- Top Sheet
- Hinged Ramp
- Latch Mechanism
- Other Subsystems

04 Critical Subsystem Selection

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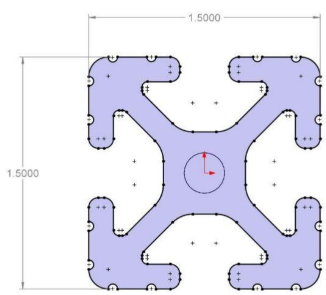
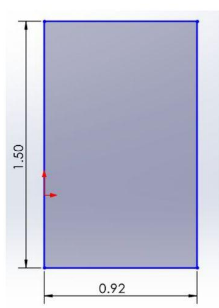
Frame Critical Subsystem: Equivalent Beams





1) $\sigma = \frac{my}{I}$

2) $I = \frac{1}{12}bh^3$

3) $b = \frac{12I}{h^3}$

- Complexity of frame geometry necessitated a simplification
- An *equivalent* beam was created with identical area moment of inertia and height
- This equivalent beam was tested using both analytical and FEA results

Method:	Normal (Bending) Stress in Z Direction	% Error from analytical results
Analytical	2.596 ksi (9" from fixed end)	0.00%
FEA Equivalent Beam	2.597 ksi (9" from fixed end)	0.03%
FEA Aluminum Extrusion	2.639 ksi (9" from fixed end)	1.66%

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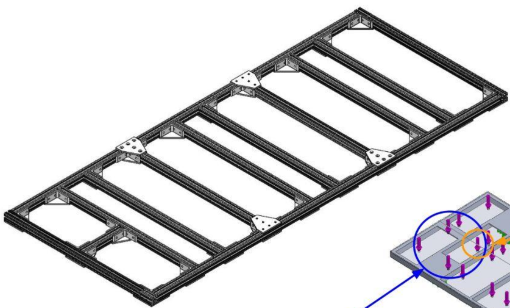
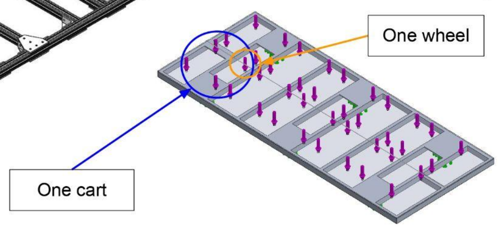
Critical Subsystem: Frame CAD Model & Loading



- Base frame: 1.5”x1.5” Aluminum T-Slot Extrusions
- Material: Aluminum 6105 T5
- Brackets: Anodized Aluminum
- Hardware: 5/18”-18 Zinc Plated Steel bolts



- Loaded for 10 dishcarts
  - Four loading points (one load per wheel)
  - Loads per point: (20.75/37.5/68.125 lbf)
  - Total loads: (830/1500/2725 lbf)
- Fixed supports at 6 caster wheels

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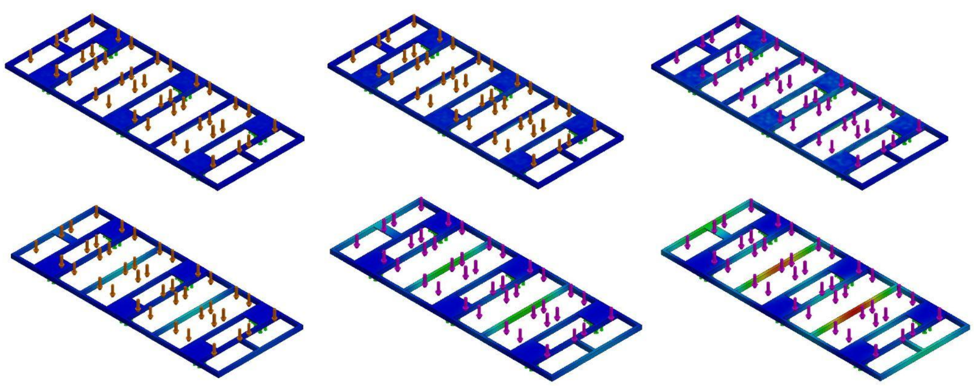
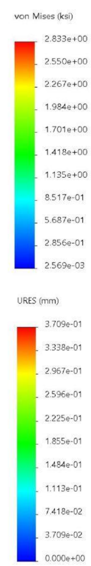
Critical Subsystem: Frame FEA Simulation

- Aluminum Extrusion
- Yield Strength masonite: 4 ksi
- F.O.S for masonite: 2.53

05 FEA Simulations





Total Load	830lb	1500lb	2725lb
Max Stress [ksi]	0.86	1.58	2.83
Max Displacement [mm]	0.1127	0.2083	0.3709

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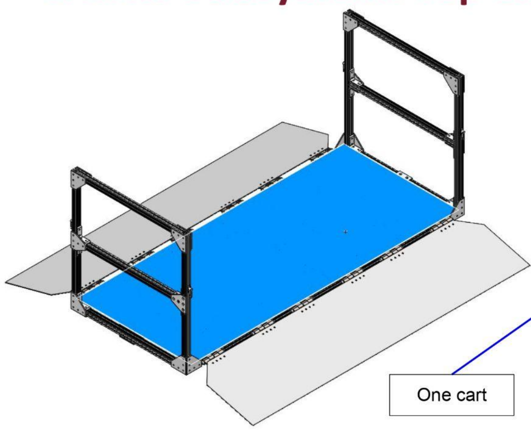
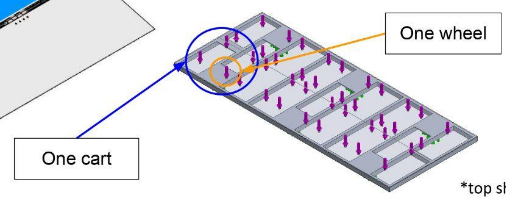
Critical Subsystem: Top Sheet CAD Model & Loading



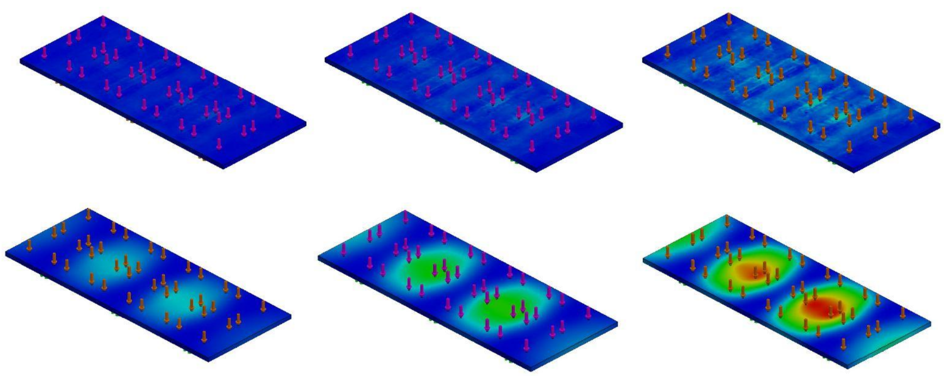
- Top Sheet: 36” x 84” Overall
- ⅛” Thickness
- Material: Aluminum 6061 T6
- Purpose: Acts as support platform for dishcarts

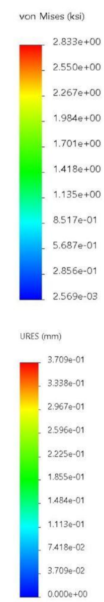


*top sheet is shown as transparent

Critical Subsystem: Top Sheet FEA Simulation

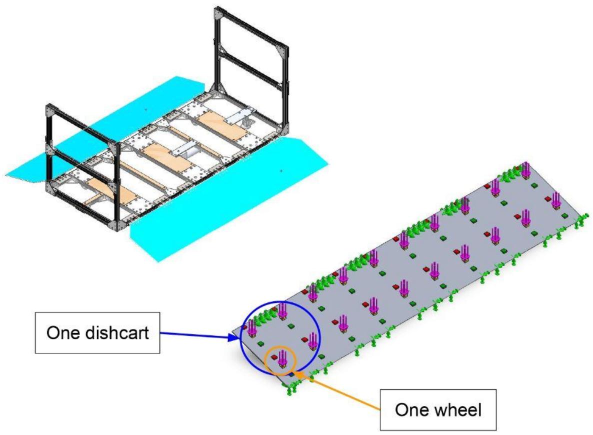
- 6061 T6 Aluminum
- Yield Strength: 39.89 ksi
- Factor of Safety @1500lbf: 28.15*





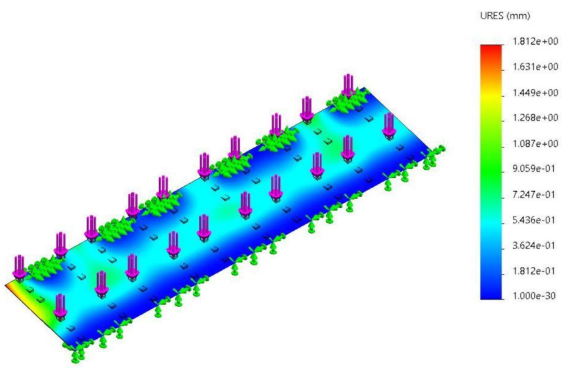
Total Load	830lb	1500lb	2725lb
Max Stress [ksi]	0.002569	1.417	2.8333
Max Displacement [mm]	0.1153	0.1955	0.3709

Critical Subsystem: Hinged Ramp CAD Model & Loading



- Ramp Sheet: 87" x 20"
- ⅛" Thickness
- Material: Aluminum 6061 T6
- Purpose:
  - Roll carts on/off of platform
  - Folds up to secure dishcarts

Hinged Ramp Critical Subsystem: FEA Simulation

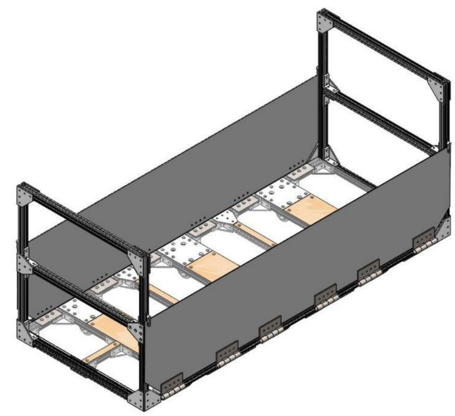


- Assume bolt holes and bottom edge are fixed
- Assume a worst case loading scenario
  - Five carts being loaded at once
  - 150 lbf / Cart
- Yield Strength: 39.89 ksi
- Max Von Mises Stress: 18.41 ksi
- F.O.S: 2.16 (for 750 lb load)

Dishcraft update

How Our Task Changed

- Dishcraft Robotics failed to receive series B funding
  - No box-truck or Dishcraft resources
  - Continue designing cart loader
  - Dishcraft donation



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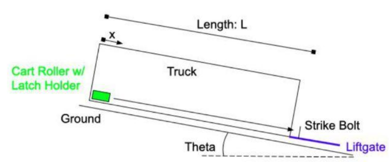
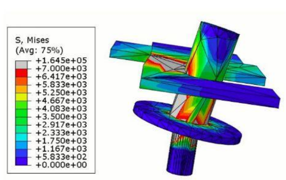
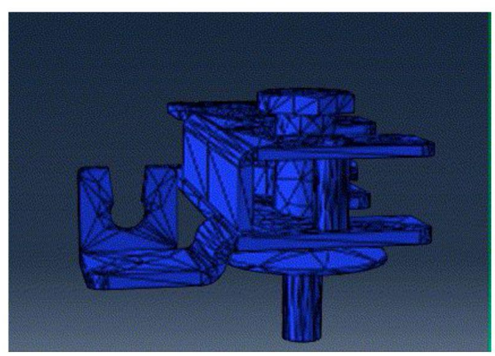
Unbuilt Critical Subsystem: Latch Mechanism



Potential Dangerous Situation



Stress on Dynamic Collision



Dynamic Collision Animation

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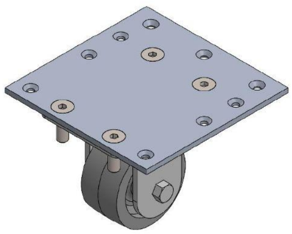
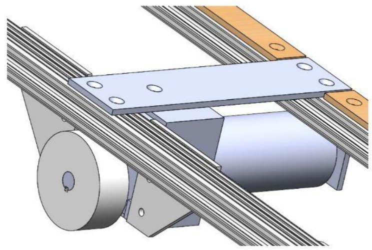
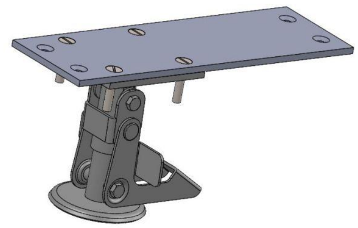
Other Subsystems



Caster Wheels



Motor Wheel System



Foot Brake

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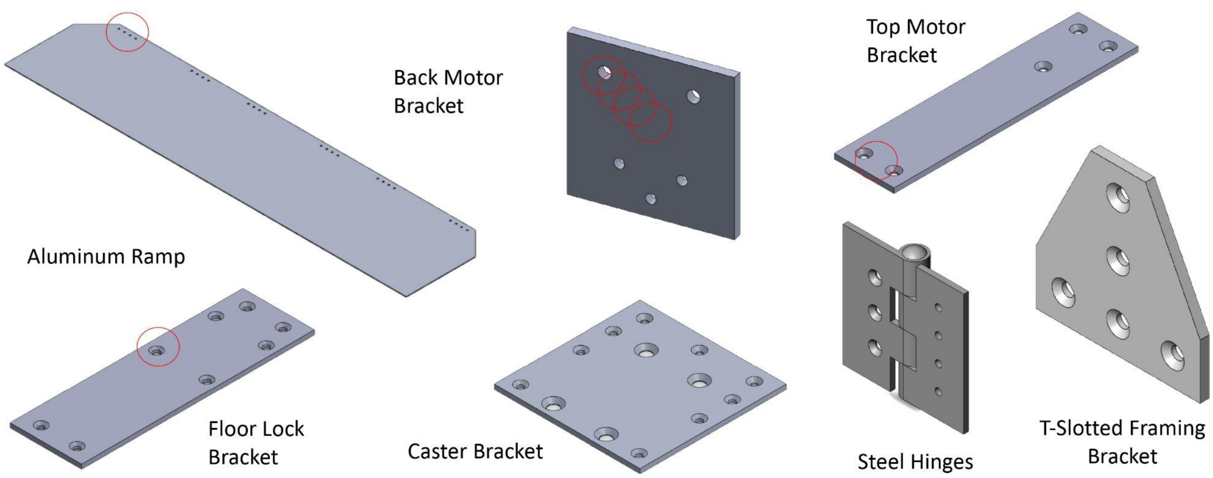

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Fabricated Top Plate Support: Masonite

- Masonite was added for support
    - Eliminates gap between top plate & Aluminum Extrusions
- Process: Laser Cut & Countersink Holes

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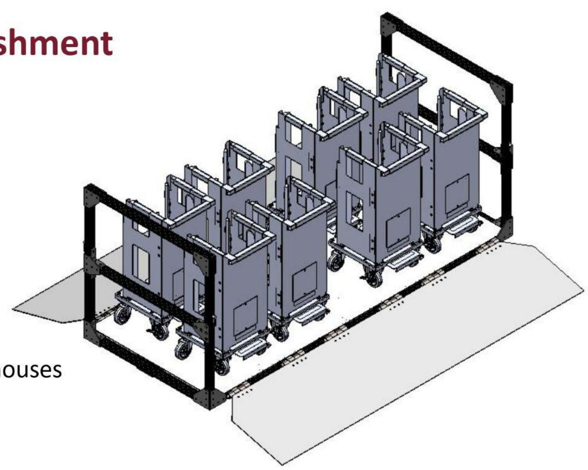
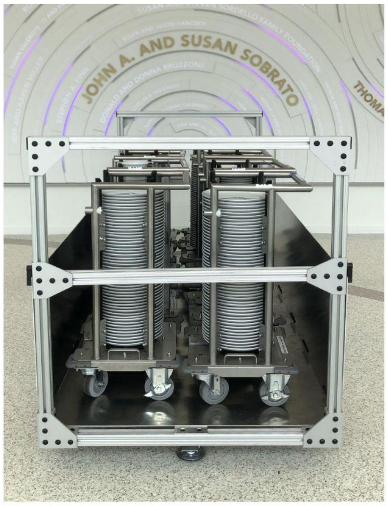
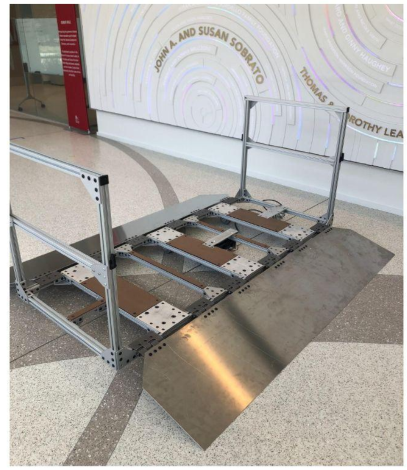
Senior Design Project Accomplishment

- Fully built the Cart Loader
    - Provides larger surface area
    - Securely contains any goods
    - Can withstand 2725 lbf
    - Motorized movement
- Potential Uses
    - Efficiently move goods
        - Delivery Trucks, Factories, Warehouses



Cart Loader: Final Assembly





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Testing: Background

- Current Load Process
  - Placed & Braked two carts on Liftgate
  - Raised Liftgate up
  - Unbraked & Pushed Carts to end of truck
  - Repeat
- Loading Time for 60 Carts: 60 minutes
- Our Goal: 20 min.

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Testing Overview

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Testing: New Design

Loading Operation: 8 Carts	Fast Time (sec)	Slow Time (sec)	Average Time (sec)
1. Raise Liftgate	7	7	7
2. Load Carts on Cart Loader	34	67	50.5
3. Push Cart Loader	8	12	10
4. Raise/Lower Ramps	10	22	16
5. Unload Carts	29	47	38
6. Apply Cart Brakes	40	80	60
7. Pick Up Ramps	9	13	11
8. Move Cart Loader to Liftgate	8	12	10
9. Lower Liftgate	7	7	7
8 Cart Time	152	267	209.5
60 Carts Time	**19.4 minutes**	**34.8 minutes**	**27.1 minutes**

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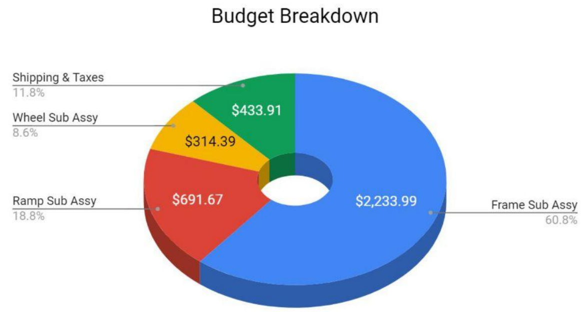
Budget Analysis

Parts	Cost	Sub Assembly	Total
Aluminum T Frame	$678.62	Frame	$3,673.96
Fasteners	$790.28	Frame	
Hardware	$262.72	Frame	
Caster Bracket Aluminum 6061 Blanks	$118.14	Frame	
Aluminum Sheet	$308.75	Frame	
Zinc-Steel Floor Lock	$66.28	Frame	
End caps	$9.20	Frame	
Steel Hinges w/o Holes	$382.92	Ramp	
Aluminum Sheet	$308.75	Ramp	
Casters	$208.50	Wheel	
Motor Wheels	$62.87	Wheel	
Machine Key	$5.03	Wheel	
Battery	$37.99	Wheel	
Shipping & Taxes	$433.91	Shipping & Taxes	



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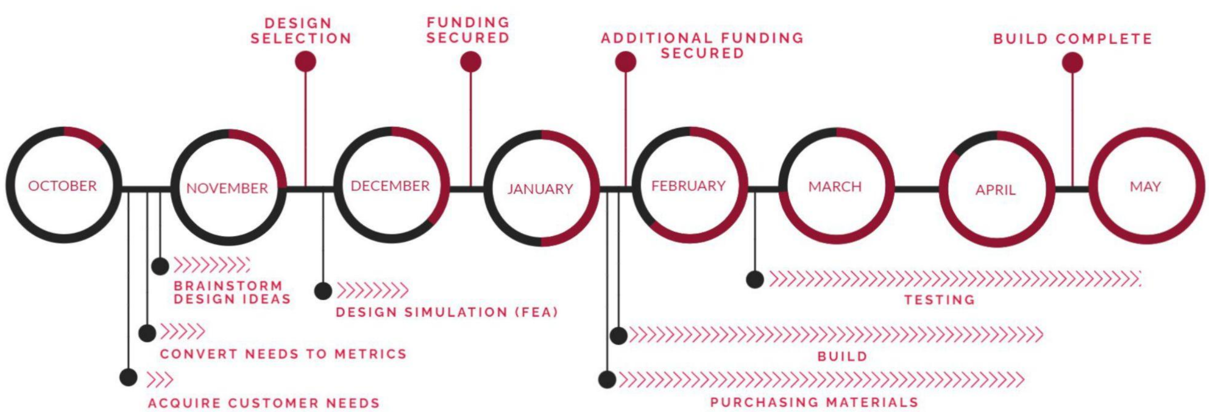
Timeline



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Future Plans

- Contact other companies we interviewed
  - Donate cart loader
- Speak with Frugal Innovation/other companies
  - Determine potential clients
  - Build powered rail system to fit their truck
  - Build attachment to attach Cart Loader to liftgate

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Acknowledgements

- School of Engineering
- Frugal Innovation Hub
- Dr. Robert Marks
- Dishcraft Robotics
- Hayden

Frugal Innovation Hub
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dishcraft robotics

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