Summer 2023

JME 4110: Upgraded Refrigeration Door Cycling System

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Joint Engineering Program

University of Missouri–St. Louis ▪ Washington University in St. Louis

ELEVATE YOUR FUTURE.
ELEVATE ST. LOUIS.

This project focuses on improvements to a door cycling system. Both a fortified rope for the pulley system, ensuring extended operation, and the integration of a support track. This track is designed to bolster the clevis linked to an air piston that facilitates smooth piston rod travel without deflection. With these advancements, our door cycling system attains a new level of reliability, durability and functionality.

JME 4110
Mechanical Engineering
Design Project

Upgraded Refrigeration Door Cycling System

Kelvin Woods
Keenan Bland
Tyler Mclaughlin

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2 INTRODUCTION

2.1 VALUE PROPOSITION / PROJECT SUGGESTION

Our enhanced cycling system features a reinforced rope for a seamless pulley operation and an engineered support track for the clevis and air piston mechanism; our upgraded system guarantees effortless and reliable door cycling. Say goodbye to maintenance hassles and hello to lasting performance.

2.2 LIST OF TEAM MEMBERS

Kelvin Woods

Tyler McLaughlin

Keenan Bland

3 BACKGROUND INFORMATION STUDY

3.1 DESIGN BRIEF

Design a new or improve upon the current door cycling station used by Hussman to test their refrigerated cases. The cycling station must be able to work on doors of multiple sizes, open up to 6 doors at once and work for millions of cycles with high precision and speed with low maintenance requirements. Our device will also be removable so the cases can be swapped out when needed.

3.2 BACKGROUND SUMMARY

When conducting background research for similar concepts, we were able to find several video and design examples for door cycling systems. Below are two examples of the designs we observed during research.

Figure 1 below shows an example of an automatic door opening system using an electric motor to spin a reel that is connected to the door handle with a steel cable.

Figure 1 Source

List of Figures

S.-B. Wang, C.-F. Wu / International Journal of Industrial Ergonomics 49 (2015) 1–10

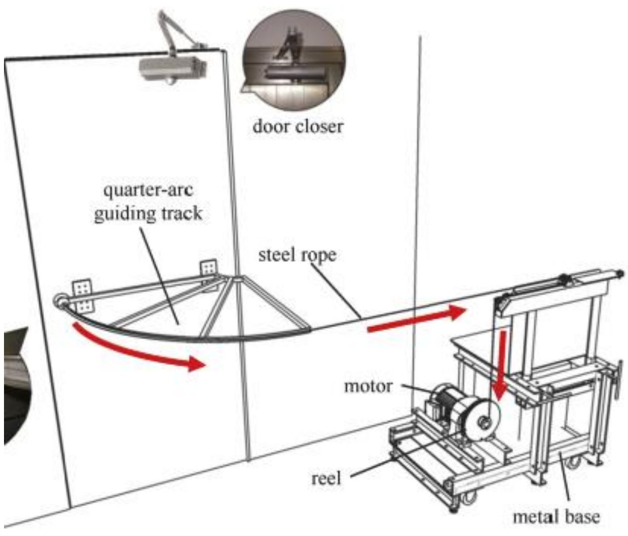


Fig. 5. The schematic diagram for the force measuring system of the hinged door.

Figure 2 below shows a door testing system that uses an air cylinder to repeatedly open and close a door over a small distance.

Figure 2 Source

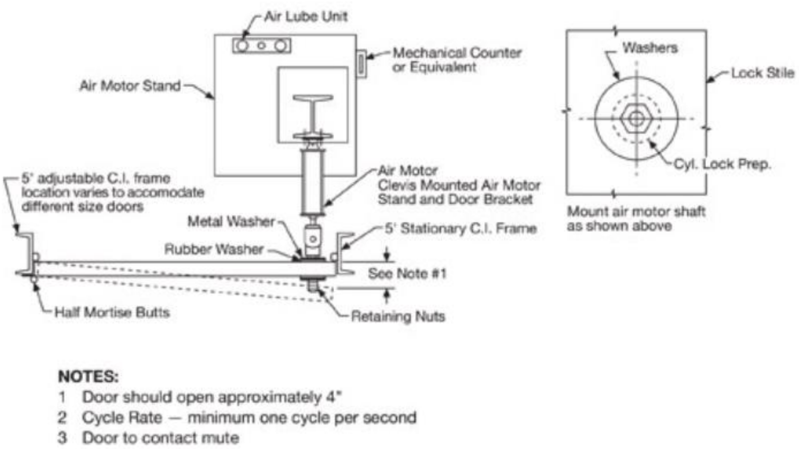


Figure 1 – Cycle Test Detail

4 CONCEPT DESIGN AND SPECIFICATION

4.1 USER NEEDS AND METRICS

4.1.1 Record of the user needs interview

1. Does the cycling system use only continuous cycles or does it include single cycle use?

    a. The Project needs to be able to function for millions of cycles

2. Would you prefer a design update or new design?

    a. Either works, whichever we think is a better option.

3. What are some prior design iterations?

    a. Track under lug and clevis connection
        i. Track used to stabilize and support weight lug and clevis. Deflection occurs when piston rod is fully extended causing the seal on the air cylinder to be damaged do to misalignment
    b. Vertical air cylinders with Pulley System
        i. Matches intended use of the cylinders
4. How important is material cost?

    a. Husman would provide us a budget of around $2,000.

5. Does your cycling test have a cycle speed requirement?

    a. The cycling system needs to be functional and run at around 11,500-12,000 cycles per day

6. Is the door cycling system manually operated or automated?

    a. Automated

7. Are there any weight constraints? (force required to open the door)?

    a. The system needs to open refrigerated doors from about 35 lbs- 85 lbs. This takes about 8-10 lbs of force to break the magnetic seal to open the doors.

8. Are cosmetic blemishes a problem?

    a. You need to update or come up with a new design that doesn't damage the cases. We're trying to see how the door will fail, not cause any other damage to them to make them fail faster which would in fact skew the test results. It needs to work as smoothly as possible.

4.1.2 List of identified metrics

Table 1: Needs Table for Door Cycling System

Need Number	Need	Importance
1	Low Maintenance	5
2	Open Up to 6 doors	5
3	Low Cost	3
4	Work on multiple variations	5
5	Removable	5
6	Millions of Cycles	4
7	Not damage doors	4

Table 2: Metrics Table for Door Cycling System

Metric Number	Associated Needs	Metric	Units	Min Value	Max Value
1	1,2,4, 7	Force to Open Door	lbf	8	10
2	2,4,5	Height of Case	ft	12.5	12.5
3	2,4	Weight of Door	lbs	35	85
4	2,4,5	Number of Doors	Integer	5	6
5	3	Budget	Dollars	0	2,000
6	1,6,7	Cycles per day	Integer	11,500	12,000

4.1.3 Table/list of quantified needs equations

Table 3: Quantified Needs Equations for Concepts

Gear Based Door Opening System		Metric								
		Force to Open Door	Height of Case	Weight of Door	Number of Doors	Cost	Cycles per Day			
Need#	Need	1	2	3	4	5	6	Need Happiness	ht (all entries sh	al Happiness Va
1	Low Maintenance	0.25					0.75	0.94375	0.161	0.15194375
2	Open Up to 6 doors	0.25	0.25	0.25	0.25			0.8303921569	0.161	0.1336931373
3	Low Cost					1		0.5	0.097	0.0485
4	Work on multiple variations	0.25	0.25	0.25	0.25			0.8303921569	0.161	0.1336931373
5	Removable		0.5		0.5			0.9166666667	0.161	0.1475833333
6	Millions of Cycles						1	0.9583333333	0.129	0.123625
7	Not damage doors	0.8					0.2	0.9116666667	0.097	0.08843166667
	Units	lbs	ft	lbs	Integer	Dollars	Integer	Total Happiness		0.8274700245
	Best Value	10	12.5	85	6	0	12000			
	Worst Value	8	12.5	35	5	2000	11500			
	Actual Value	9	12.5	50	5	1000	11500			
	Normalized Metric Happiness	0.9	1	0.5882352941	0.8333333333	0.5	0.9583333333			

Roller Track		Metric								
		Force to Open Door	Height of Case	Weight of Door	Number of Doors	Cost	Cycles per Day			
Need#	Need	1	2	3	4	5	6	Need Happiness	ht (all entries sh	al Happiness Va
1	Low Maintenance	0.25					0.75	0.96875	0.161	0.15596875
2	Open Up to 6 doors	0.25	0.25	0.25	0.25			0.9852941176	0.161	0.1586323529
3	Low Cost					1		0.9	0.097	0.0873
4	Work on multiple variations	0.25	0.25	0.25	0.25			0.9852941176	0.161	0.1586323529
5	Removable		0.5		0.5			1	0.161	0.161
6	Millions of Cycles						1	0.9583333333	0.129	0.123625
7	Not damage doors	0.8					0.2	0.9916666667	0.097	0.09619166667
	Units	lbs	ft	lbs	Integer	Dollars	Integer	Total Happiness		0.9413501225
	Best Value	10	12.5	85	6	0	12000			
	Worst Value	8	12.5	35	5	2000	11500			
	Actual Value	10	12.5	80	6	200	11500			
	Normalized Metric Happiness	1	1	0.9411764706	1	0.9	0.9583333333			

Pistion lever		Metric								
		Force to Open Door	Height of Case	Weight of Door	Number of Doors	Cost	Cycles per Day			
Need#	Need	1	2	3	4	5	6	Need Happiness	ht (all entries sh	al Happiness Va
1	Low Maintenance	0.25					0.75	0.91875	0.161	0.14791875
2	Open Up to 6 doors	0.25	0.25	0.25	0.25			0.9352941176	0.161	0.1505823529
3	Low Cost					1		0.75	0.097	0.07275
4	Work on multiple variations	0.25	0.25	0.25	0.25			0.9352941176	0.161	0.1505823529
5	Removable		0.5		0.5			1	0.161	0.161
6	Millions of Cycles						1	0.9583333333	0.129	0.123625
7	Not damage doors	0.8					0.2	0.8316666667	0.097	0.08067166667
	Units	lbs	ft	lbs	Integer	Dollars	Integer	Total Happiness		0.8871301225
	Best Value	10	12.5	85	6	0	12000			
	Worst Value	8	12.5	35	5	2000	11500			
	Actual Value	8	12.5	80	6	500	11500			
	Normalized Metric Happiness	0.8	1	0.9411764706	1	0.75	0.9583333333			

Electromagnet		Metric								
		Force to Open Door	Height of Case	Weight of Door	Number of Doors	Cost	Cycles per Day			
Need#	Need	1	2	3	4	5	6	Need Happiness	ht (all entries sh	al Happiness Va
1	Low Maintenance	0.25					0.75	0.984375	0.161	0.158484375
2	Open Up to 6 doors	0.25	0.25	0.25	0.25			0.9852941176	0.161	0.1586323529
3	Low Cost					1		0.25	0.097	0.02425
4	Work on multiple variations	0.25	0.25	0.25	0.25			0.9852941176	0.161	0.1586323529
5	Removable		0.5		0.5			1	0.161	0.161
6	Millions of Cycles						1	0.9791666667	0.129	0.1263125
7	Not damage doors	0.8					0.2	0.9958333333	0.097	0.09659583333
	Units	lbs	ft	lbs	Integer	Dollars	Integer	Total Happiness		0.8839074142
	Best Value	10	12.5	85	6	0	12000			
	Worst Value	8	12.5	35	5	2000	11500			
	Actual Value	10	12.5	80	6	1500	11750			
	Normalized Metric Happiness	1	1	0.9411764706	1	0.25	0.9791666667			

4.2

4.3 CONCEPT DRAWINGS

Figure 3: Concept 1 Drawing

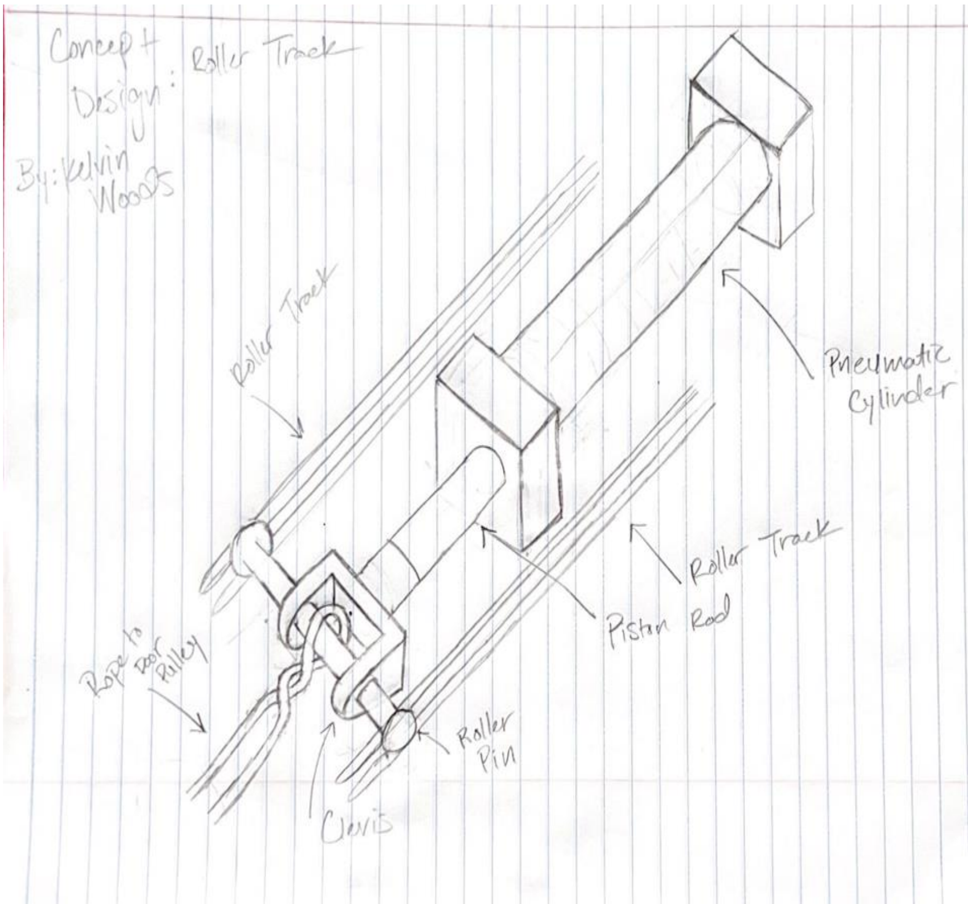


Figure 4: Concept 1 Parts Drawing

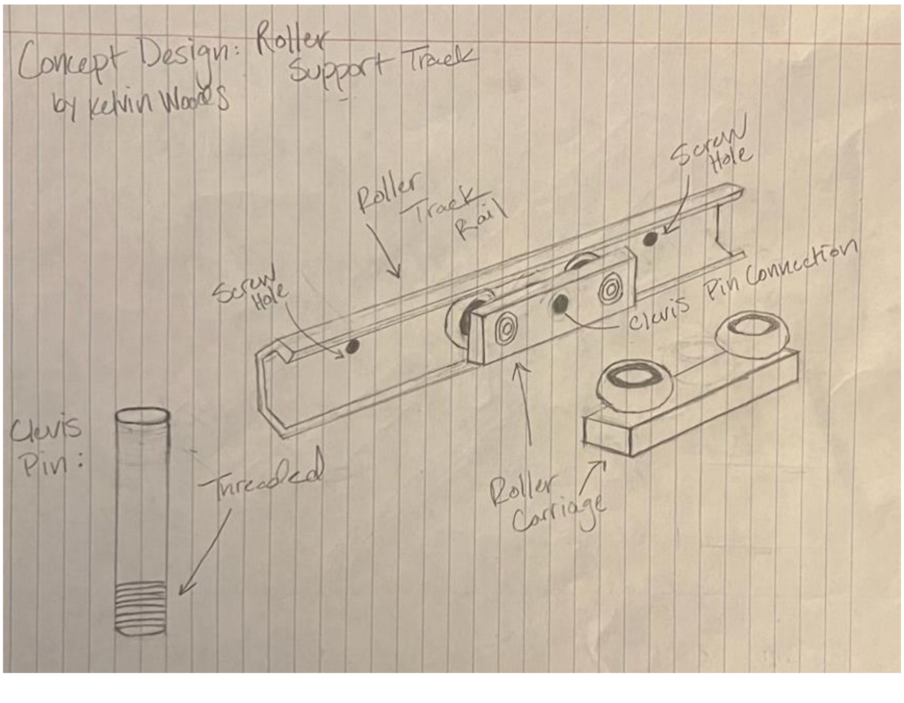


Figure 5: Concept 2 Drawing

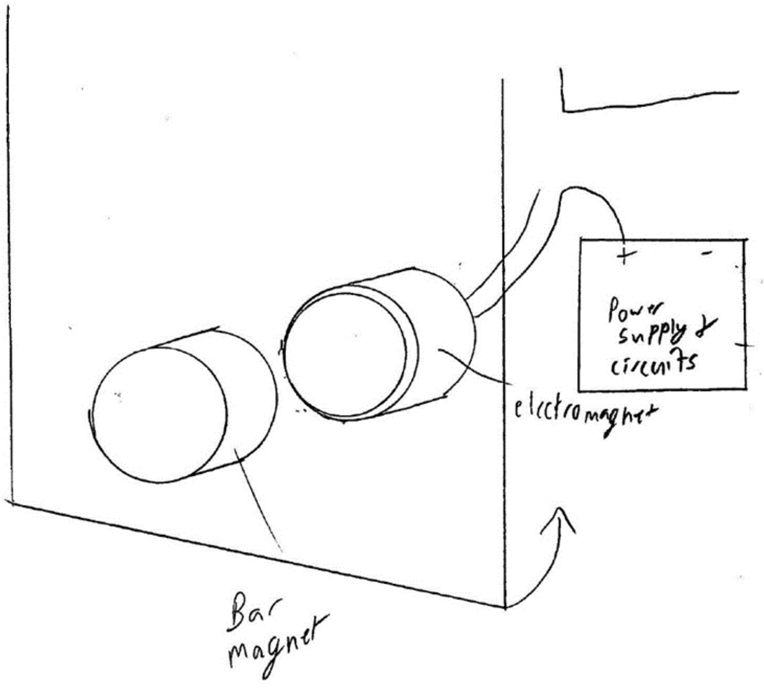


Figure 6: Concept 3 Drawing

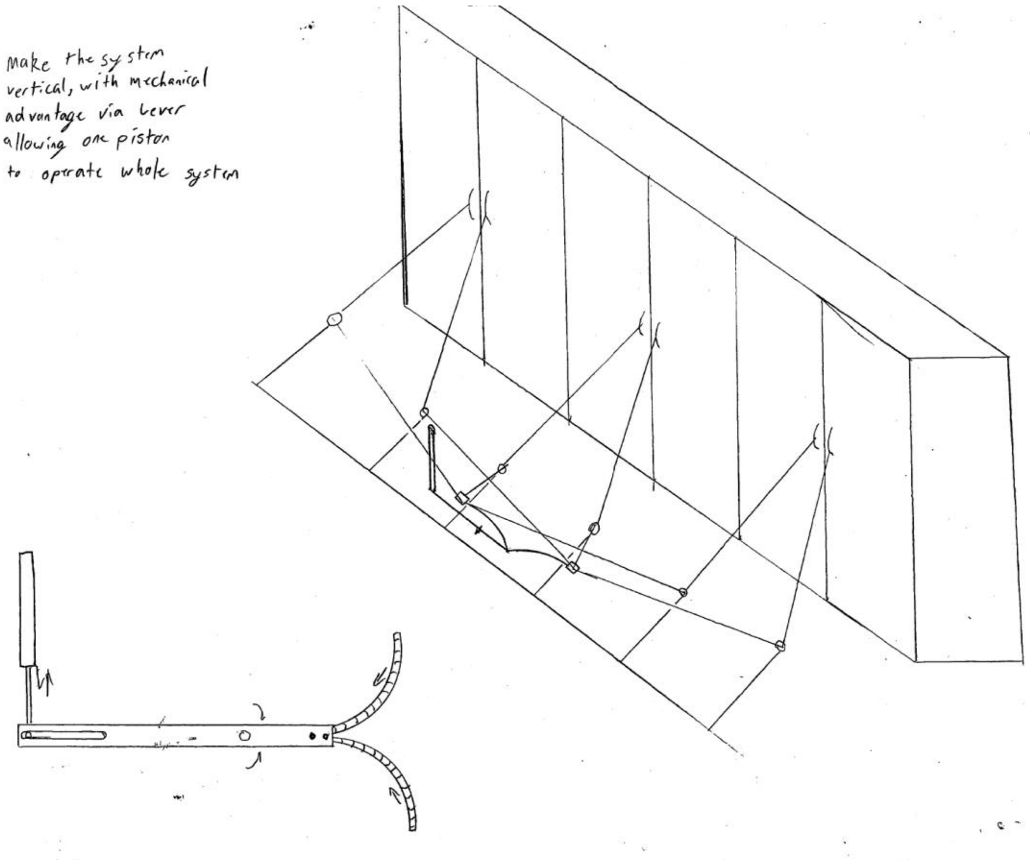
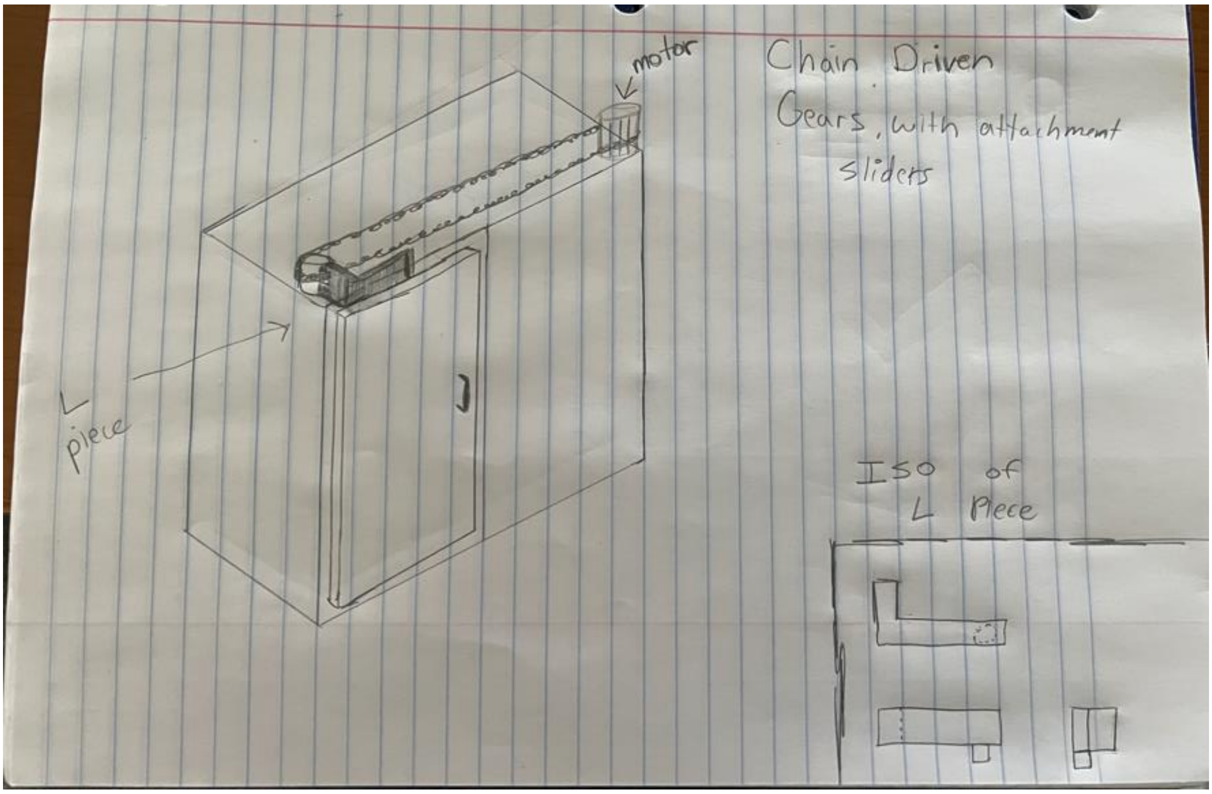


Figure 7: Concept 4 Drawing



4.4 A CONCEPT SELECTION PROCESS.

4.4.1 Concept scoring

Table 4: Happiness Values of Concepts

Concept	Happiness Value
Magnetic Actuator	0.8839
Roller Track	0.9413
Gear Based System	0.82747
Piston Lever System	0.8871

4.4.2 Preliminary analysis of each concept’s physical feasibility

Magnetic Actuator: Using an electro-magnet and a fixed bar magnet, the electromagnet is charged creating a force on the door opening the door. This can be combined with multiple sets of electromagnet and a central power supply to be able to open up to the needed doors and with switches and timing the doors can be opened continuously.

Roller Track: Requires fabrication of new pin for the clevis that allows roller track capabilities. Nothing extraordinary to function. Based on the support track, the system will support removing deflection from the piston rod.

Gear Based System: This method may damage the cases depending on how they are mounted at the top. We would have to use chains and not rope or a belt because it would last longer and is stronger. The existing system already uses gears which may also cause some parts on the case to fail, like the L piece rubbing against the top of the case.

Piston Lever System: By changing the system's current setup to one where the piston is pushing down or up on a rotating lever arm with a slide/roller there would be enough mechanical advantage to open the doors with one piston.

4.4.3 Final summary statement

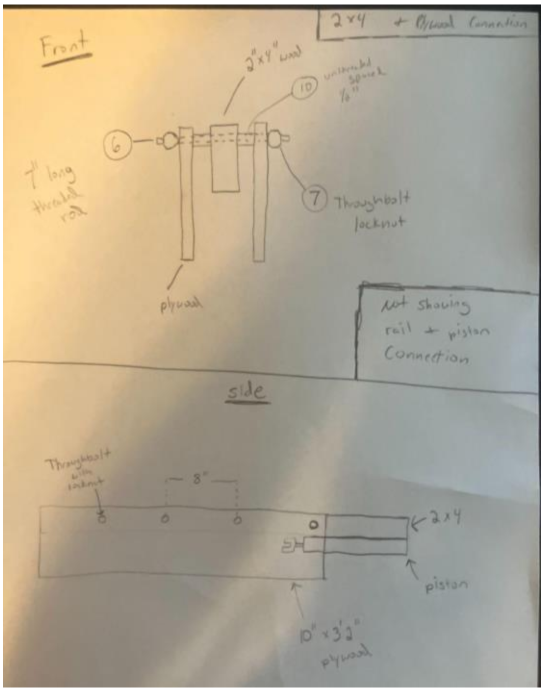
Our winning design after the concept selection process is the roller track design. This design will be very easy to integrate with the existing system. Out of all the other design ideas it received the highest happiness value. Due to the nature of the design being an add on to the current system, it will be a cheap option and is projected to be well below our budget. The track design doesn’t require analysis of a new system working off the proven existing design. The biggest problem Hussmann faced was parts breaking and the maintenance cost. With these material improvements, it will lessen the maintenance cost and keep other parts from breaking.

4.5 PROPOSED PERFORMANCE MEASURES FOR THE DESIGN

The most important metric for our design is Cycles per Day. Due to the support rail decreasing the maintenance required upon the system, we must ensure that we are not negatively impacting the performance.

5 EMBODIMENT AND FABRICATION PLAN

5.1 INITIAL EMBODIMENT/ASSEMBLY DRAWING



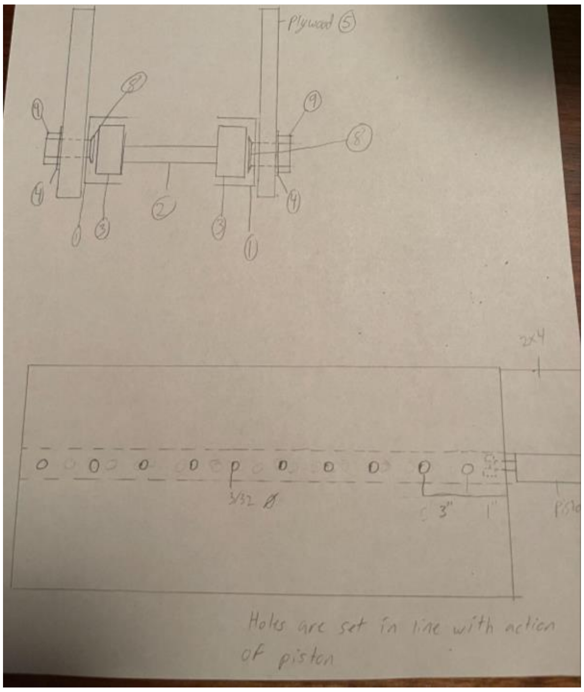


Figure 8&9: Partial Embodiment and Assembly Drawings

5.2 PARTS LIST

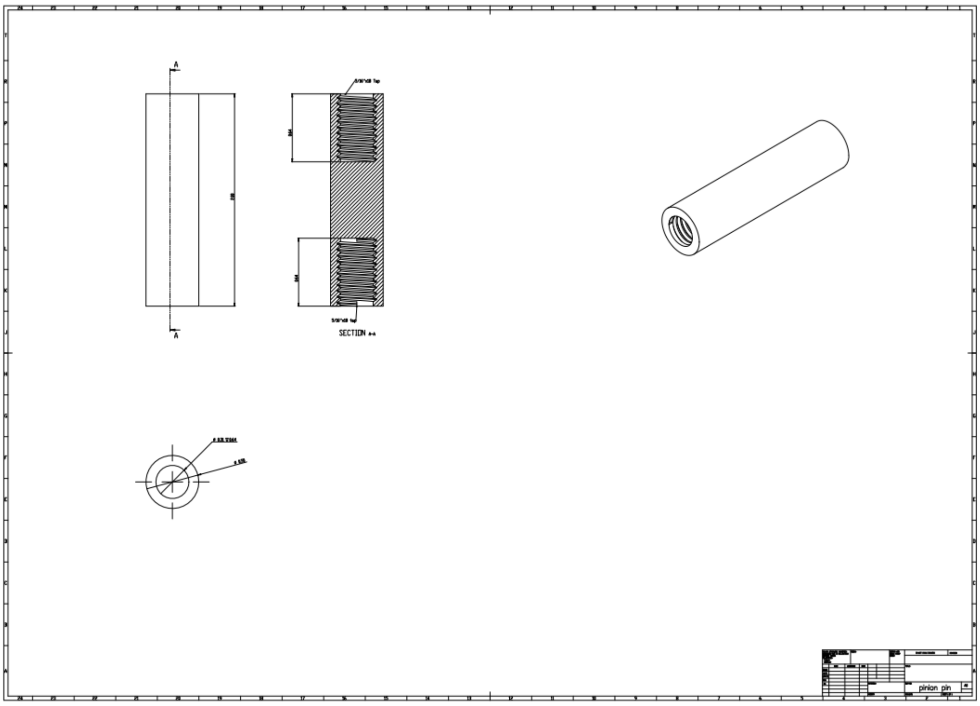
Table 5: Parts List

No.	Item Description	Unit	Qty.	Material
1	Guide Rail	60135K13-60135K22	4	Zinc-Plated Steel
2	Clevis Pin	Fabricated	2	Stainless Steel
3	Roller Wheels	60135K71	4	steel
4	Washers(100 pack)	90107A003	1	316 Stainless Steel
5	1/2" x 2' x 4' Plywood	1125T611	2	Varies
6	1/2" 7" Long Threaded Rod	92580A344/	8	Black oxide steel
7	Throughbolt lock nut (50 pack)	95615A210	1	Steel
8	3/4" long Screw (100 pack)	91772A084	1	18-8 Stainless Steel
9	Rail Lock Nut 2-56 (100 pack)	90631A003	1	Zinc-Plated Steel

10	1/2" unthreaded Spacer	6389K119	16	LDPE Plastic

5.3 DRAFT DETAIL DRAWINGS FOR EACH MANUFACTURED PART

Figure 10: Clevis pin



5.4 DESCRIPTION OF THE DESIGN RATIONALE

The dimensions of the clevis pin's diameter and length were constrained by the existing clevis. The tapped screw size and depth were constrained by the wheels that will be inserted into them. The bolt lengths were sized to be 1.5 times the length of the thickness of the material being fastened. The guide rail length was sized to fully span the piston rod displacement area.

6 ENGINEERING ANALYSIS

6.1 ENGINEERING ANALYSIS PROPOSAL

6.1.1 Signed engineering analysis contract

MEMS 411 / JME 4110
MECHANICAL ENGINEERING DESIGN PROJECT

ASSIGNMENT 5: Engineering analysis task agreement (2%)

ANALYSIS TASKS AGREEMENT

PROJECT: **Hussmann Door Cycling Machine**
NAMES: Keenan Bland , Kelvin Woods, Tyler McLaughlin
INSTRUCTOR: Professor Jakeila
Professor Giesmann

The following engineering analysis tasks will be performed:

Pre Analysis: analysis of the design before construction using moment, static and dynamic equations to describe the motion of the piston and carriage throughout the range of motion

After Analysis: analysis of the rail system to ensure that enough support is given to the piston so that there is no bending.

Analysis of the clevis pin to ensure that with prolonged use that the threads do not unscrew

The work will be divided among the group members in the following way:

Tyler McLaughlin-Pre Analysis
Kelvin Woods : Post Analysis
Keenan Band : Post Analysis

Mark Jakiela

Instructor signature: ____________; Print instructor name: _Craig J. Giesmann______

(Group members should initial near their name above.)

6.2 ENGINEERING ANALYSIS RESULTS

6.2.1 Motivation

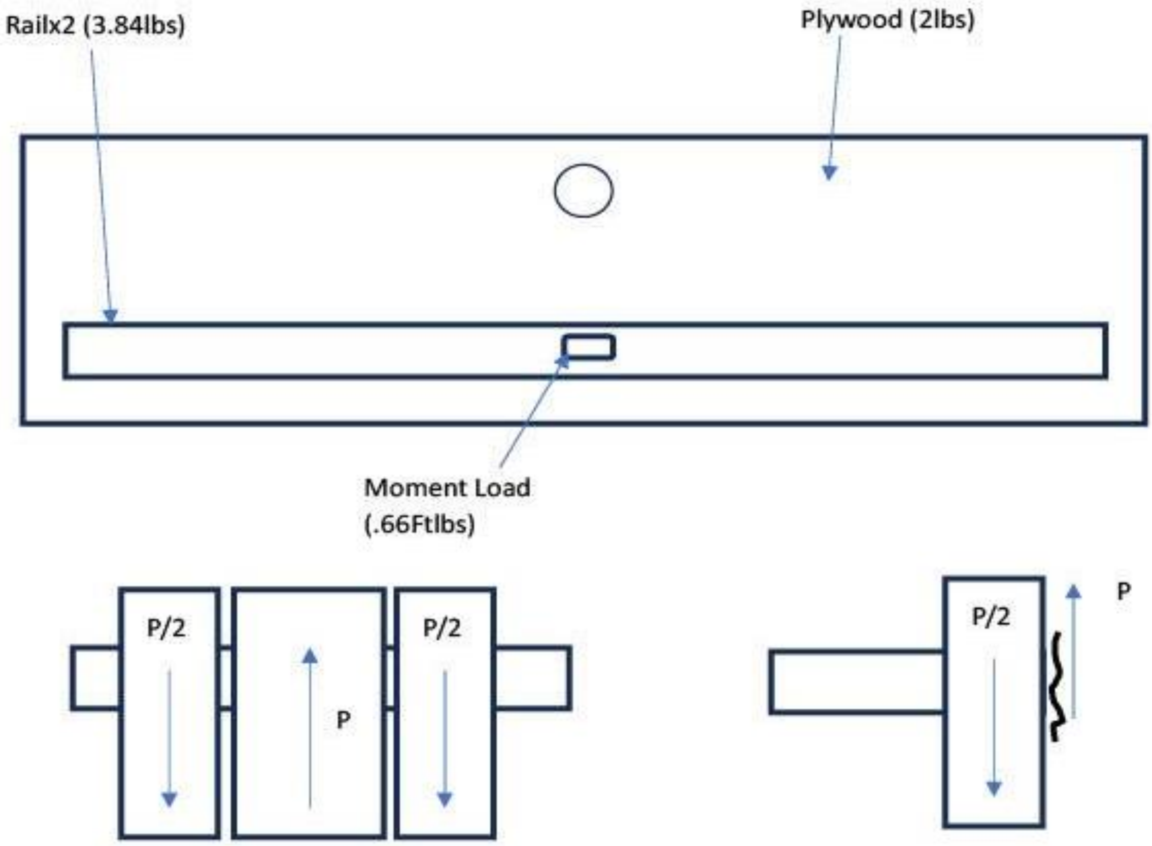
We are improving the current door cycling machine at Hussmann. The current system they have set up is a horizontal piston attached to some ropes connected to 2-3 doors. Over time, the piston seal gets worn and the piston rod begins to deflect down at clevis connection when fully extended. This can lead to the piston's seal becoming broken and defunct. We have come up with a rail and roller wheel design to keep the rod aligned with the piston preventing it from being damaged. To ensure this method is feasible, we must look at the moment arm at the end of the piston cylinder. This will provide information for if the guide rail is capable of holding the clevis and keep it from deflecting.

6.2.2 Summary statement of analysis done

6.2.3 Figure 11: Load Analysis on Structural Bolt

Project: Hussman Door	Max Load on Structural Bolts

Find the maximum load on structural bolts to fasten apparatus to main wooden strut. It is assumed that all weight and forces acting on the bolt will be vertical. Maximum load will aid in determining minimum bold diameter to resist existing shear stresses.



Total force acting on double shear of bolt:

Diameter proposes = .5 in

Force = 2x Rail +Moment Load+ 2x Plywood = 3.84 lbs x2+.66 lbs +2lbs x2= 12.34lbs

Shear on a bolt= $\tau=(2P)/(\pi d^2) \Rightarrow 2(12.34lbs/2)/(\pi .5^2)=15.72$ lb/ft^2

Expected load is well below maximum load before plastic deformation at 12100lb/ft^2

Conclusion: one bolt will provide enough resistance to support the weight and force of materials, at least 2 bolts recommended to prevent rotation or misalignment.

6.2.4

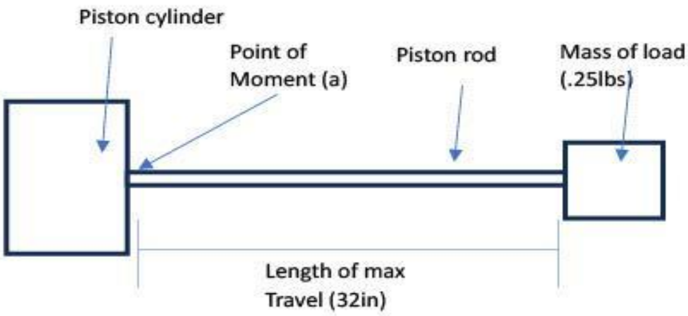
6.2.5

6.2.6

6.2.7 Figure 12: Moment Analysis of Piston Rod

Project: Hussman Door	Moment of Piston Rod

Design reinforcement for deflection in piston rod. It is assumed that the rod itself does not experience deflection and that all deflection occurs at the point of the piston cylinder, all forces experienced on the piston rod are experienced at the furthest point and are a point mass.



Given:

Moment= Force(F) * Length(L)

Length = 32in/12in (1ft)= 2667 ft

Moment =0.25lbs *2.667 ft

Load at max travel =.667 lbs

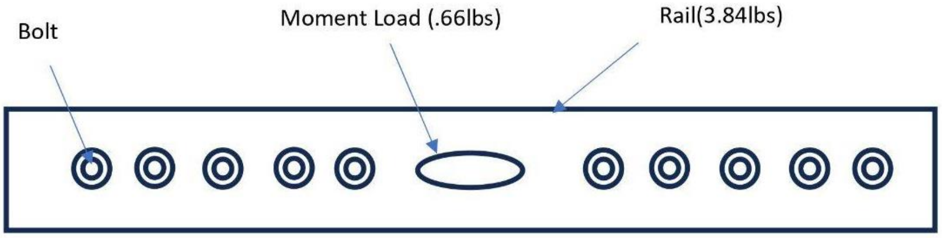
6.2.8

Figure 13: Analysis of Load on Rail Bolts

Project: Hussman Door	|Load on Rail bolts
	|

Design number and thickness requirements for bolts that will be supporting the rails to the plywood.

Assuming even distribution of load across all bolts at



Given:

Force= Moment Load + Rail weight= .66+3.84=4.50lbs

Force on each bolt= Force /10 = .45lbs each

Conclusion: One bolt is able to withstand shear of over 400lbs of force, we do not need to use more than two for alignment purposes, though a recommended amount of 5 or 7 would give the structure more uniformity and better control of alignment.

6.2.9 Methodology

The analysis was a moment analysis and load calculations that were required to calculate the size of bolts needed for our connections.

6.2.10 Results

The results of the analysis study showed that the size bolts that were originally sized for the apparatus were magnitudes of scale larger for the load that they would be enduring. It also showed that there were less bolts needed than originally predicted.

6.2.11 Significance

7 THE SIZE OF BOLTS THAT WERE PICKED OUT ORIGINALLY FOR THE RAIL TO PLYWOOD CONNECTION WAS LARGER THAN NEEDED AND WAS ORIGINALLY TOO NUMEROUS, ALLOWING FOR SMALLER AND FEWER BOLTS TO BE USED. THE LARGER PLYWOOD TO WOOD TO PLYWOOD CONNECTING BOLTS WERE FOUND TO HAVE FAR MORE STRUCTURAL INTEGRITY THAN WHAT WAS NEEDED, WE STILL CHOOSE TO USE 3 BOLTS FOR THE FINAL DESIGN TO ALLOW FOR EASE OF ADJUSTMENTS TO THE ANGLE OF THE RAIL TO KEEP BOTH OF THEM PARALLEL WITH EACH OTHER. THE

ANALYZED MOMENT SHOWS THAT THE GUIDE RAIL WAS MORE THAN CAPABLE OF SUPPORTING THE EXPERIENCED LOAD.

8 RISK ASSESSMENT

Table 6: Risk Assessment

Risk Management Register

0	Open Red Risks
0	Open Yellow Risks
0	Open Green Risks
0	Risks w/ no Response Strategy
0	Closed risks

Project Name: Hussman Door Cycling System
Project Manager: Kelvin Woods
Start Date: 6/28/2023

Overall Project Ri

Item	Project/ Phase	Risk Status	Risk	Potential Impact (Cause and Effect)	Risk Response Strategy	Triggers (Indicators that the risk will occur)	Estimated Schedule Impact (Days)
1	1	Accepted	Parts being on back order/ Not arriving on time.	Project Scope delayed	Get parts approved and ordered as soon as possible. Have backup options available.	The price goes up on a certain part. Shows a low number in inventory left.	7
2	1	Accepted	Sponsor is on vacation/ leave.	Project may be delayed.	Ask sponsor for another contact at company to ensure no change to project scope	Sponsor lets us know in advance.	7
3	1	Accepted	Teamate goes on vacation	Project can be delayed	Have daily/ weekly meetings to make sure we are all on schedule.	Teammate lets us know in advance.	7
4	1	Accepted	Prototype breaks during testing.	Possibly need to order new parts, delayed project.	Have backup parts or backup design/ strategy.	We notice the design not operating as planned. Missing certain parts.	7
5	1	Accepted	Power Outtage	Project Automation is disrupted	Contact Sponsor to check system status	Bad weather broadcasted. Stormy season	1
6							

Location: 12999 Saint Charles Rock Rd
Add'l Info:
Updated On: 31-Jul-23
Overall Project Risk Indicator: 1

Risk Level

Probability					
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5
Impact	1	2	3	4	5

Legend:

Impact
1 - Negligible
2 - Marginal
3 - Significant
4 - Critical
5 - Catastrophic

Probability
1 - Rare
2 - Unlikely
3 - Possible
4 - Likely
5 - Certain

Estimated Schedule Impact (Days)	Maximum Exposure ($000)	Estimated Exposure (Contingency) ($000) $13	Risk Category	Risk Sub Category	Action Owner	Start Exposure	End Exposure	Baseline Risk Scoring: Impact: Tech Perf	Schedule	Cost	Safety	Probability	Risk Ranking
7	$50	$0	Technology	Technology Maturity	Tyler	07/31/23	07/07/23	1	1	3	1	2	6
7	$0	$0	Operational Impact	O&M Support Needed	Keenan/ Kelvin	07/17/23	07/21/23	4	2	1	1	3	12
7	$0	$0	Operational Impact	Operational Flexibility	All	07/20/23	07/24/23	3	2	1	1	2	6
7	$500	$13	Construction	Layout and Constructability	Keenan/ Kelvin	08/02/23	08/14/23	5	4	4	1	3	15
1	$0	$0	Technology	Fuel Flexibility and Impacts	All	07/31/23	8/14/23	5	4	1	1	2	10

8.1 RISK IDENTIFICATION

Our group came together and discussed potential risks to our project. In addition to risks that had already occurred in the planning stages of our project, we came up with risks that could affect our future project scope.

Identified Risks:

Parts being on back order/ Not arriving on time.

Sponsor is on vacation/ leave.

Teammate goes on vacation

Prototype breaks during testing.

Power Surge/ Outage

8.2 RISK ANALYSIS

Some of these risks can be more significant than others during this project. The risk with the highest impact on the team was the prototype breaking during testing. The class was already on a tight schedule with it being during the summer, so there definitely was a time constraint. The parts list does come with some extra parts but if all the plywood gets broken, or the system doesn't function properly as proposed, then there would have to be a design change. This would cause a project delay and possibly even have to order new parts.

The sponsor being on leave was the next highest risk. The sponsor was scheduled to go on vacation for a week in July and that's accepted. This could slow the project down and delay it but at least it's scheduled. If group members have questions about the project or want to come into work, it may be difficult. Luckily during the initial visit, a second connection was present who had also gone through the same engineering program as the students and was to be a backup contact person.

A power outage risk was also in play during the project timing. Around the midwest area in Missouri, it was about to begin the rainy season. To do the research and collaborate on different parts of the project, you would need internet access. Another possible effect the power outage might have was disrupting the run time of the automated system. With our most important metric being cycles per day a power outage could cause our testing phase to be derailed. Heavy winds and heavy rain was present during this project and luckily when the power did go out it only did for less than 8 hours. At least it's less than a day but the risk of this happening could cause the project to be delayed.

The last two risks were tied for last place. Parts being on backorder was not much of a concern considering the parts are usually delivered the next day. Plus if they didn't have a specific part, a new one that is very similar could be found and used using McMaster-Carr. A teammate going on vacation was also not such a high risk considering they all have tasks that are needed to be completed. When our member was absent, they still were able to complete all assigned tasks. For both risks, the response strategy is that the project can be delayed.

8.3 RISK PRIORITIZATION

The group filled out a risk management register and was used to prioritize the different possible risks. The prototype breaking during testing was the highest concern for the group. Only having 3 days to build and troubleshoot, time was running out. Problems did occur during the building process, but with great engineering, they were passed. Time management was a big part of the construction process. The first day of building was used to analyze parts and get wood cut. The next day was used for rail and plywood connection. Some issues with the design were noticed but they were improved with great speed. The final day was used for assembly and completion of the project. Adaptation had to be used during assembly since it was the first of this design. The design started out rough but with small adjustments, it began to run very smoothly. The other risks were neglectable since they were or could have been inevitable, but were not a major impact on the project.

9 CODES AND STANDARDS

9.1 IDENTIFICATION

We identified two standards that applied to our project requirements

- ASHRAE 72
- ISO 23953

9.2 JUSTIFICATION

We chose these standards to examine for our upgraded door cycling system. Our design is used to test the refrigerator doors capabilities. A good place to start is ASHRAE 72 which is made just for that. This standard tells us about the requirements for an open and closed refrigerator door. It says products should be removed by doors or panels and the system is attached to ropes pulling on the door handles.

ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) Standard 72 provides guidelines for the testing and rating of commercial refrigerated display cases. It specifies methods for determining factors such as energy consumption, display area, and product temperature performance.

ISO 23953 is an international standard titled "Refrigerated storage cabinets and counters for professional use - Classification, requirements, and test conditions." It provides guidelines for the classification, performance requirements, and testing of refrigerated storage cabinets and counters used in professional applications.

9.3 DESIGN CONSTRAINTS

9.3.1 Manufacturing

Originally, the team agreed to use two symmetrical pieces of plywood to bolt to the existing 2x4. However, the existing pulley system required that a notch be cut into the plywood on the interior side.

9.3.2 Timing

The threaded rod that we planned to use was on backorder until one month after our project deadline.

9.3.3 Economic

Our team was given a budget from Husmann of $2,000. This budget allowed us to comfortably source parts for our project.

9.3.4 Life cycle

The current cycling system used by Husmann was able to run at a minimum 11,500 cycles a day. Our project was required to at least maintain this number of cycles, while improving the system reliability

9.4 SIGNIFICANCE

The most impactful constraints on our design were the back ordered part and the existing obstruction on the pulley system. Our Sponsor at Husmann was able to source a similar threaded rod that was used in our bolting connection only setting us back one day of build time. The existing obstruction forced us to design a notch cut in one side of our plywood. This problem was remedied quickly as we were able to get our plywood cut on site.

10 WORKING PROTOTYPE

10.1 PROTOTYPE PHOTOS

Figure 14 is an image of the whole system and the refrigerated case being tested. Our design is made to open 3-4 doors. This design can be replicated and mounted on the other end of the center beam to control the 3 right opening doors. The goal of this system was to give the piston clevis a smooth path and resist the downward force on the extended piston rod. With this design, the upgraded piston clevis pin gives the clevis a smooth ride to pull the doors smoothly. The ropes have a clear path as well.

Figure 14: Prototype Assembly

Figure 15 below shows an overhead view of our final track design. A track is bolted to plywood on each side of the center beam. They are then connected to the center beam with 2 steel rods. The tracks are mounted at a certain distance apart in order for the clevis pin with roller wheels to ride smoothly through them. The plywood is connected to the center beam with spacers, washers and locknuts to keep the track from moving.

Figure 15: Prototype Overview

10.2 WORKING PROTOTYPE VIDEO

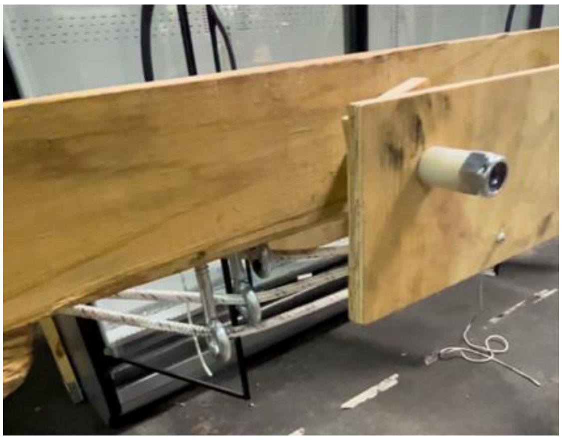
https://www.youtube.com/watch?v=tmJcm_fGU5Q

Door Cycling System Prototype

10.3 PROTOTYPE COMPONENTS

In figure 16 you can 3 screw eyes. We noticed that we needed to incorporate these in the construction stage. These holes give the rope a path to travel through in order to keep them from rubbing against the plywood on our system. We used 3 for the 3 different ropes being used to open the 3 doors. We staggered these screw eyes to keep the rope from running into each other and other wood.

Figure 16: Eye hole Component

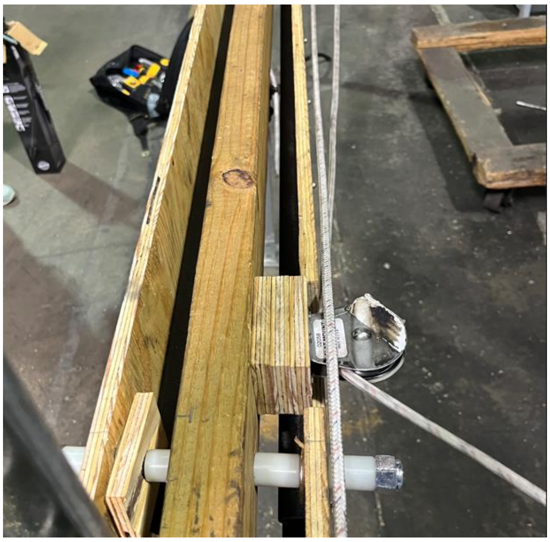


Shown below in figure 17, you can see a couple of the pulley systems that the different ropes feed through. The far right one leads to the closest, left opening door. The middle one leads to another pulley mounted next to the roller track which then connects to the second in line left opening door. The left one leads to a pulley further down the line of the center beam then to the last left opening door. Notice how they are staggered to keep the rope from touching and give them a clear path.

Figure 17: Staggered Pulleys

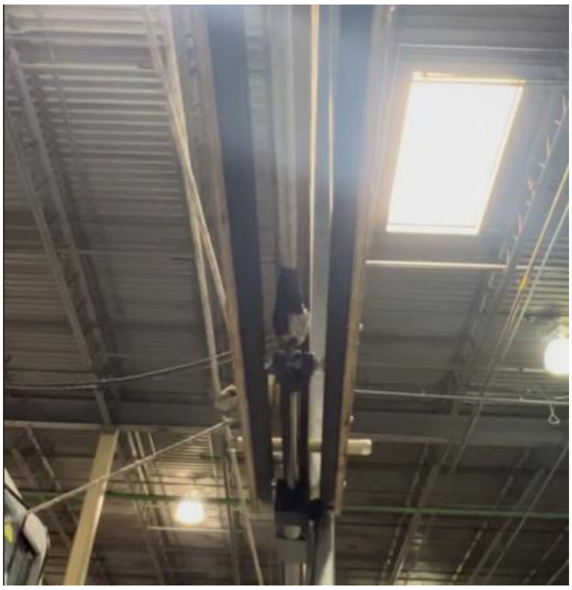
Figure 18 shows an overhead view of the track system. As you can see there is a pulley mounted in line with our design on the center beam. This pulley needed to be spaced away so the rope feeding through it, wouldn't rub up against the plywood which can lead to breakage. We even cut out a little opening on the plywood to add in some room some spacer blocks to mount onto. The rope going through this pulley then heads to the second door this system is testing.

Figure 18



Lastly in figure 19, we can see the bottom of the track roller system. You can see the piston rod extended out a couple of inches on the roller track. The track extends a couple of inches past the fully extended piston rod, so the clevis is fully secure. The clevis pin is threaded on both sides so roller wheels could be attached to them. The rope we used was new and tied together and connected to a hook used to clip onto our clevis pin.

Figure 19



11 DESIGN DOCUMENTATION

11.1 FINAL DRAWINGS AND DOCUMENTATION

11.1.1 Engineering Drawings

See Appendix C for the individual CAD models.

Figure 20- Isometric Drawing of Final Design

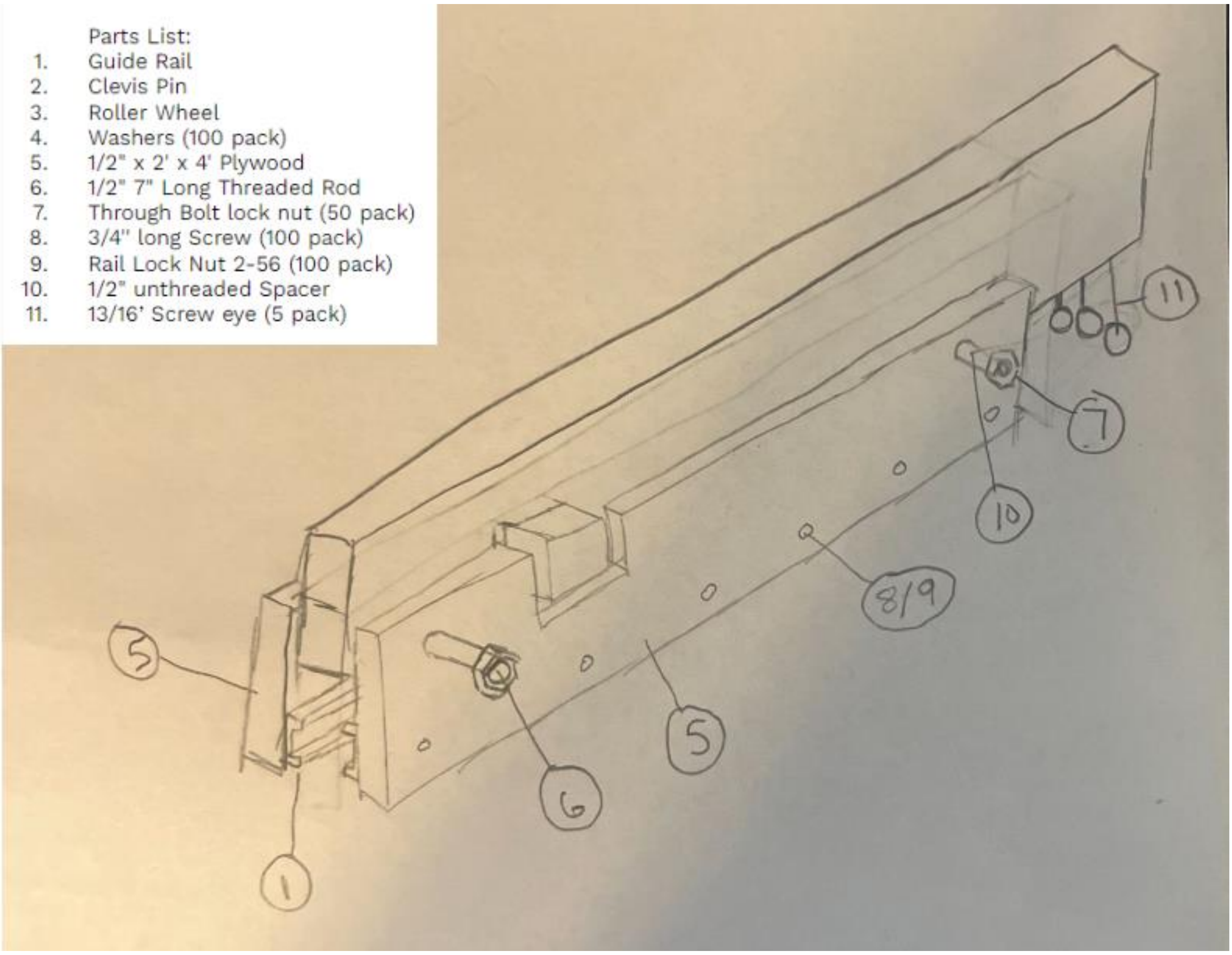


Figure 21: Clevis Pin

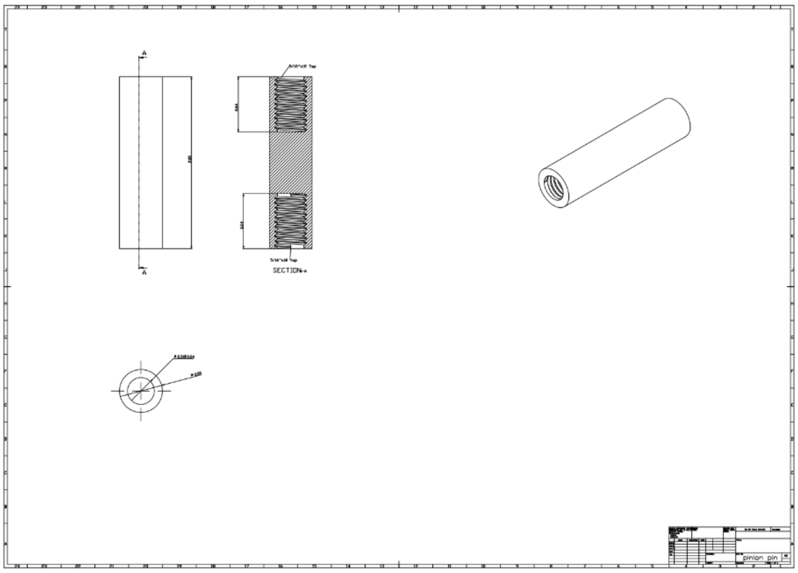


Figure 22: Guide Rail

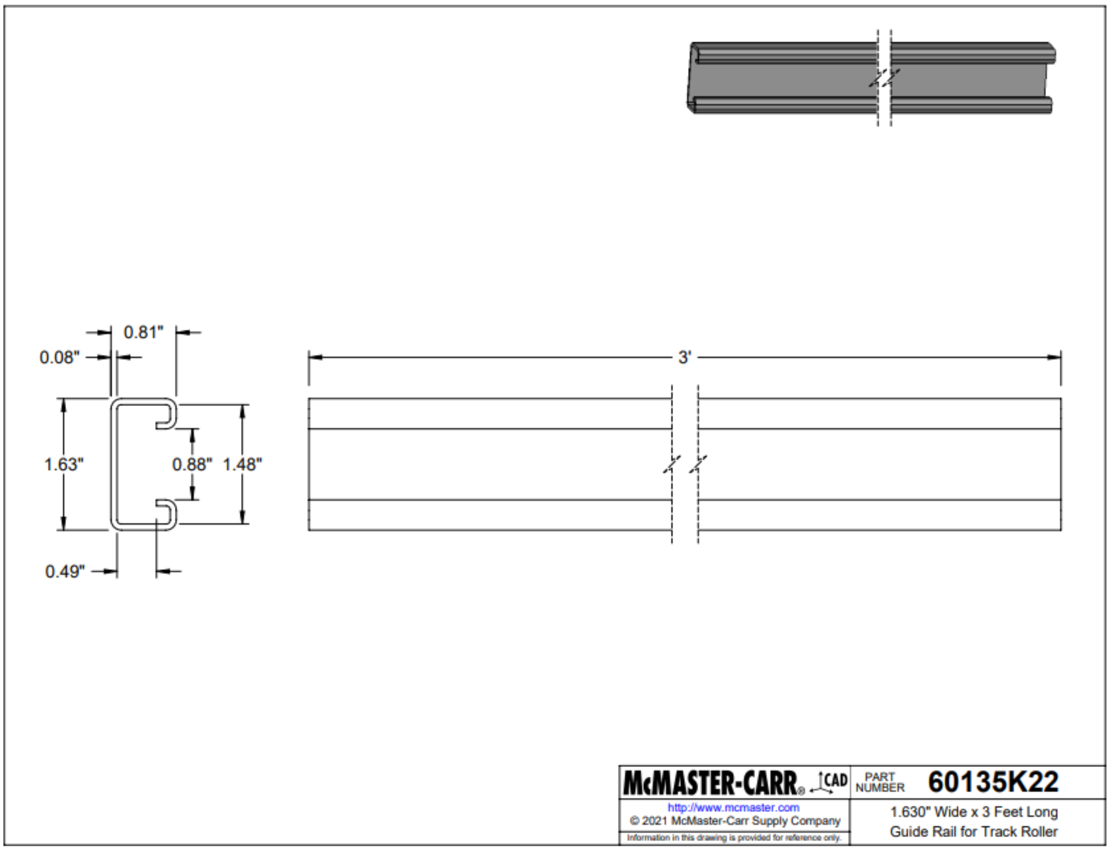


Figure 23: Track Roller

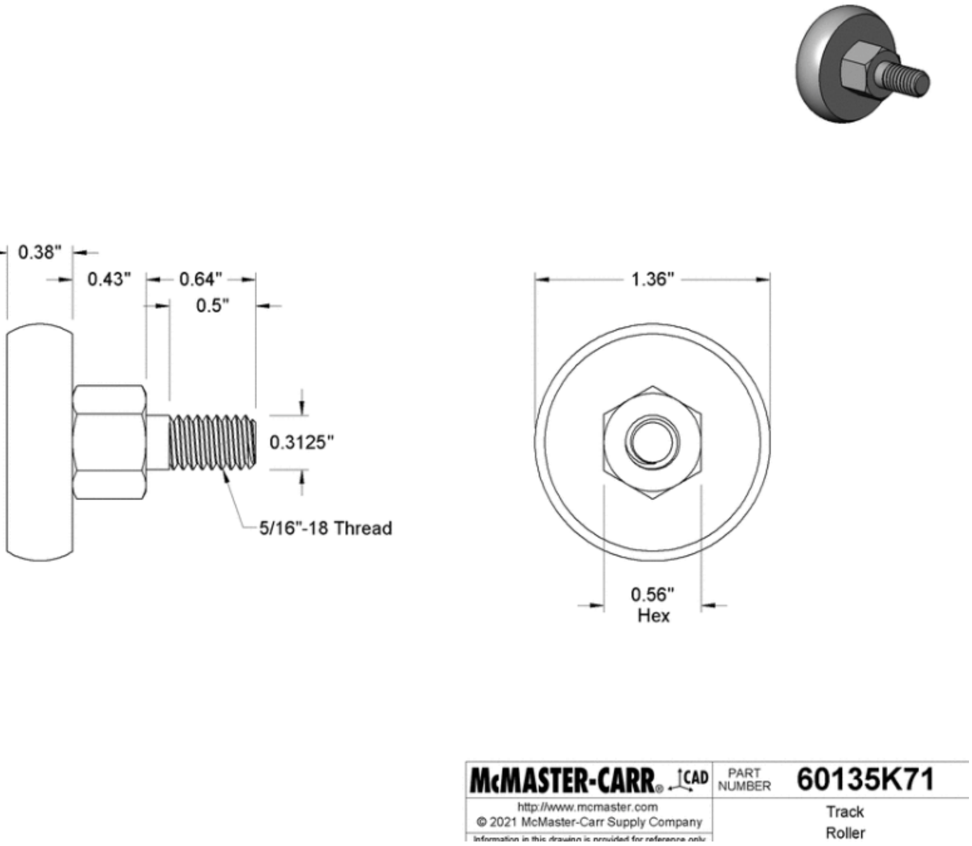
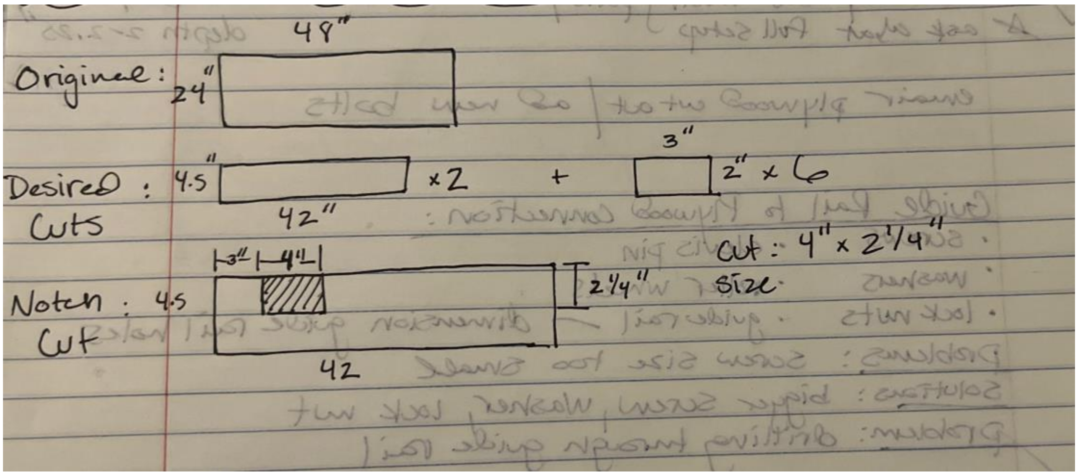


Figure 24: Cut Dimensions for Plywood



11.1.2 Sourcing instructions

Some 3 foot guild rails are needed for our system to function. We need long enough rails for the pin roller to glide through to prevent the piston pin from deflecting.

McmasterCarr has some ideal ones for us to use at the link listed. We would need 4 for a full system but we only used 2 for our half system. One will cost about $99.54.
60135K13-60135K22

We fabricated 2 clevis pins to hold our roller wheels. This pin was needed to be 2 inches in length with a diameter of .5 inches with threaded screws on either side to mount the wheels to. While fabricating the part would be best to reduce wear and need for replacement another option would be to have a threaded fastener that fits the wheels and is the length between them. We were unable to source a part that matches this description however it should exist.

The roller wheels will be screwed into each end of the clevis pin. These will glide through the guide rails allowing the clevis to have a clear path. Our half system uses 2 of these and they go for about $33.80.These can be found on McMasterCarr
60135K71

This fist set of washers are 0.09”. They will be used to hold in the bolt for the guide rail and plywood connection. This comes in a pack of 100 which costs about $2.73. These are also on McMasterCarr
90107A003

The plywood we found on McMastercarr was ½” x 2’ x 4’. Two boards of these are good enough for the design and will need to be cut accordingly to hang on the sides of the centerbeam to hold the guild rail. The material varies and 1 board goes for $20.90.
1125T611

To hang the plywood up to the centerbeam, it will use 8 , ½”x7” long threaded rods. Our half system will use less and with the factor safety for these rods, 2 will be enough for holding up the system accordingly. McMasterCarr has these for about $7.34 each.
92580A344/

These through bolt lock nuts will secure the threaded rod in place. This will keep the plywood from slipping off or moving while connected to the threaded rod. McMasterCarr has a pack of 50 for $7.08.
95615A210

In order to fasten the guid rail to the plywood, we used some ¾” long screws. We used these since the head of the screw was small enough for the roller wheels to slide by them in the roller track. We drilled multiple holes in the guide rail for these screws to be inserted. McMasterCarr has a pack of 100 for $3.72.
91772A084

The Rail Lock Nuts are used to secure the ¾ in long screws from loosening from the plywood and repeated rail use. This will allow the track to be used without worrying about the track wobbling or shifting.
McMasterCarr has them in a pack of 100 for $5.09
90631A003

The ½ in unthreaded spacers were used to space the plywood away from the 2x4 allowing the wheels and track to be housed while attached to the clevis pin. We choose the LDPE Plastic version of these due to them being the proper size as well as to save on cost.
McMaterCarr has them individually for $1.49
6389K119

The ropes needed a clear unobstructed path to travel. We needed to keep them away from rubbing against plywood or any other objects that may fray or damage the rope. Some eye screws from McMAsterCarr helped to do the trick. They were placed on the bottom side of the center beam toward the end to guide the ropes to their respective pulleys. These go for about $15.58 for a pack of 5.
30425T19

The lock nuts on the threaded rod needed washers so that they could be tightened without damaging the plywood or the spacers. The ½ in washers were chosen to secure the threaded rod because of the cost and availability.
McMasterCarr has them in a pack of 25 for $8.83
90107A032

11.2 Final Presentation Video

Upgraded Door Cycling System Presentation

https://www.youtube.com/watch?v=KELr2MNtXCo

12 TEARDOWN

Since Hussmann provided funding for the parts they will be keeping the prototype. They communicated they will be implementing some aspects of our design in future iterations.

13 APPENDIX A - PARTS LIST

Upgraded Hussmann Door Cycling System- Parts list			
Part Number	Description	Source	Quantity
1	Guide Rail	60135K13-60135K22	4
2	Clevis Pin	Fabricated	2
3	Roller Wheel	60135K71	4
4	Washers (100 pack)	90107A003	1
5	1/2" x 2' x 4' Plywood	1125T611	2
6	1/2" 7" Long Threaded Rod	92580A344/	8
7	Through Bolt lock nut (50 pack)	95615A210	1
8	3/4" long Screw (100 pack)	91772A084	1
9	Rail Lock Nut 2-56 (100 pack)	90631A003	1
10	1/2" unthreaded Spacer	6389K119	16
11	13/16' Screw eye (5 pack)	30425T19	1
12	½" Washers (25 Pack)	90107A032	1

14 APPENDIX B - BILL OF MATERIALS

Table B.1: Bill Of Materials

No.	Item Description	Unit	Unit Cost	Qty.	Material	Total
1	Guide Rail	60135K13-60135K22	99.54	4	Zinc-Plated Steel	398.16
2	Clevis Pin	Fabricated	0	2	Stainless Steel	0.00
3	Roller Wheels	60135K71	33.8	4	steel	135.20
4	Washers (100 pack)	90107A003	2.73	1	316 Stainless Steel	2.73
5	1/2" x 2' x 4' Plywood	1125T611	20.9	2	Varies	41.80
6	1/2" 7" Long Threaded Rod	92580A344/	7.34	8	Black oxide steel	58.72
7	Through Bolt lock nut (50 pack)	95615A210	7.08	1	Steel	7.08
8	3/4" long Screw (100 pack)	91772A084	3.72	1	18-8 Stainless Steel	3.72
9	Rail Lock Nut 2-56 (100 pack)	90631A003	5.09	1	Zinc-Plated Steel	5.09
10	1/2" unthreaded Spacer	6389K119	1.49	16	LDPE Plastic	23.84
11	13/16" Screw eye 5 pack	30425T19	15.58	1	Steel	15.58
12	1/2 " washers (25 pack)	90107A032	8.83	1	Stainless steel	8.83
13						
14	Total Direct costs					700.75
15						
16	Indirect Overhead Costs					0
17						
18						
19						
20	Total before contingency					700.75
21	Contingency (15%)					105.12
22	Engineers estimate					$805.86

15 APPENDIX C – COMPLETE LIST OF ENGINEERING DRAWINGS

https://drive.google.com/drive/folders/1QBV1Q3yL0W6NXHk13gdA6ZODsQAuBlNB

16 ANNOTATED BIBLIOGRAPHY

Figure 1 Source

Figure 2 Source

Hibbeler, R. C. *Engineering Mechanics: Statics and Dynamics*. Pearson, 2016.