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Portable Shopping Cart

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Joint Engineering Program

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

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This document captures the complete design-to-prototype process for a portable shopping system. The following report outlines the decision making processes dictated by consumer interviews, safety regulations, and manufacturing constraints. All pertinent photographs, CAD drawings, and video links are included in this document.

JME 4110
Mechanical Engineering
Design Project

Portable Shopping Cart

Stacy Otzenberger
Heath McClung

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 VALUE PROPOSITION / PROJECT SUGGESTION

The shopping cart design has remained unchanged for decades despite a significant change to consumer behaviors. Retailers like Aldis, Sam's Club, and Costco have moved away from the traditional use of plastic shopping bags, fueled by consumer demands for more sustainable and environmentally-friendly practices. A new design for a shopping that embraces reusable bags can make trips to the store much easier and efficient by streamlining the checkout process while providing a more organized approach to storing purchases.

1.2 LIST OF TEAM MEMBERS

Heath McClung
Stacy Otzenberger

2 BACKGROUND INFORMATION STUDY

2.1 DESIGN BRIEF

Design a mobile modular shopping system that the user owns and has the ability to go from the user's vehicle to the store and back to the vehicle with ease, or more specifically the least amount of physical exertion by the user. The design utilizes versatile and reusable shopping bags and/or baskets and assists in organizing groceries in a more strategic pattern. We intend to use an existing bag/basket that will fit into a fabricated cart system. This cart system will be lightweight, collapsible, and easy to store in vehicle. The entire system should be able to hold at least 100 pounds of groceries, fit into a trunk size of 20 cubic feet. The system will be designed to expedite the whole shopping process, eliminating the need to obtain and return a store owned cart to the corral or store. System should require no more than two minutes to assemble or disassemble. To minimize cost, risk, and size, a child restrain will not be included.

2.2 BACKGROUND SUMMARY

Research into non-traditional shopping cart design yielded an appealing design by the IDEO design company. The entire design process was featured in a 1999 episode of ABC's *Nightline*, where the final prototype included a dual child seat, removable plastic baskets, and steerable back wheels. Despite the attractiveness of the redesign, the cart did not become patented or commercially produced. The *Nightline* segment can be seen here: https://www.youtube.com/watch?v=M66ZU2PCIcM.

Figure 1 - IDEO Shopping Cart

Although not an entire shopping cart design, another existing product addressing the design problem is the Lotus Trolley Bag. This reusable shopping bag can hang on a traditional shopping cart as well as the eventual prototype of our design with some minor alterations.

Figure 2 - Lotus Trolley Bags

A significant goal of our design is for the cart to have the ability to move up a flight of stairs much easier than traditional shopping carts. During our research, this patent for a Stair Climbing Wheel Unit Assembly by L.E. Whitaker presented a unique concept for achieving this goal. With the three wheels all operating from a single axle, incorporating this existing product into our design requires minimum effort.

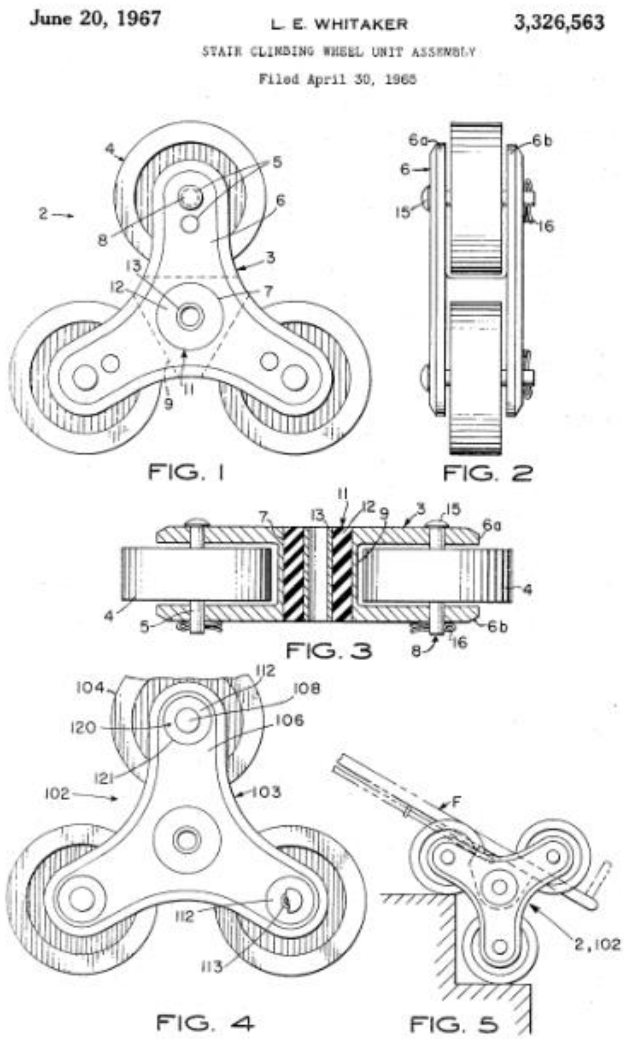


Figure 3 - Drawing for Stair Climbing Wheel

Lastly, the only related standard of safety for shopping carts is ASTM F2372-15 Standard Consumer Safety Performance Specification for Shopping Carts:

"The ASTM standard also requires retailers to inspect and replace broken seat belts and to ensure that every shopping cart remains in good working order. Also the standard suggests that the retailer provide safety information and use safety posters to communicate safe behavior to consumers. Most retailers provide shopping cart restraints on all of their carts The ASTM shopping cart standard is intended to cover children who are 6 months to 4 years old and weigh 15 to 35 pounds. Among other things, the standard requires that shopping carts with a child seating area have adjustable child restraint systems with child-resistant buckles or closures. It also requires that each shopping cart include a warning label with pictograms that includes specific safety messages, such as "ALWAYS buckle-up child in cart seat and fasten securely."

Given the implications of this safety standard, a child seat was purposefully not incorporated into the goals of the design. Instead the focus became to create a device for individuals shopping without children or those using public transportation.

3 CONCEPT DESIGN AND SPECIFICATION

3.1 USER NEEDS AND METRICS

3.1.1 Record of the user needs interview

Table 1 – User Needs Interview

Project/Product Name: Shopping Cart
Customer: Dr. Mark Jakiela — Interviewer(s): Heath McClung, Stacy Otzenberger

Address: Washington University
Willing to do follow up? Yes — Date: 01/29/2018

Type of user: Non-bagged grocery shoppers — Currently uses: Traditional cart and boxes

Question	Customer Statement	Interpreted Need	Importance
How many pounds of groceries do you buy in a single trip?	A full week's worth of groceries can probably weigh up to 100 lbs.	Cart can operate with a 100 lb load.	5
How many pounds of groceries can you lift at one time?	I can move short distances with about 20 lbs of groceries per hand. So 40 lbs in a single trip.	Bags or baskets should not be used to hold more than 20 lbs of groceries.	4
How long does a typical trip to Aldis take?	My weekly trip to Aldis can take 45 minutes to an hour.	Cart must hold load of groceries and operate for at least 1 hour increments.	5
How long does the checkout to car process take during a trip to Aldis?	Typically it takes about 10-15 minutes to checkout, reorganize purchases, and then load them into my SUV.	Cart should expedite checkout to car process.	3
Do you use bags and a cart, or how do you organize your purchases now?	I use different sized boxes that I keep in my trunk to line the entire floor of the shopping cart. As I shop, I subdivide items into boxes by type and where it goes into the house. At checkout, I have to unload the boxes and then reorganize purchases after checking out to load the boxes in my SUV.	Cart system should allow users to keep purchases organized throughout the shopping experience.	5
How often do you make a trip to Aldis?	I go once a week, usually on Saturdays.	Cart should be durable for at least one trip per week.	4
During a shopping trip, do you typically buy the same items each week or does it vary drastically?	I usually purchase mostly the same items and due to Aldis store layout, almost in the same sequence each time.	Cart allows adaptability for different shopping habits.	3

Do you want the cart to help just at the store, or at home as well?	If it could help me go up a flight of stairs once I get home, that would be great. My kids sometimes help me now, but it takes several trips up the stairs from the garage to the kitchen to unload groceries.	Cart can go up stairs with a load of purchases.	4
How big do you expect the cart to be?	I hope it can fit in the trunk of my SUV with groceries, especially if I can use it once I get home.	Cart must collapse and fit into the trunk of a car.	5
How much would you pay for a cart system that addresses your needs?	I think I would pay around $100-$150.	Cart costs less than $200.	3

Table 2 - Initial Needs Table for Portable Shopping System

Need Number	Need	Importance
1	System can hold at least 100 lbs of groceries	5
2	System and groceries can fit into trunk space with $16ft^3$ volume	5
3	System allows user to carry no more than 40 lbs at a time	4
4	System can go up a flight of stairs	3
5	Requires no more than 2 minutes to put all groceries into car	4
6	System (without groceries) is light	4
7	System allows user to organize groceries to fit their unique shopping style	3
8	System can break down into a compact size	3
9	System is reasonably priced for consumer	4
10	System is easy to operate	5
11	System can be safely operated for an hour shopping trip without any issues	4

3.1.2 List of identified metrics

Table 3 – Identified Metrics

Metric Number	Associated Needs	Metric	Units	Min Value	Max Value
1	3, 4, 6, 10	Weight	Pounds	1	40
2	2, 4, 8, 11	Overall Height	Inches	1	48
3	2, 4, 8, 11	Overall Width	Inches	1	36
4	1, 7, 11	Maximum Grocery Capacity	Pounds	1	150
5	2, 4, 6, 8, 11	Portability	Integer	1	5
6	1, 3, 4, 10, 11	Operator Safety	Integer	1	5
7	5, 7, 10, 11	Ease of Use	Integer	1	5
8	9	Price	Dollars	1	200
9	5, 10, 11	Time	Minutes	1	15

3.1.3 Table/list of quantified needs equations

Table 4 – Quantified Needs Matrix

Portable Shopping System		Metric											
		Weight	Overall Height	Overall Width	Maximum Grocery Capacity	Portability	Operator Safety	Ease of Use	Price	Time	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
	Need	1	2	3	4	5	6	7	8	9			
1	Hold at least 100 lbs. of groceries				0.9		0.1				1	0.2	0.2
2	Fit into trunk space w/ 16ft^3 volume		0.4	0.4		0.2					1	0.1	0.1
3	User carry no more than 40 lbs. at a time	0.3			0.3		0.2	0.2			1	0.1	0.1
4	Can go up a flight of stairs					0.3	0.2	0.3		0.2	1	0.05	0.05
5	Less than 2 min. to put groceries in car							0.5		0.5	1	0.05	0.05
6	System (without groceries) is lightweight	0.8				0.1		0.1			1	0.1	0.1
7	Can organize groceries							0.5		0.5	1	0.15	0.15
8	Can break down into compact size		0.3	0.3		0.2		0.2			1	0.05	0.05
9	Reasonably priced								1		1	0.025	0.025
10	Easy to operate							1			1	0.1	0.1
11	Safely operate for hour shopping trip						1				1	0.075	0.075
Units		lbs	inches	inches	lbs	Integer	Integer	Integer	Dollars	Minutes	Total Happiness		0.925
Best Value		1	1	1	150	5	5	5	1	1			
Worst Value		40	48	36	1	1	1	1	200	15			
Actual Value		1	1	1	150	5	5	5	1	1			
Normalized Metric Happiness		1	1	1	1	1	1	1	1	1			

3.2 CONCEPT DRAWINGS

<u>Concept #1</u>

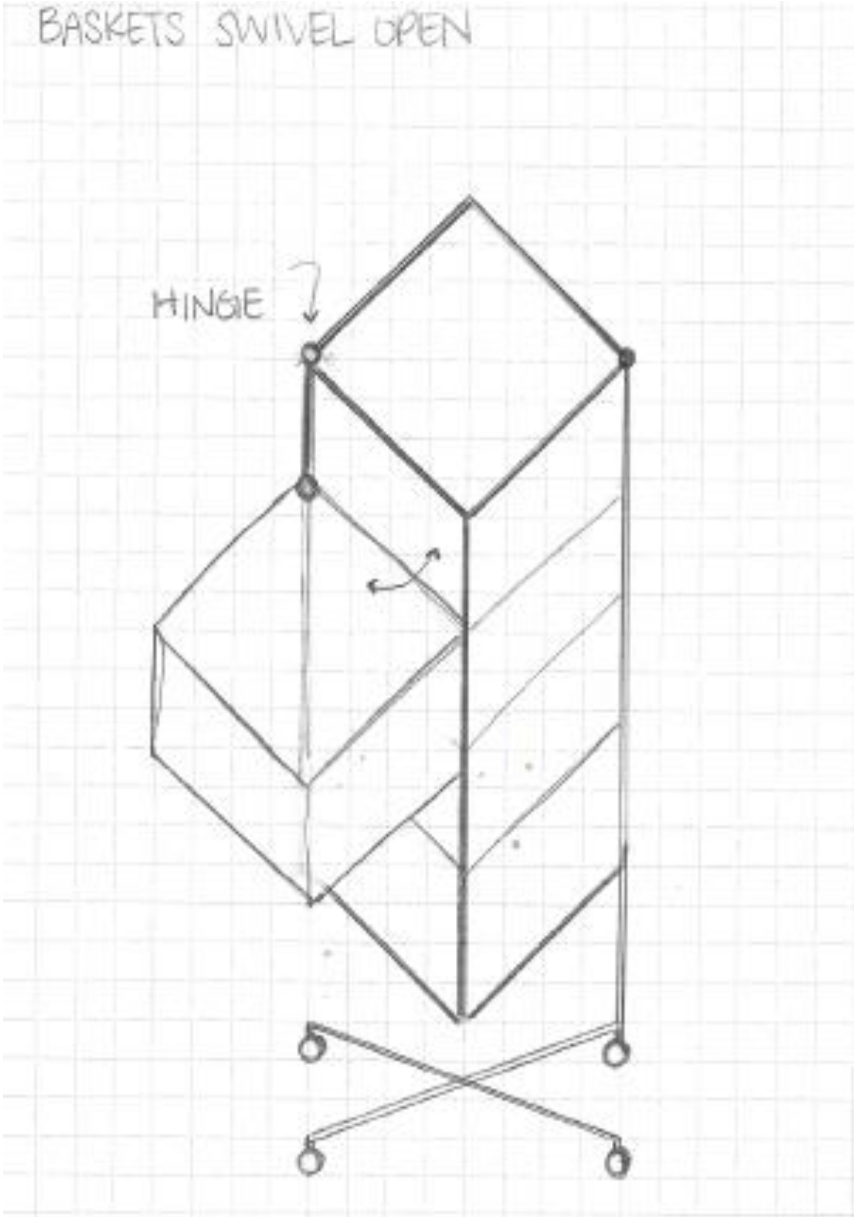


Figure 4-Concept #1 design sketch

Concept #2

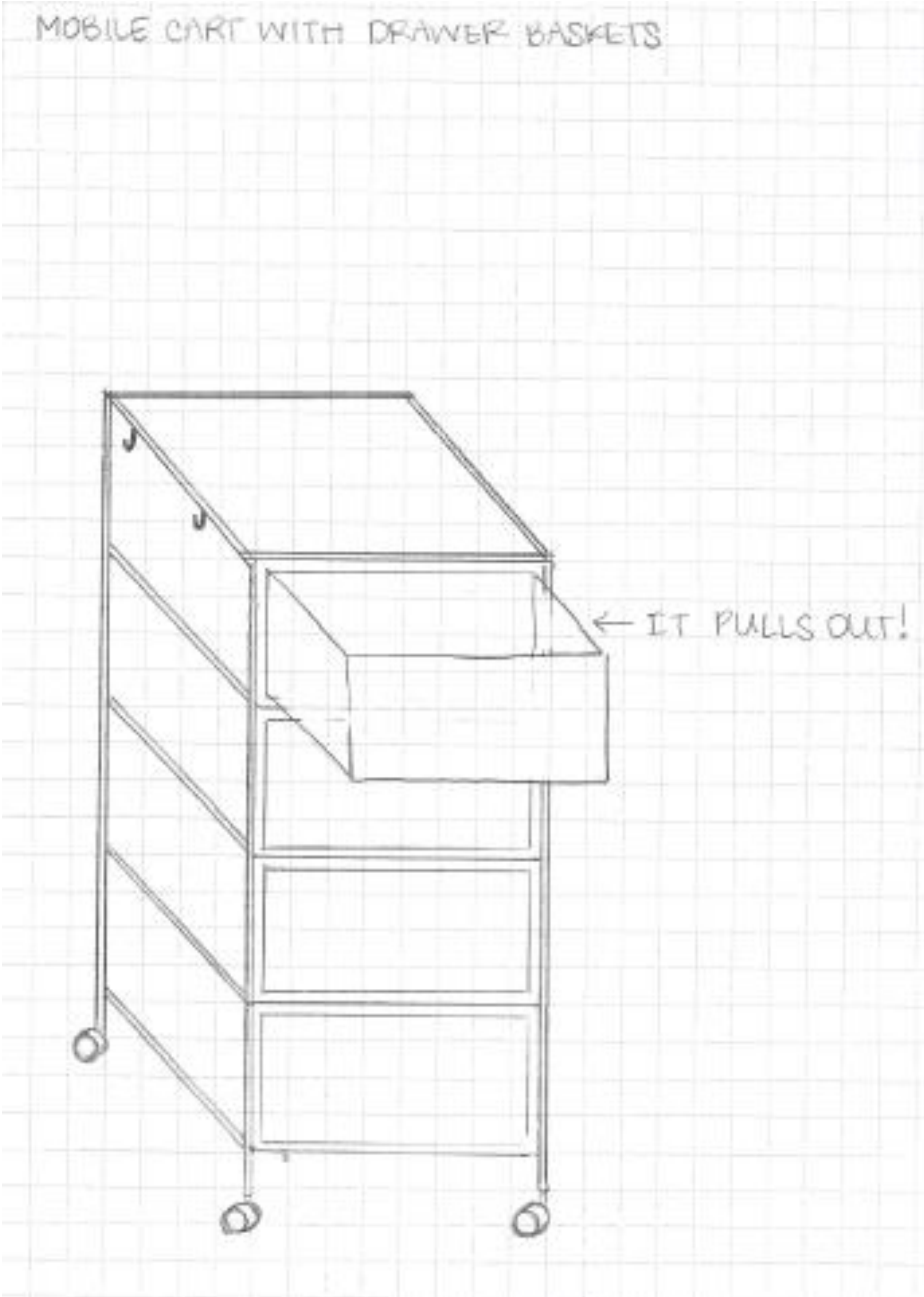


Figure 5-Concept #5 design drawing

Concept #3

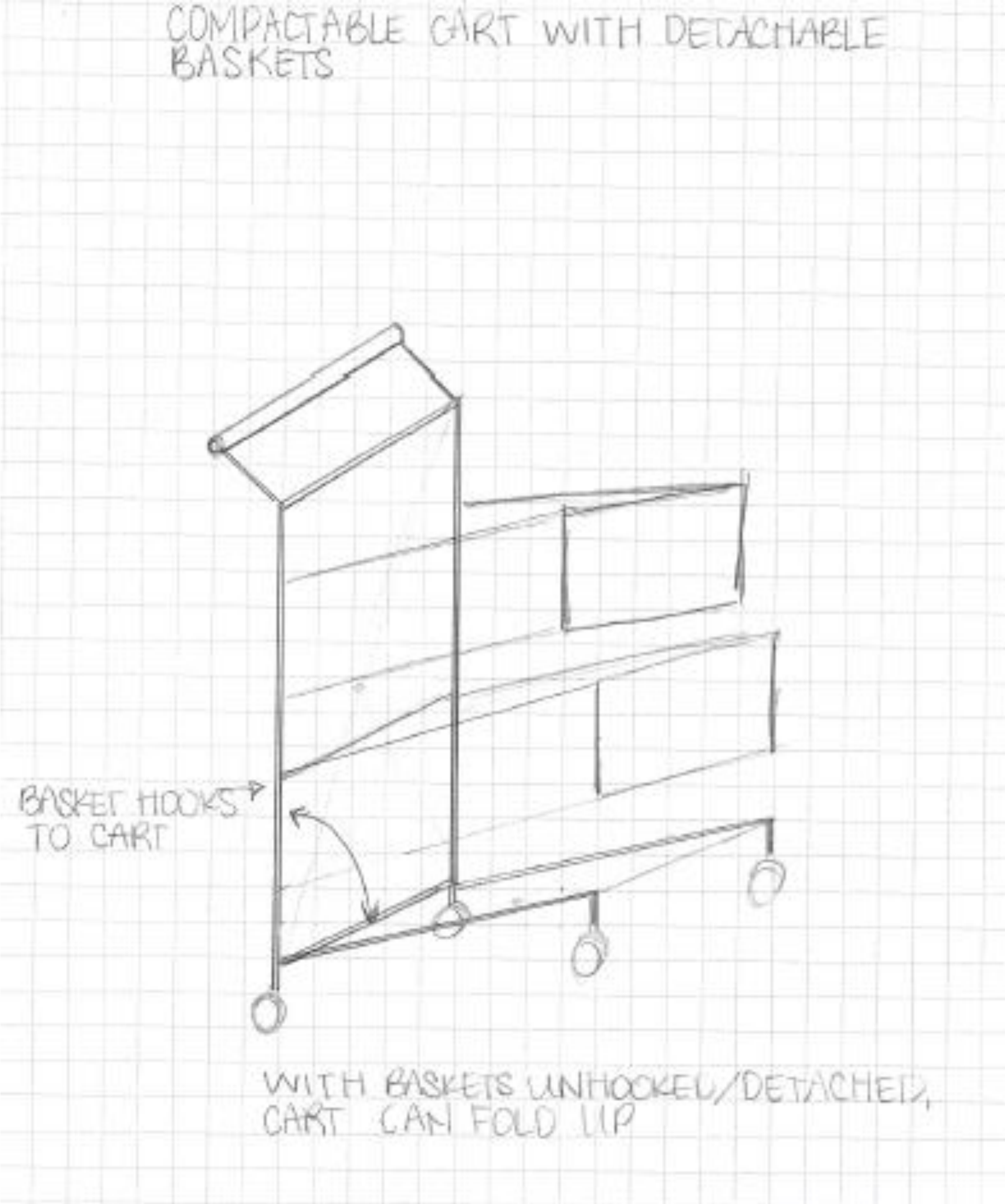


Figure 6-Concept #3 design drawings

Concept #4

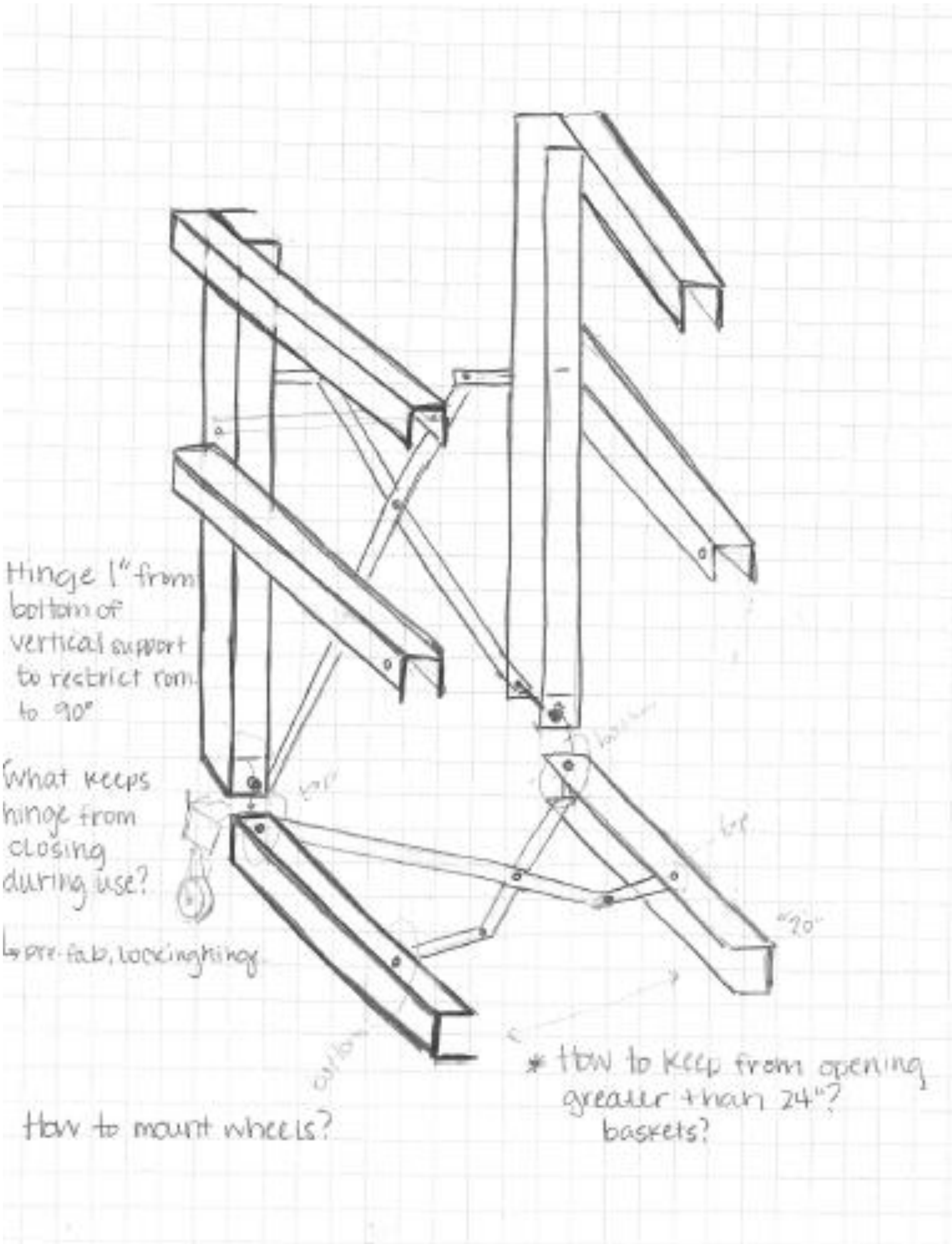


Figure 7-Concept #4a design drawing

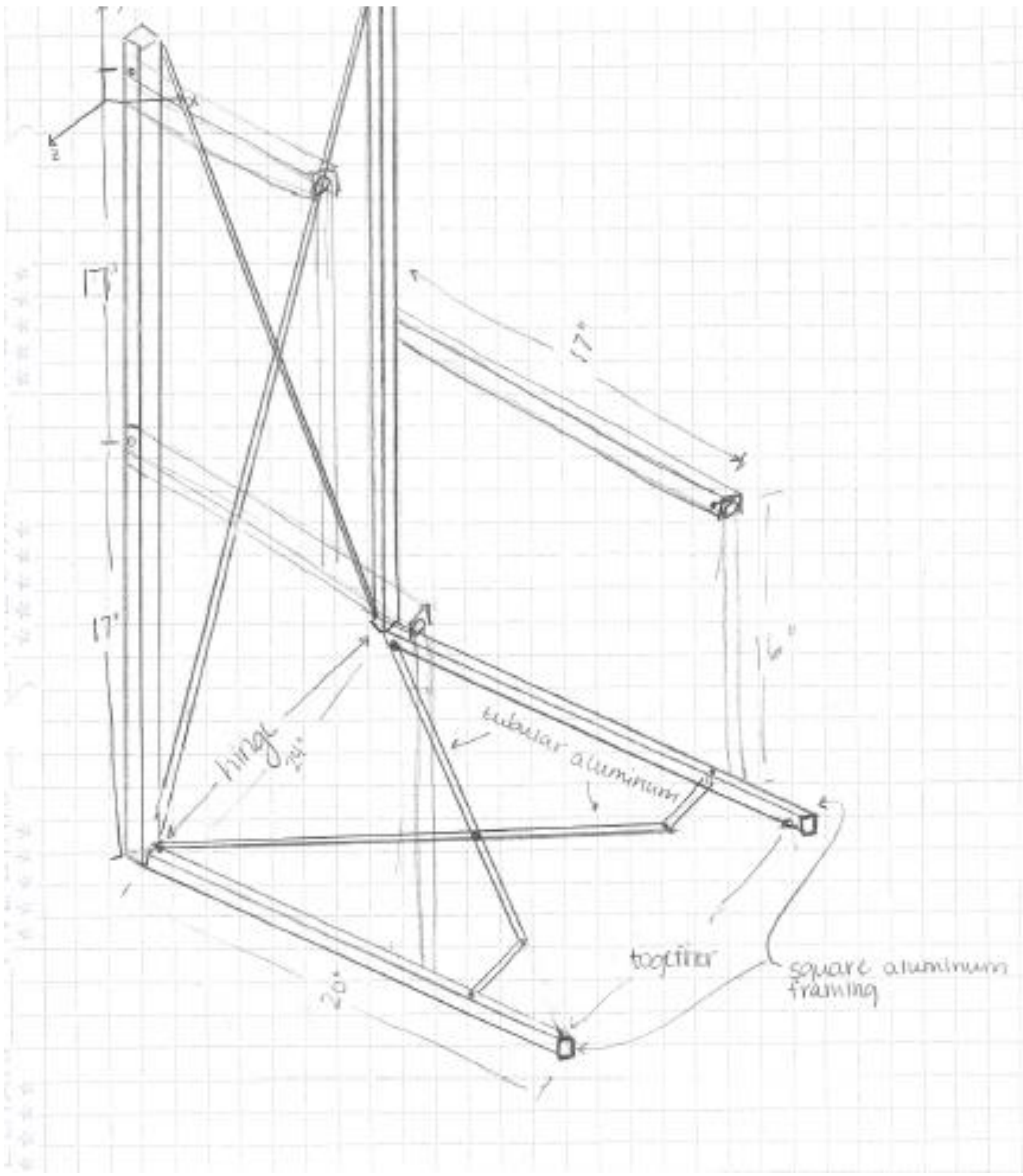


Figure 8-Concept #4b design drawing with dimensions

3.3 A CONCEPT SELECTION PROCESS.

3.3.1 Concept scoring

Concept #1

Table 5-Concept #1 Metrics Table

	Portable Shopping System	Metric											
		Weight	Overall Height	Overall Width	Maximum Grocery Capacity	Portability	Operator Safety	Ease of Use	Price	Time	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
	Need	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**			
1	Hold at least 100 lbs. of groceries				0.9		0.1				0.294	0.2	0.0588
2	Fit into trunk space w/ 16ft^3 volume		0.4	0.4		0.2					0.144	0.1	0.0144
3	User carry no more than 40 lbs. at a time	0.3			0.3		0.2	0.2			0.32	0.1	0.032
4	Can go up a flight of stairs					0.3	0.2	0.3		0.2	0.4	0.05	0.02
5	Less than 2 min. to put groceries in car							0.5		0.5	0.3	0.05	0.015
6	System (without groceries) is lightweight	0.8				0.1		0.1			0.192	0.1	0.0192
7	Can organize groceries							0.5		0.5	0.3	0.15	0.045
8	Can break down into compact size		0.3	0.3		0.2		0.2			0.208	0.05	0.0104
9	Reasonably priced								1		0.25	0.025	0.00625
10	Easy to operate							1			0.4	0.1	0.04
11	Safely operate for hour shopping trip						1				0.6	0.075	0.045
	Units	lbs	inches	inches	lbs	Integer	Integer	Integer	Dollars	Minutes	**Total Happiness**		**0.26105**
	Best Value	5	12	12	150	5	5	5	50	1			
	Worst Value	40	48	36	1	1	1	1	200	15			
	Actual Value	35	48	30	40	2	3	2	150	10			
	Normalized Metric Happiness	0.14	0	0.16	0.26	0.4	0.6	0.4	0.25	0.2			

Concept #2

Table 6-Concept #2 Metrics Table

	Portable Shopping System	Metric											
		Weight	Overall Height	Overall Width	Maximum Grocery Capacity	Portability	Operator Safety	Ease of Use	Price	Time	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
	Need	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**			
1	Hold at least 100 lbs. of groceries				0.9		0.1				0.42	0.2	0.084
2	Fit into trunk space w/ 16ft^3 volume		0.4	0.4		0.2					0.316	0.1	0.0316
3	User carry no more than 40 lbs. at a time	0.3			0.3		0.2	0.2			0.36	0.1	0.036
4	Can go up a flight of stairs					0.3	0.2	0.3		0.2	0.574	0.05	0.0287
5	Less than 2 min. to put groceries in car							0.5		0.5	0.535	0.05	0.02675
6	System (without groceries) is lightweight	0.8				0.1		0.1			0.12	0.1	0.012
7	Can organize groceries							0.5		0.5	0.535	0.15	0.08025
8	Can break down into compact size		0.3	0.3		0.2		0.2			0.387	0.05	0.01935
9	Reasonably priced								1		0.25	0.025	0.00625
10	Easy to operate							1			0.6	0.1	0.06
11	Safely operate for hour shopping trip						1				0.6	0.075	0.045
	Units	lbs	inches	inches	lbs	Integer	Integer	Integer	Dollars	Minutes	**Total Happiness**		**0.3849**
	Best Value	5	12	12	150	5	5	5	50	1			
	Worst Value	40	48	36	1	1	1	1	200	15			
	Actual Value	40	40	24	60	3	3	3	150	8			
	Normalized Metric Happiness	0	0.16	0.33	0.4	0.6	0.6	0.6	0.25	0.47			

Concept #3

Table 7-Concept #3 Metrics Table

Portable Shopping System		Metric											
		Weight	Overall Height	Overall Width	Maximum Grocery Capacity	Portability	Operator Safety	Ease of Use	Price	Time	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
	Need	1	2	3	4	5	6	7	8	9			
1	Hold at least 100 lbs. of groceries				0.9		0.1				0.683	0.2	0.1366
2	Fit into trunk space w/ 16ft^3 volume		0.4	0.4		0.2					0.238	0.1	0.0238
3	User carry no more than 40 lbs. at a time	0.3			0.3		0.2	0.2			0.536	0.1	0.0536
4	Can go up a flight of stairs					0.3	0.2	0.3		0.2	0.714	0.05	0.0357
5	Less than 2 min. to put groceries in car							0.5		0.5	0.735	0.05	0.03675
6	System (without groceries) is lightweight	0.8				0.1		0.1			0.18	0.1	0.018
7	Can organize groceries							0.5		0.5	0.735	0.15	0.11025
8	Can break down into compact size		0.3	0.3		0.2		0.2			0.3685	0.05	0.018425
9	Reasonably priced								1		0.075	0.025	0.001875
10	Easy to operate							1			0.8	0.1	0.08
11	Safely operate for hour shopping trip						1				0.8	0.075	0.06
	Units	lbs	inches	inches	lbs	Integer	Integer	Integer	Dollars	Minutes	Total Happiness		0.515
	Best Value	5	12	12	150	5	5	5	50	1			
	Worst Value	40	48	36	1	1	1	1	200	15			
	Actual Value	38	42	30	100	3	4	4	185	5			
	Normalized Metric Happiness	0.05	0.125	0.17	0.67	0.6	0.8	0.8	0.075	0.67			

Concept #4

Table 8-Concept #4 Metrics Table

Portable Shopping System		Metric											
		Weight	Overall Height	Overall Width	Maximum Grocery Capacity	Portability	Operator Safety	Ease of Use	Price	Time	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
	Need	1	2	3	4	5	6	7	8	9			
1	Hold at least 100 lbs. of groceries				0.9		0.1				1	0.2	0.2
2	Fit into trunk space w/ 16ft^3 volume		0.4	0.4		0.2					0.624	0.1	0.0624
3	User carry no more than 40 lbs. at a time	0.3			0.3		0.2	0.2			0.825	0.1	0.0825
4	Can go up a flight of stairs					0.3	0.2	0.3		0.2	0.88	0.05	0.044
5	Less than 2 min. to put groceries in car							0.5		0.5	0.9	0.05	0.045
6	System (without groceries) is lightweight	0.8				0.1		0.1			0.6	0.1	0.06
7	Can organize groceries							0.5		0.5	0.9	0.15	0.135
8	Can break down into compact size		0.3	0.3		0.2		0.2			0.668	0.05	0.0334
9	Reasonably priced								1		1	0.025	0.025
10	Easy to operate							1			0.8	0.1	0.08
11	Safely operate for hour shopping trip						1				1	0.075	0.075
	Units	lbs	inches	inches	lbs	Integer	Integer	Integer	Dollars	Minutes	Total Happiness		0.7673
	Best Value	5	12	12	150	5	5	5	50	1			
	Worst Value	40	48	36	1	1	1	1	200	15			
	Actual Value	19.5	43.5	10	150	4	5	4	200	1			
	Normalized Metric Happiness	0.55	0.33	0.83	1	0.8	1	0.8	1	1			

3.3.2 Physical Feasibility Analysis

Concept #1

Concept 1 consists of a set of four drawers attached to a rolling fixture. The drawers swivel open using hinges attached to a single vertical support bar and are mounted to the rolling frame by a vertical support bar on the opposite corner from the hinges. While the design seems simple and easy to use, trying to design a relatively tall system of drawers able to house different purchases is difficult. The overall height makes the cart easy to tip over, especially in circumstances of rough terrain such as parking lots and tiled floors. Although we envisioned the drawer system detaching from the cart to be placed into a vehicle, the system does not collapse further and complicates transportation.

Concept #2

Concept 2 utilizes a similar system of four drawers, but operates differently than Concept 1. The drawers pull out in the traditional fashion and are mounted to a metal frame with four caster wheels. Although organization is maintained during shopping, the user must still remove all items from the drawers during the check-out process and then re-organize everything. While these drawer systems are easy to purchase pre-made, none have the ability to carry 100 lbs worth of load. Additionally, the typical plastic caster wheels do not roll smoothly under load either.

Concept #3

Concept 3 consists of a metal cart with baskets that hook to horizontal bars mounted on the rear vertical frame. When the baskets are detached from the cart, the metal frame folds in half, leaving a flat cart of equal width but substantially shorter. The cart has four caster wheels similar to those found on a traditional shopping cart. The connection between the basket and horizontal bar may prove difficult to design with the capacity to hold a significant portion of the overall 100 lbs worth of groceries. The cantilever design requires a heavily reinforced connection, but still may result in the cart tipping forward if the load is distributed unevenly.

Concept #4

Concept 4 is the most feasible of all four concepts because it collapses to become extremely portable. The cart consists of a vertical and horizontal assemblies made from aluminum C-channel and articulating aluminum poles that allow the C-channel to move together and apart. The two identical vertical and horizontal assemblies are attached by two locking hinges. Collapsible shelving brackets mount to the vertical C-channels to allow for reusable shopping bags to span across the brackets. The most difficult aspect to the design is calculating the geometry of all articulating parts to maximize the ability to collapse and expand.

3.3.3 Final summary statement

After considering the four concepts, user needs, user metrics, and feasibility of designs, concept #4 provides the most potential in achieving desired outcomes. The concept collapses to become the most portable and user-friendly of all the designs, allowing users to store the cart in a vehicle's trunk with shopping purchases. The entire cart uses two main materials for the entire construction (aluminum C-channel, ½" aluminum pipe) which are relatively cheap and easy to manipulate with common tools. This design provides an opportunity to create a new practical shopping cart with the ability to adapt to user needs, potentially attracting real consumers.

3.4 PROPOSED PERFORMANCE MEASURES FOR THE DESIGN

The overall goal of the project is to create a portable shopping cart system that performs according to the needs of the user. With the selection of concept #4, we re-examined the original specifications defined from our user needs interview and determined the original metrics will suffice for our specific design. However, some alterations of the specific maximum and minimum values for the metrics provide a better reference for a successful or unsuccessful final product. By using strictly aluminum material for our frame, the maximum overall weight was changed to 20 pounds, since the user indicated that is the maximum weight normally carried in one hand. The price also changed to a more realistic value since the cost of aluminum is higher due to the decreased weight and also recent shifts in the market. The most important indications to the success of the design is the maximum grocery capacity compared to the size of the cart in its folded-up state. Ease of use, shopping time, and portability can vary more depending on the specific user and their familiarity of the cart. These metrics can change as the user utilizes the cart more frequently.

3.5 REVISION OF SPECIFICATIONS AFTER CONCEPT SELECTION

Table 9-Revised Identified Metrics

Metric Number	Associated Needs	Metric	Units	Min Value	Max Value
1	3, 4, 6, 10	Weight	Pounds	5	40
2	2, 4, 8, 11	Overall Height	Inches	12	48
3	2, 4, 8, 11	Overall Width	Inches	12	36
4	1, 7, 11	Maximum Grocery Capacity	Pounds	1	150
5	2, 4, 6, 8, 11	Portability	Integer	1	5
6	1, 3, 4, 10, 11	Operator Safety	Integer	1	5
7	5, 7, 10, 11	Ease of Use	Integer	1	5
8	9	Price	Dollars	50	300

9	5, 10, 11	Time	Minutes	1	15

Need Number	Need	Importance
1	System can hold at least 100 lbs of groceries	5
2	System and groceries can fit into trunk space with $16ft^3$ volume	5
3	System allows user to carry no more than 40 lbs at a time	4
4	System can go up a flight of stairs	3
5	Requires no more than 2 minutes to put all groceries into car	4
6	System (without groceries) is light	4
7	System allows user to organize groceries to fit their unique shopping style	3
8	System can break down into a compact size	3
9	System is reasonably priced for consumer	4
10	System is easy to operate	5
11	System can be safely operated for an hour shopping trip without any issues	4

Concept #4 Revised Scoring

Table 10-Revised Concept #4 Metrics Scoring

Portable Shopping System		Metric											
		Weight	Overall Height	Overall Width	Maximum Grocery Capacity	Portability	Operator Safety	Ease of Use	Price	Time	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
	Need	1	2	3	4	5	6	7	8	9			
1	Hold at least 100 lbs. of groceries				0.9		0.1				1	0.2	0.2
2	Fit into trunk space w/ $16ft^3$ volume		0.4	0.4		0.2					0.624	0.1	0.0624
3	User carry no more than 40 lbs. at a time	0.3			0.3		0.2	0.2			0.825	0.1	0.0825
4	Can go up a flight of stairs					0.3	0.2	0.3		0.2	0.88	0.05	0.044
5	Less than 2 min. to put groceries in car							0.5		0.5	0.9	0.05	0.045
6	System (without groceries) is lightweight	0.8				0.1		0.1			0.6	0.1	0.06
7	Can organize groceries							0.5		0.5	0.9	0.15	0.135
8	Can break down into compact size		0.3	0.3		0.2		0.2			0.668	0.05	0.0334
9	Reasonably priced								1		0.33	0.025	0.00825
10	Easy to operate							1			0.8	0.1	0.08
11	Safely operate for hour shopping trip						1				1	0.075	0.075
Units		lbs	inches	inches	lbs	Integer	Integer	Integer	Dollars	Minutes	Total Happiness		0.75055
Best Value		5	12	12	150	5	5	5	50	1			
Worst Value		40	48	36	1	1	1	1	300	15			
Actual Value		19.5	43.5	10	150	4	5	4	200	1			
Normalized Metric Happiness		0.55	0.33	0.83	1	0.8	1	0.8	0.33	1			

4 EMBODIMENT AND FABRICATION PLAN

4.1 EMBODIMENT/ASSEMBLY DRAWING

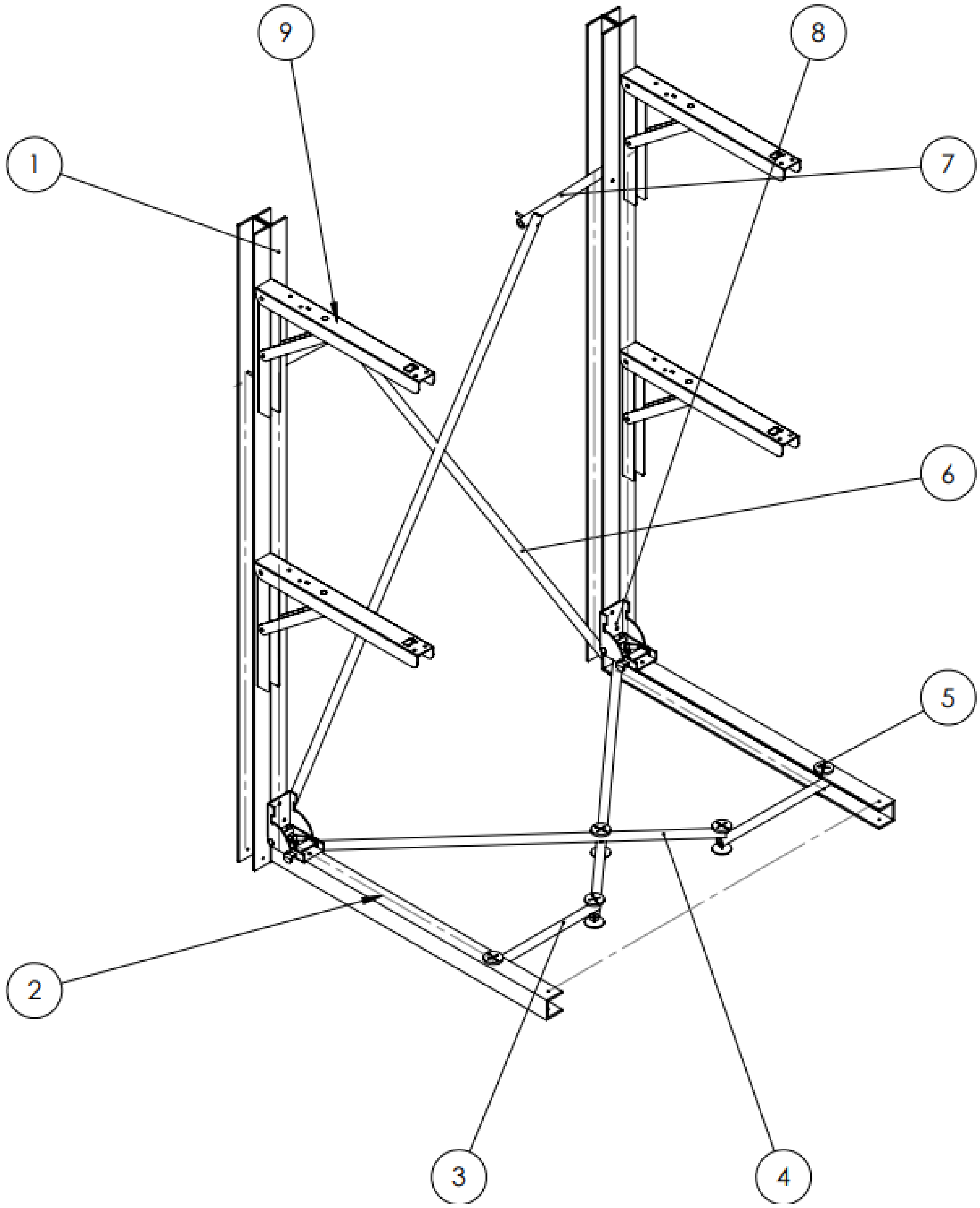


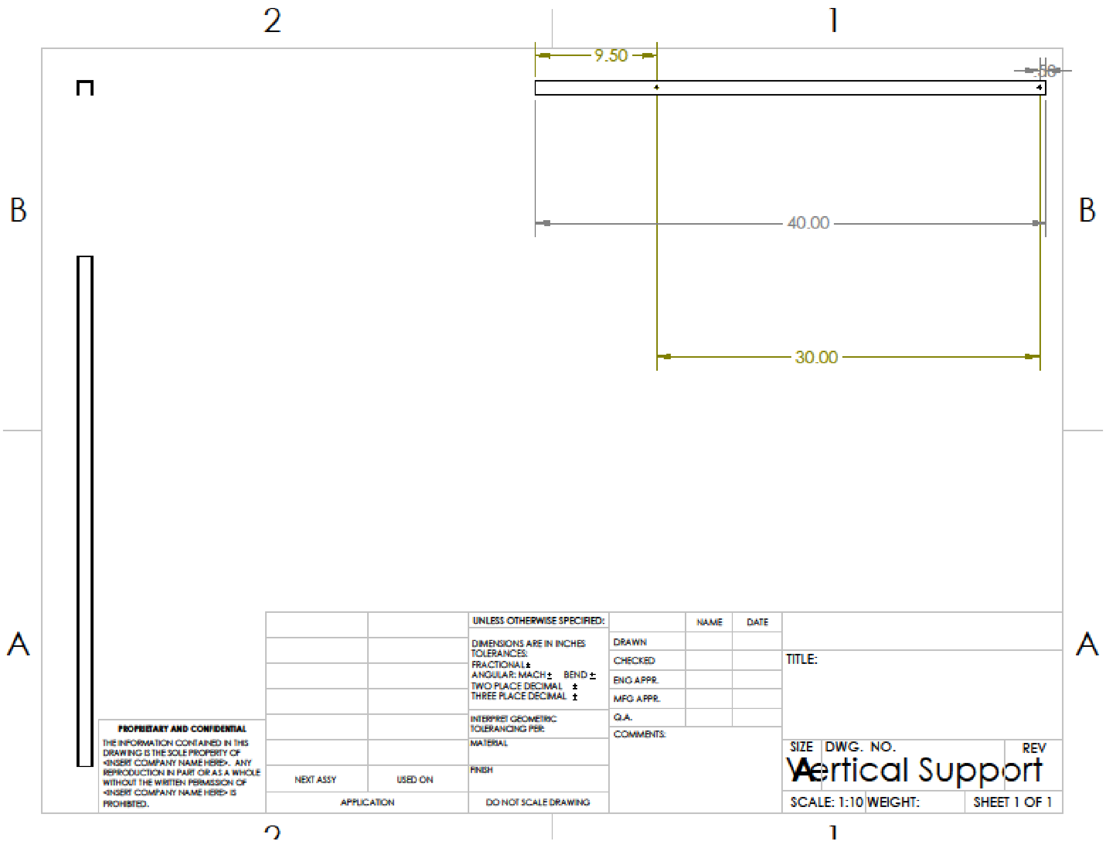
Figure 9-Main Frame Components

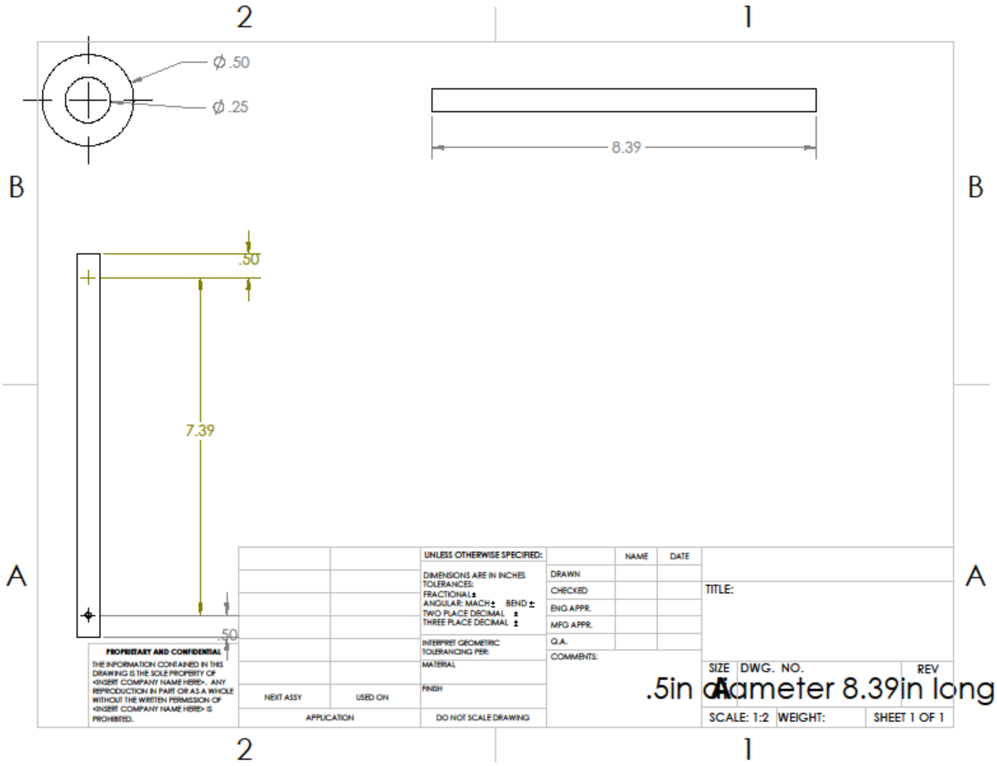
4.2 PARTS LIST

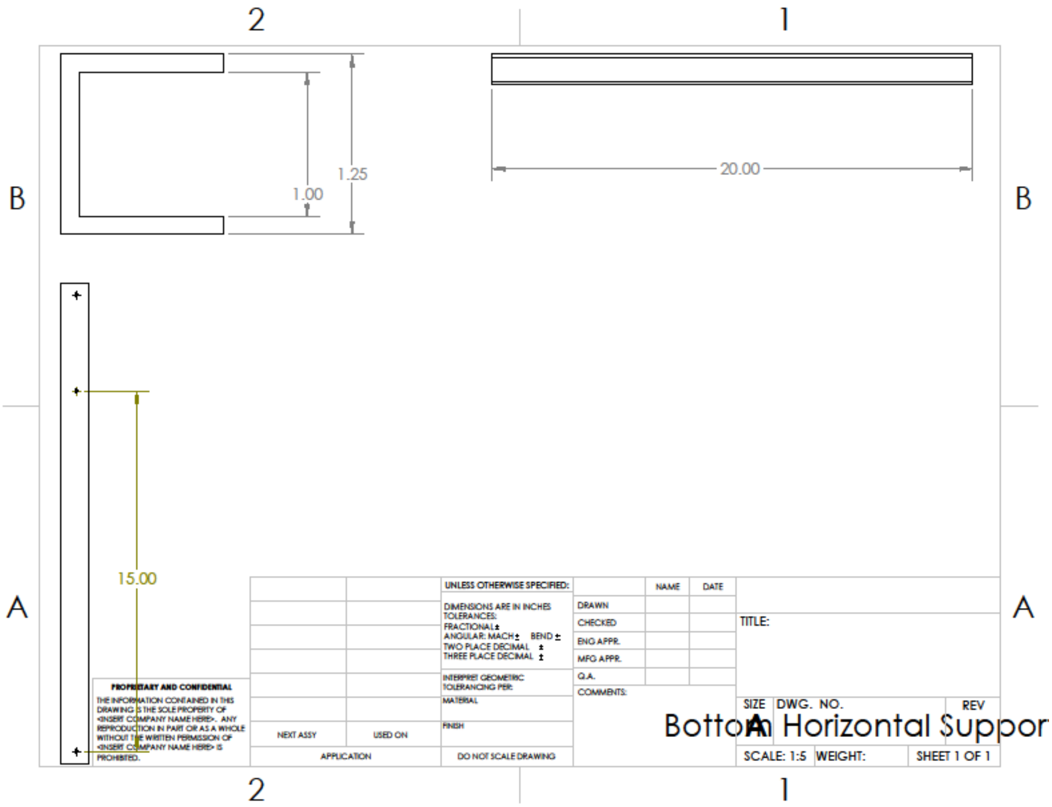
Table 11-Bill of Materials

Part Number	Description	Quantity	Vendor	Price
1, 2	Aluminum C Channel 1.25"x1.25"	16'	Shapiro Metal Supply	16.00
3, 4, 6, 7	Aluminum Round .5"	16'	Shapiro Metal Supply	46.88
8	Folding Table Leg Bracket	2	McMaster Carr	12.58
9	Folding Shelf Bracket	4	Amazon.com	43.58
10	Trolley Bags	4	Amazon.com	30.00
11	Stair Climbing Wheel Assembly	2	Amazon.com	24.00
12	3" Caster Wheels	2	Menards	12.00
13	2" Flat Aluminum	6'	Menards	5.69
14	.5" Flat Aluminum	12'	Mcmaster Carr	8.96
15	5/8" Binding Post	10	Fastenal	4.00
16	1" Binding Post	10	Fastenal	6.00
17	Square Lock Pin	2	Farm and Home Supply	3.00
18	.5" Round Aluminum	2'	Menards	5.00
19	Hanger Bolt	4	Menards	6.00
20	5/8" Screw Set	36	Menards	5.29
21	1 1/2" Screw Set	8	Menards	3.29
			Total Supplies:	**$232.27**

4.3 DRAFT DETAIL DRAWINGS FOR EACH MANUFACTURED PART







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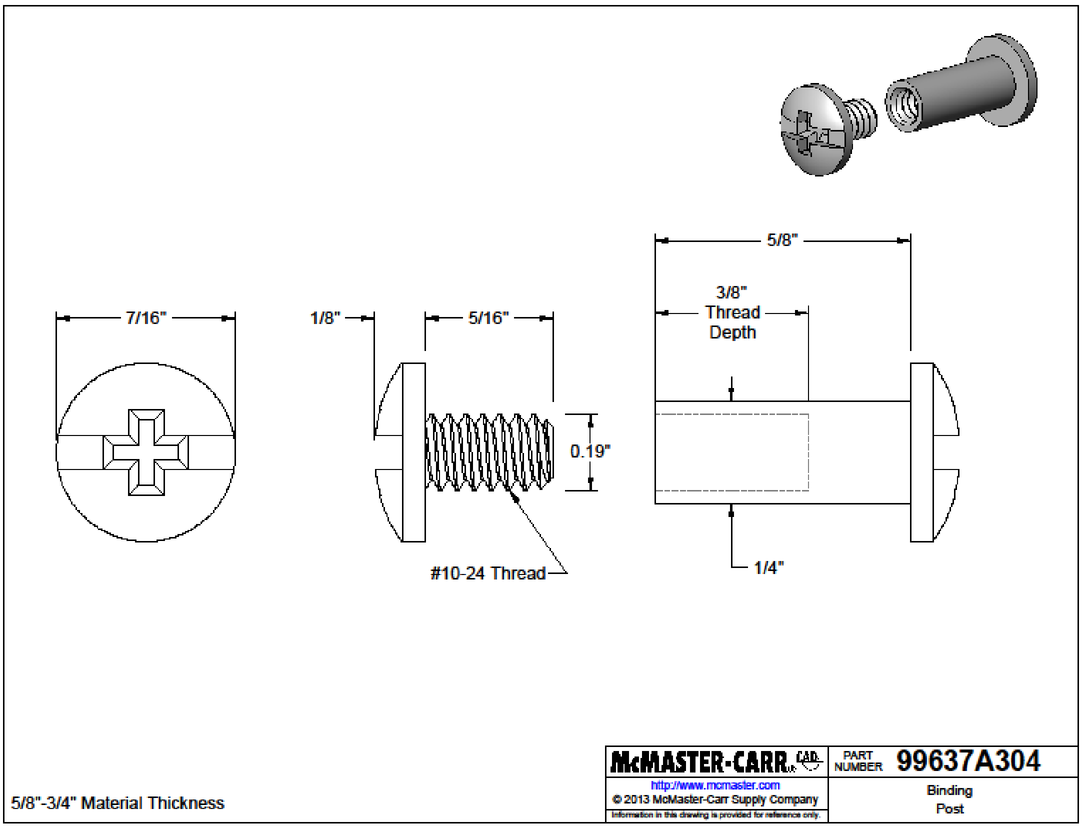
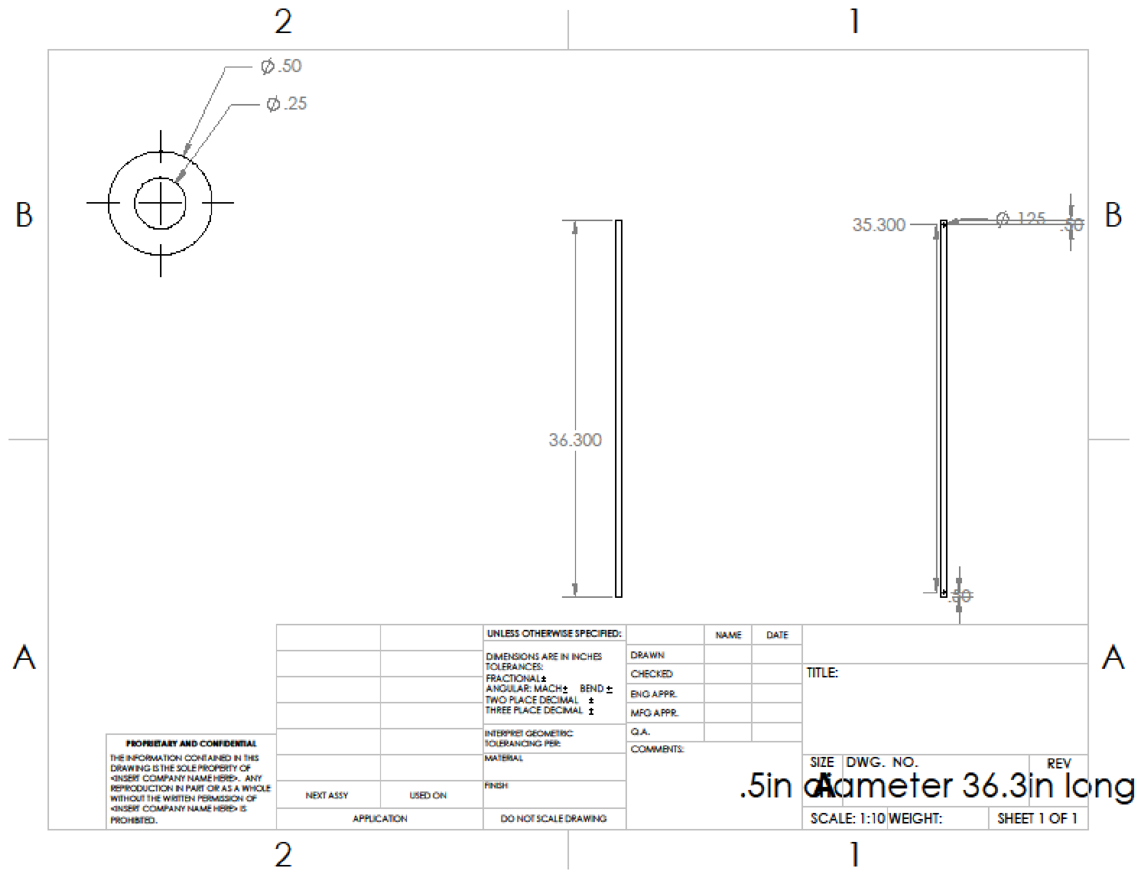
SHEET 1 OF 1



7/16"
1/8"
5/16"
0.19"
#10-24 Thread
5/8"
3/8"
Thread
Depth
1/4"
5/8"-3/4" Material Thickness
McMASTER-CARR
PART NUMBER
99637A304
http://www.mcmaster.com
© 2013 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Binding
Post



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.5in diameter 36.3in long
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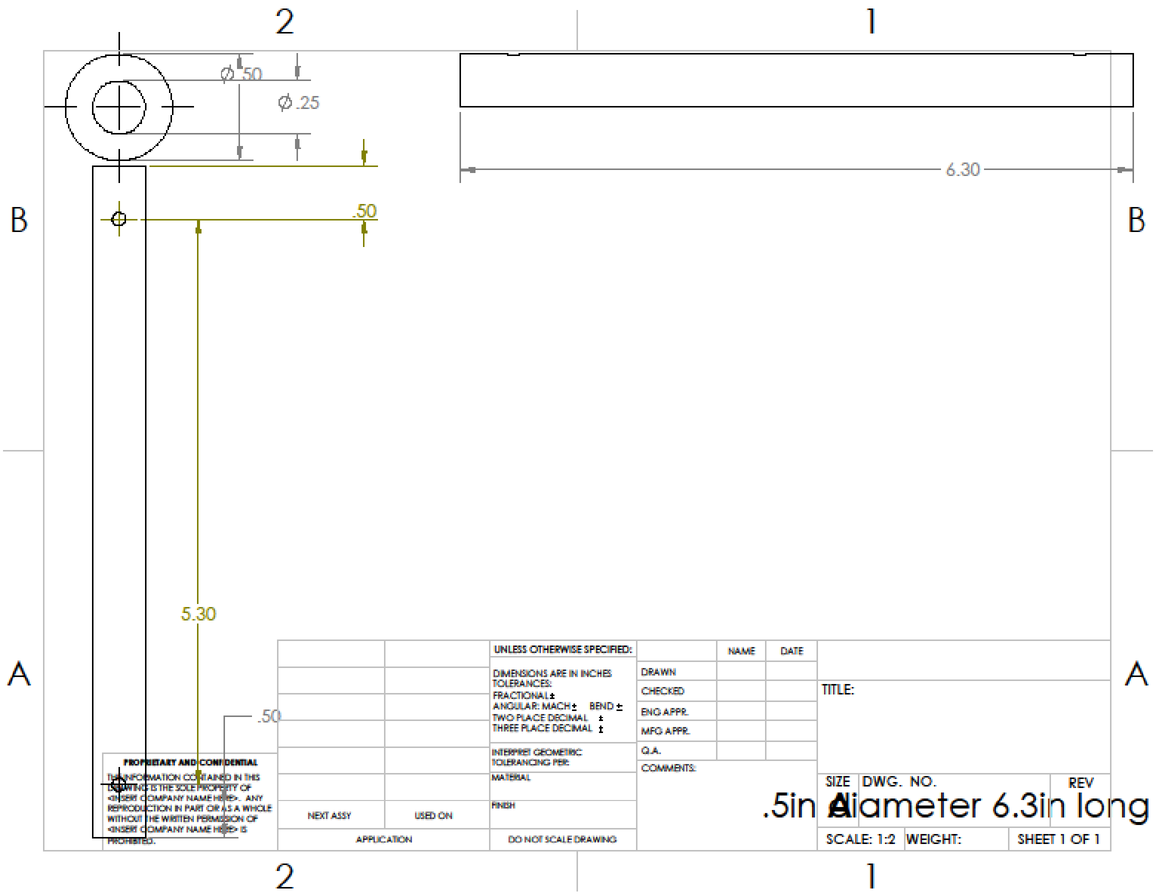
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
NEXT ASSY
USED ON
APPLICATION



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Q.A.
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.5in diameter 6.3in long
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
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USED ON
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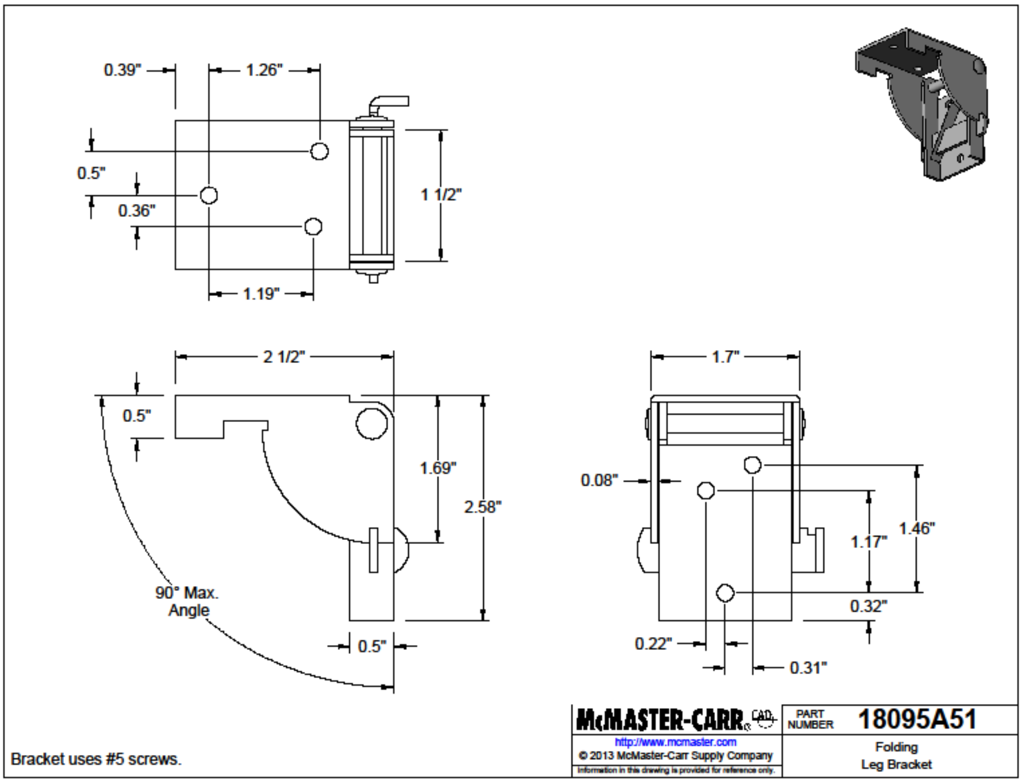
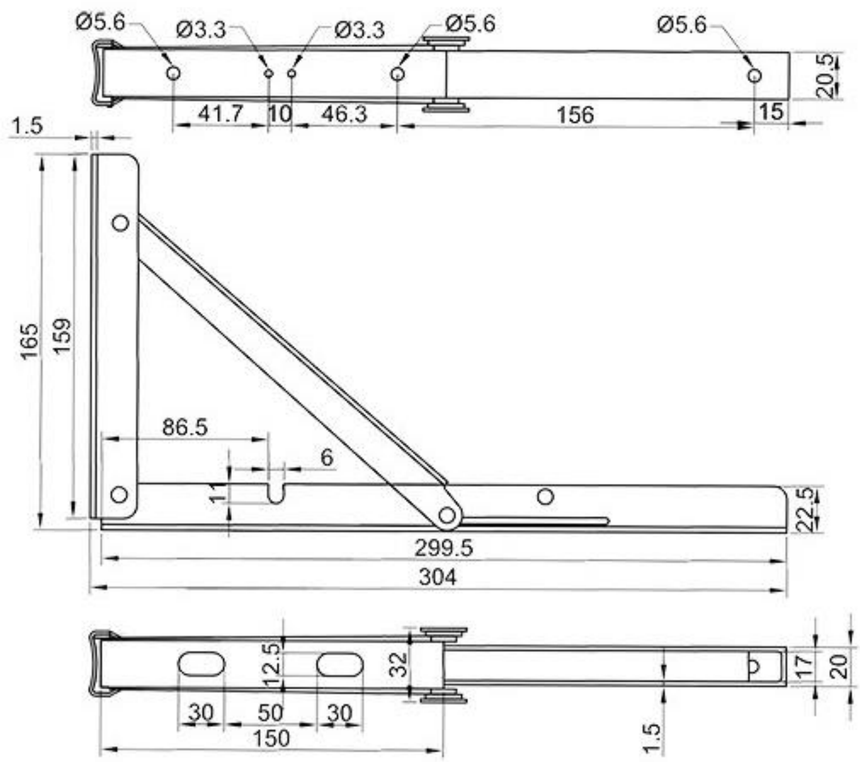

0.39"
1.26"
0.5"
0.36"
1 1/2"
1.19"
2 1/2"
0.5"
1.69"
2.58"
90° Max.
Angle
0.5"
1.7"
0.08"
1.17"
1.46"
0.32"
0.22"
0.31"
Bracket uses #5 screws.
McMASTER-CARR
http://www.mcmaster.com
© 2013 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
PART NUMBER
18095A51
Folding
Leg Bracket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4.4 DESCRIPTION OF THE DESIGN RATIONALE

1. Vertical Aluminum C Channel: This component was selected for it's ability to allow the linkages to nestle inside of it when folded. For this reason, an inner diameter of one inch was necessary. The beam was cut to 40" in length so as to closely mimic the height of traditional carts. Aluminum was the choice material for all parts of the assembly, where applicable, to minimize the weight of the entire cart.
2. Horizontal Aluminum C Channel: As with the vertical framing, this component was selected for it's ability to fit the moving linkages. The length of this component was selected at 20" to keep with the compatibility design. These outer framing parts were required to be 24" apart to allow the Trolley Bags to fit properly on the assembled shelf arms.
3. 1/2" Aluminum Round Pipe: This component was selected so that it the two pinned pieces together would snugly fit into the aluminum C channel when closed. This part was cut to 8.39 inches, with the 7/32" holes for the binding posts at ½" from the ends to meet the 7.39 inches required for proper movement from the calculations. The end of this part attached to the C channel was rounded off so movement was constrained at the flat end.
4. ½" Aluminum Round Pipe: This component was cut to 23.39 inches and connected part 3 to adjacent horizontal C channel (part 3). The holes for binding posts were also cut at 7/32" ½" from the ends of the ends.
5. Stainless Steel Binding Posts: Binding posts were the ideal fastener for this assembly to allow the pinned pieces to smoothly articulate about each other. 5/8" length posts were used to fasten the round piping to the C channel and 1" length posts were used to fasten the round piping to another piece of round piping.
6. ½" Aluminum Round Piping: This component was selected for its lightweight materialistic properties while also providing adequate support and length. It was cut to 36.3" long with 7/32" holes ½" from each end.
7. ½" Aluminum Round Piping: This component was used to secure the long vertical round piping to the adjacent vertical C channel. It was cut to 6.3" to allow for proper kinematics so as to not preclude the desired movements.
8. Folding Table Leg Bracket: This is a premanufactured part that was purchased from McMaster Carr. It was chosen for it's ease of hinge and ability to lock into position, constraining the range of motion to only 0 or 90 degrees. This ensured that the cart would not collapse during use or open when being transported.
9. Folding Shelf Bracket: This is another premanufactured part purchased from Amazon.com. This part was chosen for its load rating of 600 pounds per pair of shelves, far exceeding the design requirements. This shelf bracket also allowed for ease of locking the shelf arm into place without having to add any other fabricated parts.

5 ENGINEERING ANALYSIS

5.1 ENGINEERING ANALYSIS PROPOSAL

5.1.1 Signed engineering analysis contract

JME 4110

MECHANICAL ENGINEERING DESIGN PROJECT

ANALYSIS TASKS AGREEMENT

PROJECT: Portable Shopping System NAMES: Heath McClung INSTRUCTOR: Dr. Jakiela
Stacy Otzenberger

The following engineering analysis tasks will be performed:

Analysis before prototype:

1. Geometry and size of individual linkages
    - Calculated by hand using geometric relationships and material constraints

2. Degree of freedom for collapsible vertical and horizontal frame assemblies
    - Calculated by hand to ensure proper articulation

3. Frame stress calculations
    - Finite element analysis of frame under distributive loads with mock constraints

Analysis after prototype:

1. Testing of all articulating linkages and assembled frame for adequate clearances and operation
    - Physically cycle through full range of designed movement
    - Closely inspect individual links during cycling

2. Testing stability of assembled frame fully extended in different environments
    - Physically push/pull cart on multiple terrains unloaded and loaded

3. Testing under design brief conditions in real-world application
    - Physically take the entire system on a grocery trip to Aldis
    - Operate amongst consumers and traditional shopping carts

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

- All analysis was done by: Heath McClung & Stacy Otzenberger

Instructor signature: Mark J. Jakiela Print instructor name: JAKIELA
05/04/2018

5.2 ENGINEERING ANALYSIS RESULTS

5.2.1 Motivation

In order to ensure the shopping cart properly meets user needs, several analyses were calculated prior to prototype embodiment. Before any fabrication of the cart began, calculations were made to determine proper sizing, clearances, and capabilities of individual parts and the assembly as a whole. This was imperative to be sure the cart could handle a full load of groceries, assumed to be a maximum 100 pounds.

5.2.2 Summary statement of analysis done

Prior to physical embodiment, the shopping cart design was analyzed for proper fitment of parts, including linkages, so as to not prohibit desired articulation. Analyses were also required to utilize the most efficient materials for the overall design. Being that the portable shopping cart's purpose is to provide the user with a functional, lightweight, and durable alternative to what is currently available, the cart was analyzed to adequately fit the user needs while in both the open and compact positions.

5.2.3 Methodology

All analyses were calculated originally by hand then replicated and simulated in SolidWorks in order to ensure producibility and accuracy. After fabrication of the prototype, the cart underwent rigorous testing to verify results and capability.

5.2.4 Results

To construct the frame of the cart, linkages of the vertical and horizonal frame assemblies needed to be precisely calculated to prevent interference and allow for proper articulation. Since manufactured Trolley Bags were used, the design was needed to closely mimic the height and width of traditional shopping carts. A width of 24 inches was desired between left and right constraints. The linkages were selected to avoid having to fabricate slotted parts. The vertical frame assembly had a chosen overall height of 40 inches and the lower horizontal frame had a depth of 24 inches.

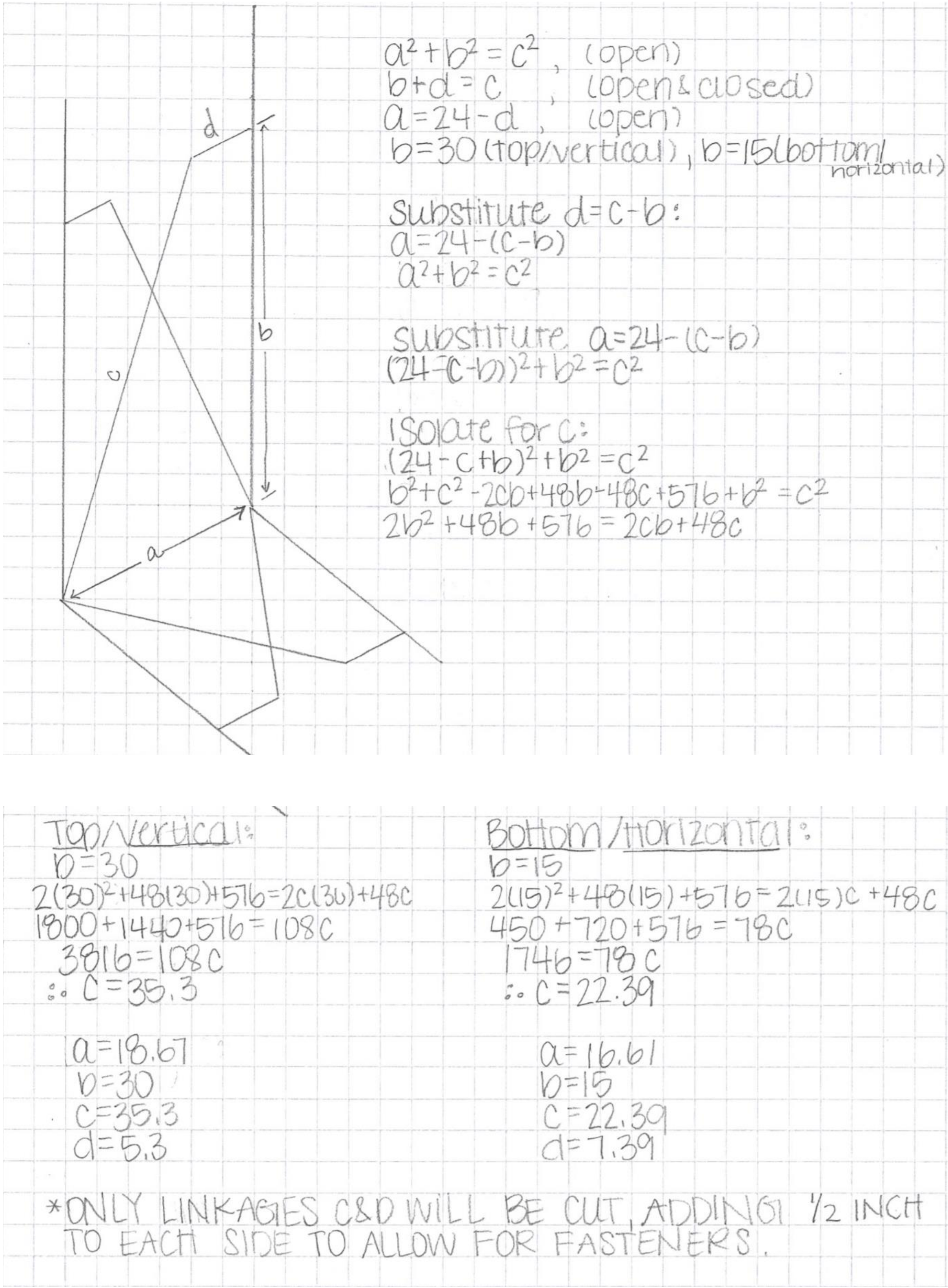

Figure 10-Linkage Sizing Hand Calculations

After calculations were made for lengths of linkages, a degree of freedom analysis was calculated to ensure the frame would articulate as required for our purposes. The top and bottom frames were analyzed once, since they had the same linkages and mechanics. For this analysis we used Gruebler's Equation:

$$DOF = 3L - 2J - 3G \tag{1}$$

Where DOF is degrees of freedom, L is number of linkages, J is number of joints, and G is number of grounded links.

$$DOF = 3(6) - 2(7) - 3(0) \tag{2}$$

Thus, resulting in four degrees of freedom, ensuring that after each link was pinned as calculated, the desired movement would still be achievable.

For the most vital purpose of the cart, to carry a heavy load of groceries, the manufactured shelf brackets were rated for a 600 pound load per pair, far exceeding the design requirements. The framing of the cart then was analyzed using SolidWorks Finite Element Analysis to verify chosen materials and sizes would not fail under the given load.

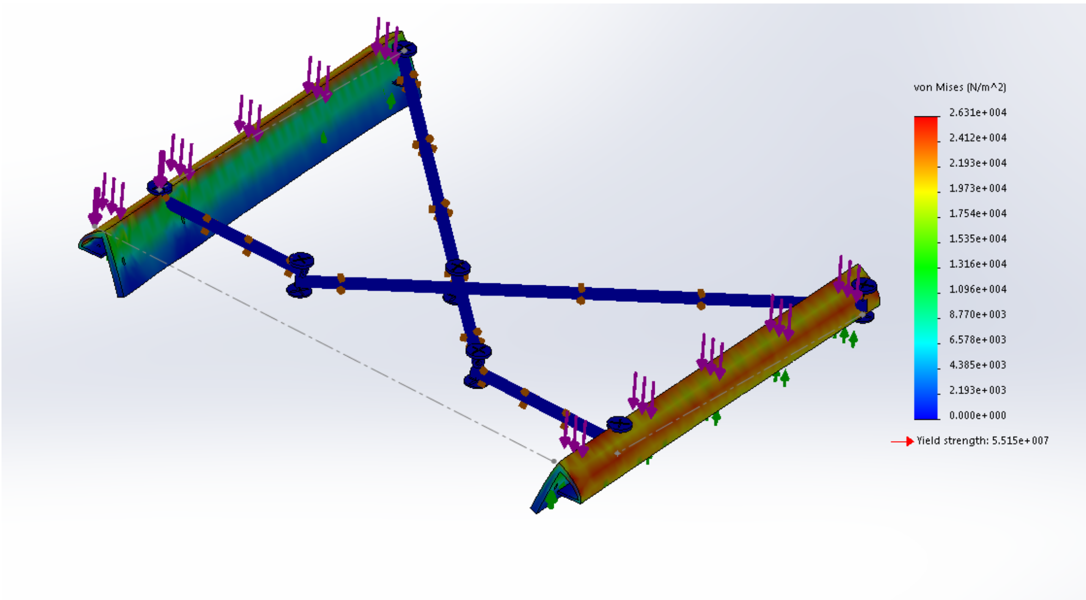

Figure 11-Bottom Frame FEA

5.2.5 Significance

The calculation of all geometries for the linkages provided exact specifications for the sizing of each part. Furthermore, the mathematical analysis of the each link proved the folding ability of the frame to behave in the desired manner. The hardware securing each link was re-examined after finding strict tolerances for the allowable articulation needed to operate correctly without unwanted play in individual links. The overall analysis sustains the kinematics potential of the design.

The Finite Element Analysis of the frame showed a potential issue of inward displacement of the bottom horizontal C-channel pieces at the maximum proposed load. Additional framework was proposed to reinforce the original design at these locations, even though our FEA models did not indicate the design would catastrophically fail.

6 RISK ASSESSMENT

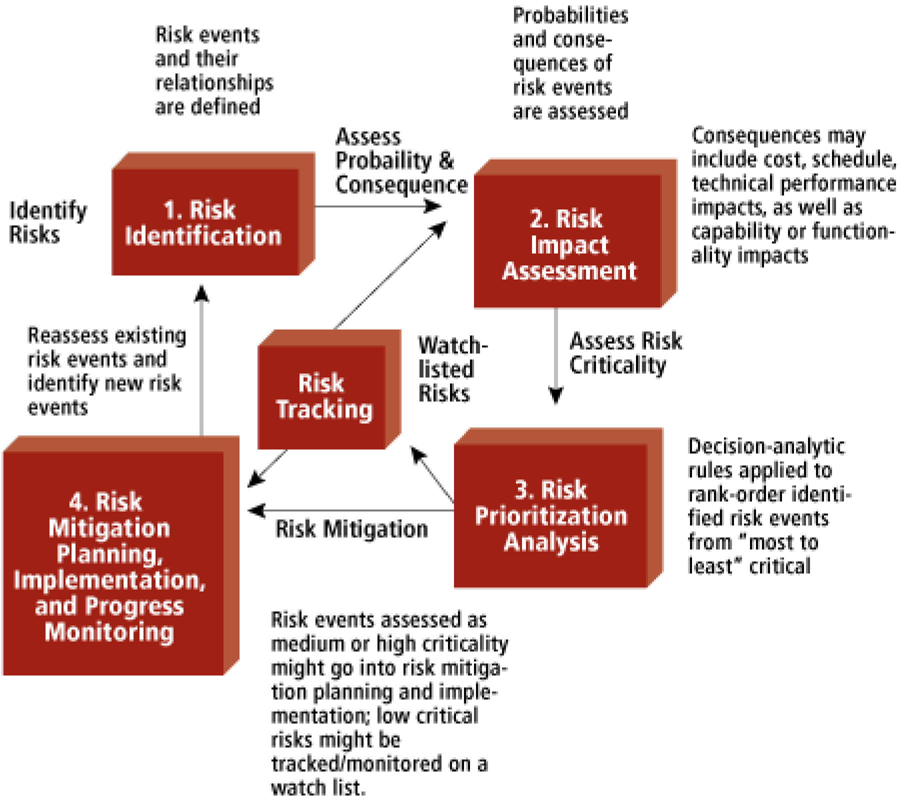

Figure 12-Risk Assessment Process

6.1 RISK IDENTIFICATION

In reference to the design of a portable shopping cart system, several types of risk have been identified. These specific risks revolve around any factors that may inhibit the safe, effective, and cost of production of the final design. This list surely does not address all potential risks that may arise from the time of the initial design to mass production of the product, but try to recognize the most significant barriers during this process.

- Product Reliability
- Fabrication
- Manufacturing Facilities

- User Preference
- Funding
- Liability

6.2 RISK ANALYSIS

6.2.1 Product Reliability

Risk associated with the continued use of the product over the course of time. Once the product leaves a manufacturing facility, the time until service is required may effect consumer perceptions.

Probability: High

Impact: High

6.2.2 Fabrication

Risk associated with issues in the ability to fabricate the design due to insufficient materials, equipment, or knowledge.

Probability: Medium

Impact: Medium

6.2.3 Manufacturing Facilities

Risk associated with the inability to manufacture the product due to a lack of manufacturing facilities being interested or capable of mass producing the design.

Probability: High

Impact: High

6.2.4 User Preference

Risk associated with potential users being comfortable with traditional designs and refusal to change behaviors despite newer technology.

Probability: Medium

Impact: High

6.2.5 Funding

Risk associated with a lack of funding from investors or consumers.

Probability: Medium

Impact: High

6.2.6 Liability

Risk associated with potential injuries or accidents involving the product being used by consumers.

Probability: Low

Impact: Medium

6.3 RISK MITIGATION

6.3.1 Product Reliability

The best way to address the reliability of the product over time is to conduct extensive testing to determine the life cycle of the final end-product. Testing in many different environments and circumstances attempts to mimic real world use of the design. Also, expanding tests to involve situations outside normal operating parameters may mitigate problems involved with the design being used in ways not initially anticipated.

6.3.2 Fabrication

The potential to experience issues in the initial fabrication process can arise due to a lack of required machinery/tools, unavailability of quality materials, or simply a lack of properly trained and educated personnel. With the inability to use WUSTL shop facilities, outside resources must be consulted to move the product from paper to the end product. Even with proper resources, machine failures and maintenance can impact timely fabrication of the design. The only way to mitigate these risks is to have redundancy in available facilities and personnel.

6.3.3 Manufacturing Facilities

Existing manufacturing facilities usually have an existing workload that keeps the workforce and resources unavailable to accept more work. Finding a facility willing to commit to providing all necessary manufacturing of a product involves persistent venturing and communication with a multitude of possibilities. To really mass produce the design, the construction of new manufacturing facilities is the only real way to ensure that quality production is the top priority. Redundancy in available facilities alleviates potential delays if a single site is compromised for any reason.

6.3.4 User Preference

Since the traditional shopping cart has remained unchanged for decades, introducing an entirely new design may not generate excitement in potential users immediately. Marketing campaigns can be developed to understand and possibly alter consumer perceptions once the product is available. Educating the masses on the improvements of the new design over the traditional design may sway some individuals to utilizing the new product, but others will always be reluctant to change. Consumer attitudes may shift over time with proven use of the new portable shopping system, but multiple marketing efforts will be required to boost potential sales and profits.

6.3.5 Funding

Securing unlimited funding for the development of a product is impossible. Efforts to attract investors is the only way to sustain adequate funding throughout the entire design to production process. Obtaining a line of credit can help in short-term gaps of funding, but relying solely on credit without available capital surely will not lead to profits. The responsibility of attracting new sources of funding falls on every individual involved in the development of a new product.

6.3.6 Liability

Eliminating potential risk of injury or property damage caused by the designed product is vital. Constant assessments regarding the safety of the product can help solve potential problems and prevent loss of funds in the form of lawsuits. Creating proper labeling and instructional material will educate the consumer regarding the product and its safe usage. To protect designers or the parent company, liability insurance should be kept current. Legal teams need to be consulted as well to review potential risks before making the product available to the public. After a product hits the market, records need to be kept on any reported safety issues or incidents to identify areas of the design that require alteration.

7 CODES AND STANDARDS

7.1 IDENTIFICATION

ASTM F2372 – 15: Standard Consumer Safety Performance Specification for Shopping Carts

Purpose and scope

1.1 This consumer safety performance specification covers performance requirements, test methods, and labeling requirements for shopping carts and restraint systems.

1.2 This specification is intended to cover children who are at least six months of age and at least 15 lb (7 kg) up to children who are not more than four years of age and who weigh no more than 35 lb (16 kg).

1.3 This specification does not include any provisions nor is intended for use of infant carriers.

1.4 No shopping cart or restraint system produced after the approval date of this consumer safety performance specification shall, either by label or other means, indicate compliance with this specification unless it conforms to all requirements herein.

1.5 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.6 The following precautionary caveat pertains only to the test method portion, Section 7, of this specification. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

[ASTM F2372-15, Standard Consumer Safety Performance Specification for Shopping Carts, ASTM International, West Conshohocken, PA, 2015, www.astm.org]

7.2 JUSTIFICATION

Justification for ASTM F2372-15

This standard was created to regulate the safety of shopping carts, specifically pertaining to the child restraints and seats. The document insists upon specific means of testing, labeling, and performance of the design. If the shopping cart is intended to provide children with a seat, then it must also be equipped with a functional restraint system that can adjust depending on the child's age and size. This standard covers children from 6 months of age and at least 15 pounds up to children weighing 35 pounds.

7.3 DESIGN CONSTRAINTS

7.3.1 Safety

The standard above place constraints on the required safety equipment needed in our design if it is intended for children to be placed in the cart. Functional and adjustable restraints must be present if any type of seat is available. Testing of required restraints is also mandated by specific modes of testing and will add time and cost the overall project. Our design will not include a child seat to mitigate the excessive constraints outlined by this standard.

7.3.2 Legal

The standard above places a constraint on the type of labeling that may be legally place on the product. Without compliance with all the standards outline, the cart must visibly show signage that indicates the device should not be used to transport children in any manner. By stating this clearly and in multiple locations, legal ramifications should be minimized for any improper use of the shopping cart.

7.4 SIGNIFICANCE

The ASTM standard presented enough constraints on the design that the choice was made to not include a child seat into our final product. Without the ability to test our product in the proscribed manner, excessive time and resources must be spent to fulfill all the obligations outlined in the standard. The threat of legal liability increases the risks significantly enough to deter including anything that falls within the scope of the standard to be involved. The final product will abide by the standard since it will be branded and marketed to be used without children.

8 WORKING PROTOTYPE

8.1 PROTOTYPE PHOTOS

Figure 13-Prototype in Opened Position

This photograph shows the full working prototype in its opened position ready for use.

Figure 14-Prototype in Folded Position

This photograph shows the full prototype in the folded position.

8.2 WORKING PROTOTYPE VIDEO

Link to YouTube video: https://youtu.be/1c9UsZjg-Zk

8.3 PROTOTYPE COMPONENTS

Figure 15-Hinge and Wheel Assembly

This photograph shows the locking hinge and wheel assembly attached to the lower frame.

Figure 16-Shelf Bracket

This photograph depicts how the shelf assembly is attached to the upper frame.

Figure 17-Carrying Handle

This photograph shows how the carrying handle affixes to the frame in the folded position utilizing a tractor pin.

Figure 18-Bottom End Closed Position

This photograph depicts the wheel assembly and opposite side of the carrying handle affixed with another tractor pin.

9 DESIGN DOCUMENTATION

9.1 FINAL DRAWINGS AND DOCUMENTATION

9.1.1 Engineering Drawings

See Appendix B for the individual CAD models.

9.2 FINAL PRESENTATION

Link to the video presentation: https://youtu.be/1c9UsZjg-Zk

10 APPENDIX A - PARTS LIST/BILL OF MATERIALS

Part Number	Description	Quantity	Vendor	Price
1, 2	Aluminum C Channel 1.25"x1.25"	16'	Shapiro Metal Supply	16.00
3, 4, 6, 7	Aluminum Round .5"	16'	Shapiro Metal Supply	46.88
8	Folding Table Leg Bracket	2	McMaster Carr	12.58
9	Folding Shelf Bracket	4	Amazon.com	43.58
10	Trolley Bags	4	Amazon.com	30.00
11	Stair Climbing Wheel Assembly	2	Amazon.com	24.00
12	3" Caster Wheels	2	Menards	12.00
13	2" Flat Aluminum	6'	Menards	5.69
14	.5" Flat Aluminum	12'	Mcmaster Carr	8.96
15	5/8" Binding Post	10	Fastenal	4.00
16	1" Binding Post	10	Fastenal	6.00
17	Square Lock Pin	2	Farm and Home Supply	3.00
18	.5" Round Aluminum	2'	Menards	5.00
19	Hanger Bolt	4	Menards	6.00
20	5/8" Screw Set	36	Menards	5.29
21	1 1/2" Screw Set	8	Menards	3.29
			Total Supplies:	**$232.27**

11 APPENDIX B – COMPLETE LIST OF ENGINEERING DRAWINGS

A complete set of SolidWorks drawing files can be found at the following link:

https://drive.google.com/drive/folders/1NxYG0KmejiIVGXZciKK2ol29jzEvy49N

12 ANNOTATED BIBLIOGRAPHY

IDEO. (1999, April). Reimagining the Shopping Cart. Retrieved January 29, 2018, from https://www.ideo.com/post/reimagining-the-shopping-cart

This website provided the most significant design similar to our own design brief and also provided a link to the actual ABC *Nightline* episode featuring the design process. The information found in this article helped shape our own priorities while creating a different design for the same problem.

ASTM F2372 – 15. (1996). Retrieved January 29, 2018, from https://www.astm.org/Standards/F2372.htm

The only safety standard found regarding shopping carts involves child restraints and clearly labeled signage warning parents of the consequences of not using provided seat belts.