Fall 2016

Autonomous Shopping Cart

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In shopping centers across the United States, customers must return shopping carts after they used them by themselves. Because the return stalls are often far away and many consumers are hesitant to do so for a variety of reasons, a significant number of shopping carts are left in parking lots after being used. This results in expenses to the store in the form of damaged carts, man hours required to return each one, and law suits from customers whose cars are damaged by free carts.

We will design a mechanism by which shopping carts are programmed to return themselves to either a stall or to the store itself. The carts would locate the nearest return area, and then navigate themselves to a preprogrammed track which they would then follow to be returned to the correct area. This system will retrofit to the rear wheels of the cart.

Autonomous Shopping Cart Return

Senior Design Project
Fall 2016

Steven Taschner, Asim Zaidi, John Gutsch

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1 INTRODUCTION

1.1 PROJECT PROBLEM STATEMENT

In shopping centers across the United States, customers must return shopping carts after they used them by themselves. For a variety of reasons, a significant number of shopping carts are left in parking lots after being used. This results in expenses to the store in the form of damaged carts, man hours required to return each one, and law suits from customers whose cars are damaged by free carts. This project is an add-on mechanism by which allows shopping carts to return to the shopping center autonomously. The cart should be able to locate a preset track that is set in the parking lot and from this track return itself to the shopping center. This system would utilized a motor and wheels located on the rear of the cart, enabling it to be retrofitted to carts currently in use without impeding the cart's ability to stack. This statement should evolve as your project progresses.

1.2 LIST OF TEAM MEMBERS

Washington University in St. Louis Engineering

The team consisted of John Gutsch, Asim Zaidi, and Steven Taschner.

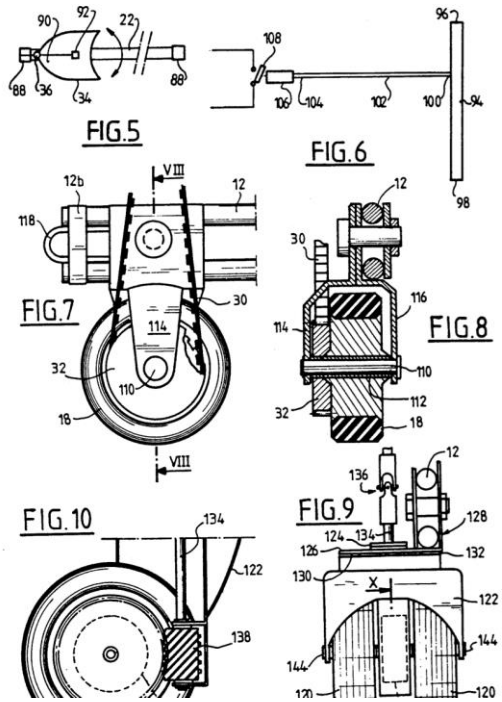
2 BACKGROUND INFORMATION STUDY – CONCEPT OF OPERATIONS

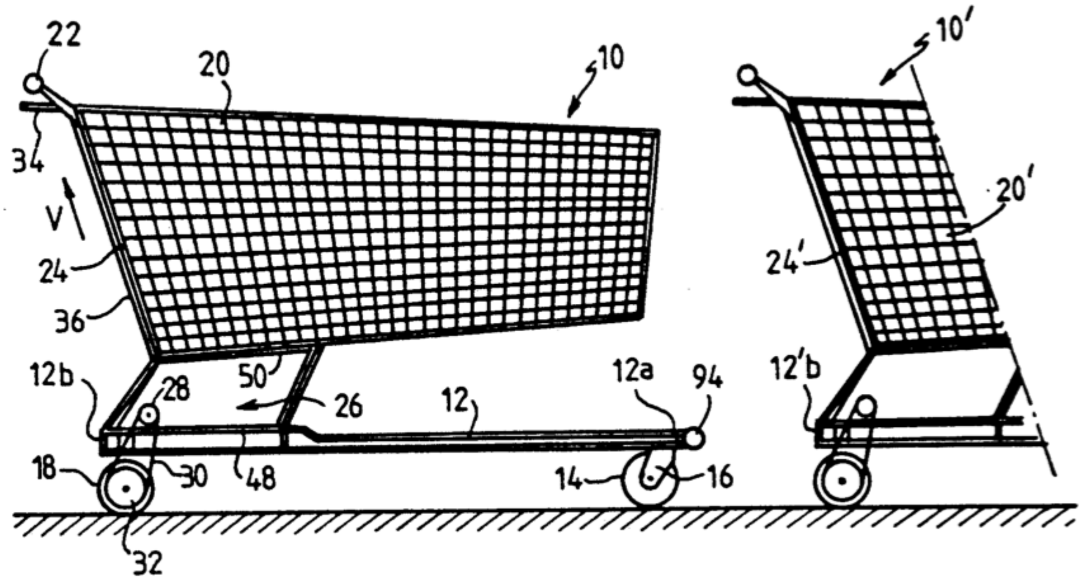
2.1 A SHORT DESIGN BRIEF DESCRIPTION THAT DESCRIBES THE PROBLEM

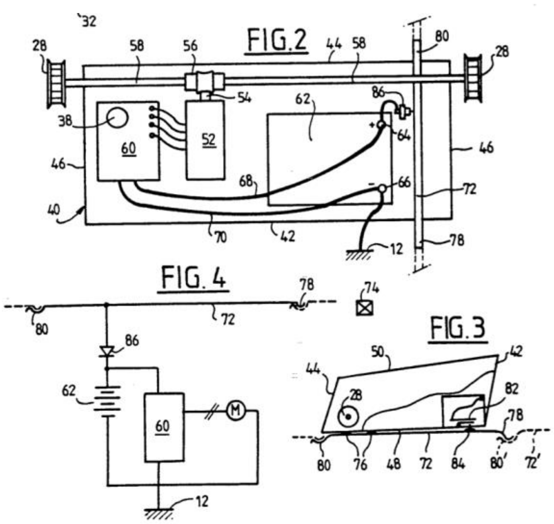
For grocery stores and other markets that who are dissatisfied with the abandon carts in their parking lot and the inefficiency of sending an employee to gather these carts, our product is a motorized shopping cart that autonomously returns to the store. This provides a more efficient means of collecting carts and ensures that carts will not be abandoned in the parking lot. This is unlike the motorized cart collector because it is unmanned and does not leave carts in the parking lot for some time before collecting them.

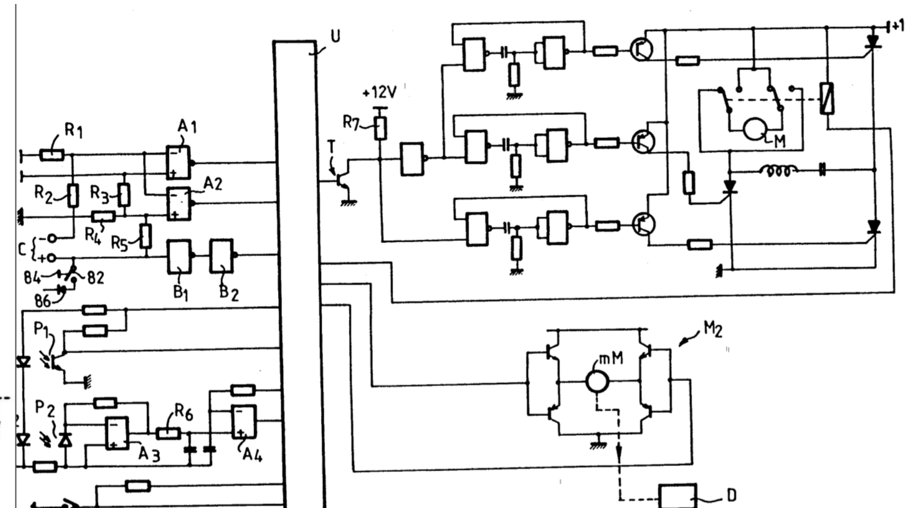
[57] **ABSTRACT**

A system for motorizing a shopping cart or the like, the system comprising: a) a drive unit including an electric motor and a motor control circuit; b) a manual control member situated close to the push bar and suitable for acting on the control circuit for controlling both forwards and backwards displacement of the cart; c) a transmission between the motor and at least one wheel of the cart; d) a rechargeable storage battery for powering the motor; e) a feed bar suitable for recharging the battery from a fixed electrical charger, said bar having a front end and a rear end such that its front end is suitable for forming an electrical contact with the rear end of the bar of the preceding cart in a row, with the first cart in a row being connected directly to the charger; f) an electrical connection between said bar and the positive terminal of the battery, when said electrical contact is established between the two above-mentioned bars; and g) a permanent electrical connection between ground constituted by the chassis and the negative terminal of the battery.









(57) **ABSTRACT**

A battery powered, electric motorized cart and burden carrier which may be manually pushed or pulled to a shopping area for use during shopping and for transporting merchandise thereafter. Battery powered motors and gearing associated with the rear driving wheels are controlled from a control box on a lanyard attached to the cart so that the loaded cart may be either operated and controlled by an individual walking in front or the rear thereof. Steering is effected through the swivelly mounted front wheels by the operating exerting a tug on the lanyard or applying forward pressure to the rear of the cart when the control box is arranged and supported thereat. Battery charging may be accomplished by actuating a control box switch to close the circuit to the battery and manually pushing the cart to rotate the motor shafts and cycle the amperage back into the battery. Another way is to utilize an alternating current charging adapter.

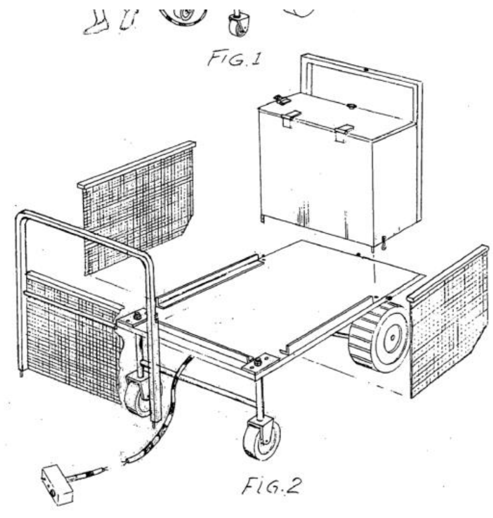


FIG.1

FIG.2

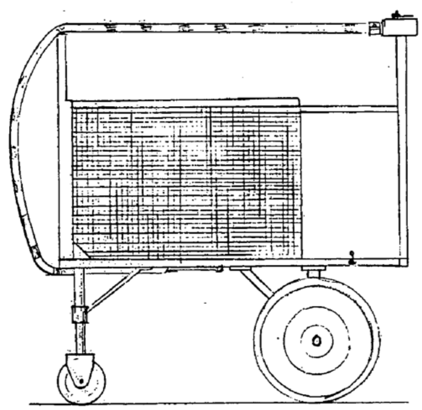
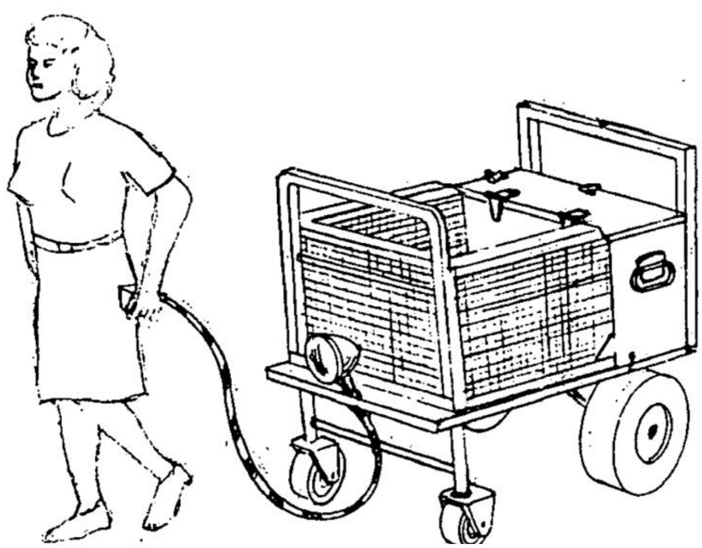


FIG. 4



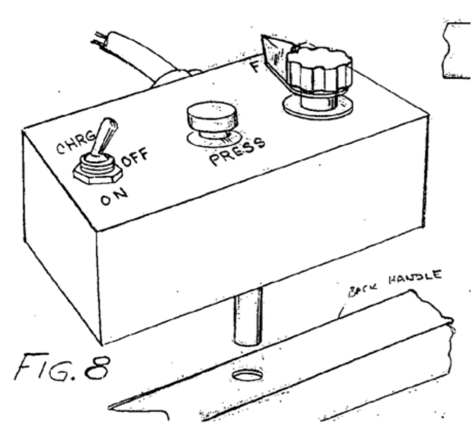


FIG. 8

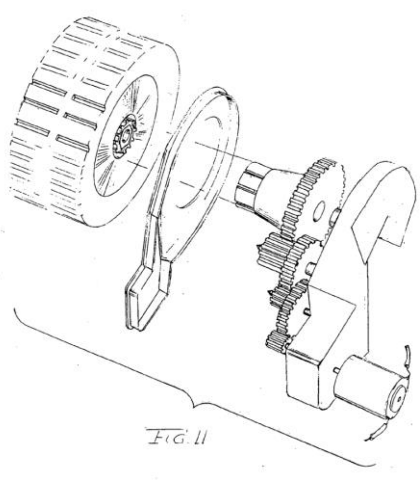


FIG. 11

http://www.nbc12.com/story/28742651/on-your-side-walmart-denies-negligence-after-cart-damages-customers-car

On Your Side: Walmart denies negligence after cart damages customer's car

Tuesday, April 7th 2015, 3:07 pm CDT

By Diane Walker, Anchor dwalker@nbc12.com

RICHMOND, VA (WWBT) -

You're in a store parking lot when a grocery cart crashes into your car and makes a dent. Who's responsible and who should pay: you or the store?That runaway shopping cart scenario played out at the Walmart on Forest Hill as Sherman Price says he was sitting in his car waiting for his nephew to finish shopping for him. He says he saw it coming."But there was nothing I could do. I'm in a chair. I couldn't get out to stop it," he said.Price says an employee removed the windblown basket off his car parked in front of the store in a handicap spot. He didn't get out to inspect his car when it happened."The wind was so high that evening, when it hit it made a bang noise," Price said. "But I didn't think that it had done enough damage to jam the door. But when I got home, I couldn't get out of the car. Someone had to take a screwdriver and pry it and open the door so I could get out."Store surveillance cameras caught everything. Price filed a claim, which was denied a week or so later."To me, they should man up and be responsible," he said. "I mean, it's their property. It's their basket. You know I didn't do anything. They should pay for the damage."

Typically, neither side wants to pay. Price said he fears his insurance rates will increase if he makes a claim, and Walmart isn't looking to pay every customer with a claim but says each case is reviewed individually.

In a statement, Walmart denied negligence on the store's part. The statement reads, "We regret that a customer's car was damaged in our parking lot. After reviewing this incident, including surveillance video, it is clear that the parking lot was properly maintained by an associate and the accident was due to another shopper allowing a cart to roll into the vehicle."

"They don't feel like they need to pay because an employee didn't leave the basket out there, which doesn't make any sense to me," Price said. "They have employees who gather the baskets up to get them inside the store. An employee could have left the basket there. It's just in front of the store."

Price says he eventually got the dent fixed for $200.

A cart with a motor on board driving around a parking lot must successfully reach the store every time. There are many examples of carts hitting cars or customers and causing damages and injuries. A significant risk to this project is the ability to get a cart to successfully find and avoid obstacles while also reaching the destination every time. This requires a very polished product.

http://www.astm.org/Standards/F2372.htm

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

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).

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

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.

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.

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.*

These standards and codes must be complied with for any cart to be approved. The shopping carts we will work with will have restraints and child seats on them. We must consider this when we add a motor on board; we must consider the chance that the motor engages unintentionally with a child onboard. We must further meet all published standards and our add–on module may not hinder the cart from the standards it held originally.

2.2 SUMMARY OF RELEVANT BACKGROUND INFORMATION

For any cart using stores that who are dissatisfied with the abandon carts in their parking lot and the inefficiency of sending an employee to gather these carts or allowing the carts to disappear all together, our product is an add on module for a motorized shopping cart that autonomously returns to the store by a predetermined safe route and uses sensor input. The cart will return upon the push of a button or actuation of a lever so long as there is no child in the seated restraint. This provides a more efficient means of collecting carts and ensures that carts will not be abandoned in the parking lot. This is unlike the motorized carts seen above because it is unmanned and can return to the store when necessary, and it does not involve creating entirely new carts or disassembling carts to install, but is an add-on module.

highlighting denotes changes to the value proposition.

The cart return module must return only when it is desired to, thus it will wait on the command from a button or lever. This ensures it will not begin tracking around with groceries or infants aboard. The seat must have a sensor within to prevent a operation when a child is still present. The tracks must keep carts away from cars, and sensors must ensure moving cars and people are avoided by the carts to prevent damage and injury as well as to comply with any codes or specifications. These sensors must also ensure the carts do not get stuck in trafficked locations or areas prone to high winds were the could potentially blow into cars or persons, ensuring carts will comply with the standards shopping carts must comply with so that the carts remain safe and convenient. This module is very different because it is quick and easy to install or uninstall keeping the initial cost low and ensuring there is no need for employee paid time to collect the carts.

3.1 CONCEPT DESIGN AND SPECIFICATION – DESIGN REQUIREMENTS\

What about this design is most appealing to you?

- Time Savings
- Cart must function whithout employee interaction including charging
- Importance: 4

What is your primary concern?

- Avoid interference with traffic
- Cart must navigate a dynamic parking lot without contacting or interfereing with vehicles or customers.
- Importance: 5

What concerns do you feel customers might have?

- Both elderly and infant people depend on the cart stability
- The cart must not activate while in use or with anything in the cart
- Importance: 5

Would you be willing to compromise any aspect of the cart for this design?

- The cart's capacity could be sacrificed with minimal loss, The carts must nest
- The battery could be stored in the cart as opposed to beneath the cart
- The carts must be able to nest with the module attached
- Importance: 4

Do you believe these carts are exposed to significant amounts of rain or snow?

- The carts will be exposed to rain storms, but can be expected to be free from submersion
- The components must be safe for use in rain
- Importance: 5

Would you be opposed to painting the parking lot?

- No, we would allow the parking lot to be painted, but we can not promise it will stay perfect
- The paint application must be durable
- Importance: 3

How often are carts replaced?

- Carts are expected to last at least 5 years.
- The module should last at least 5 years
- Importance: 3

Figure 3.1.1: Customer interview flow chart

3.2 OPERATIONAL REQUIREMENTS ALLOCATED AND DECOMPOSED TO DESIGN REQUIREMENT

3.2.1 Functional allocation and decomposition

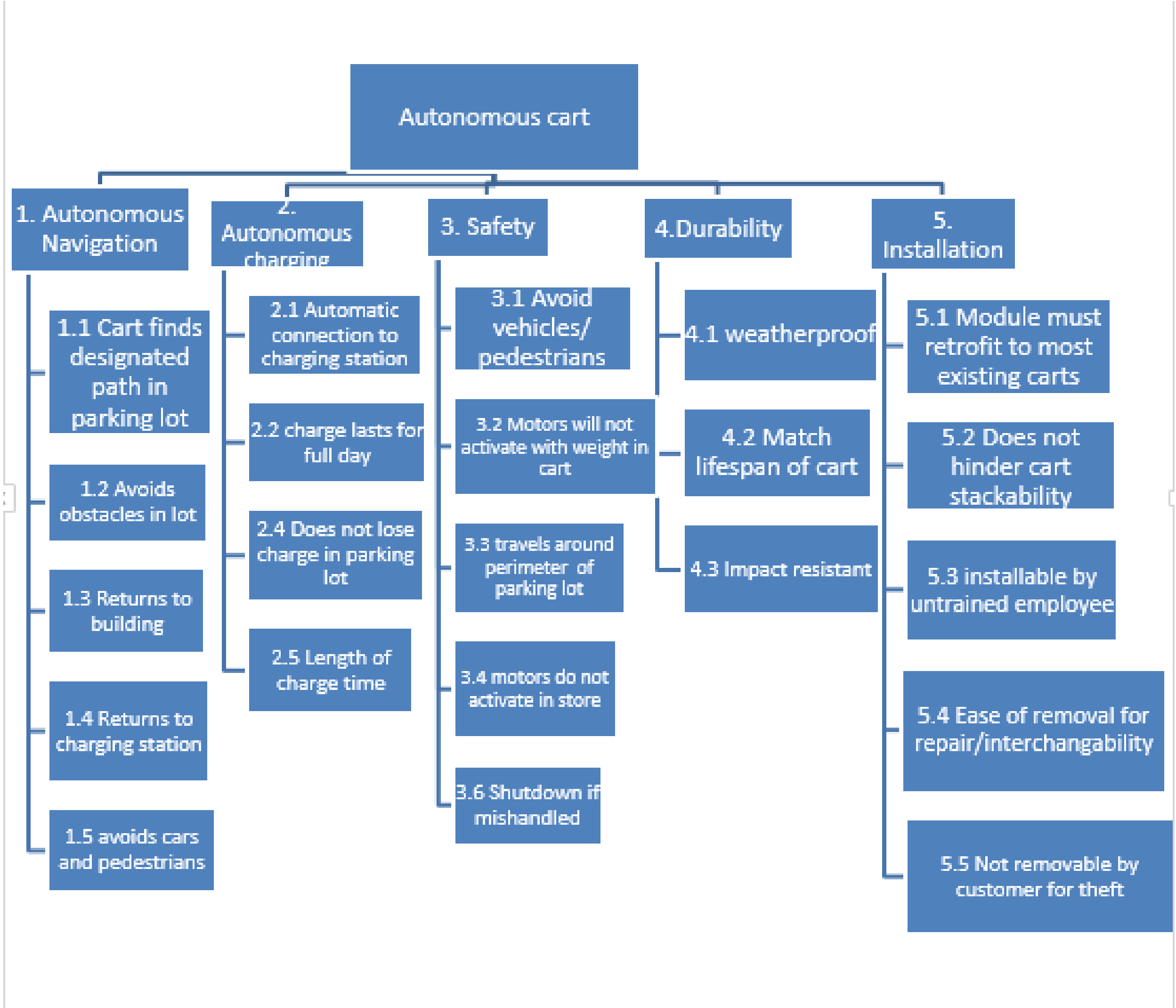


Figure 3.2.2: Operational requirements flow chart

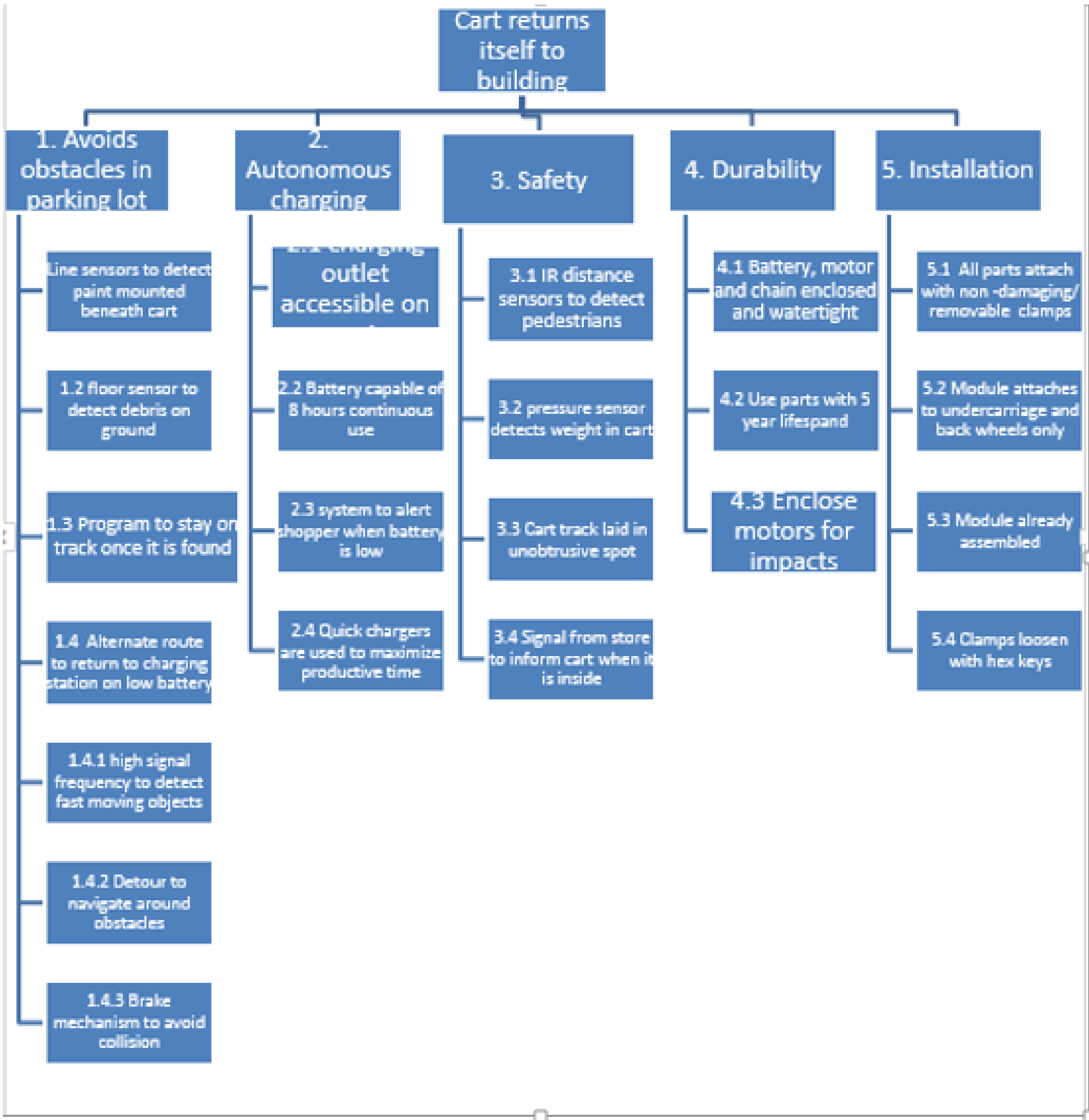


Figure 3.3.3 Design Requirements Flow Chart

3.3 FOUR CONCEPT DRAWINGS

Figure 3.3.1 Chain Driven Motor Design

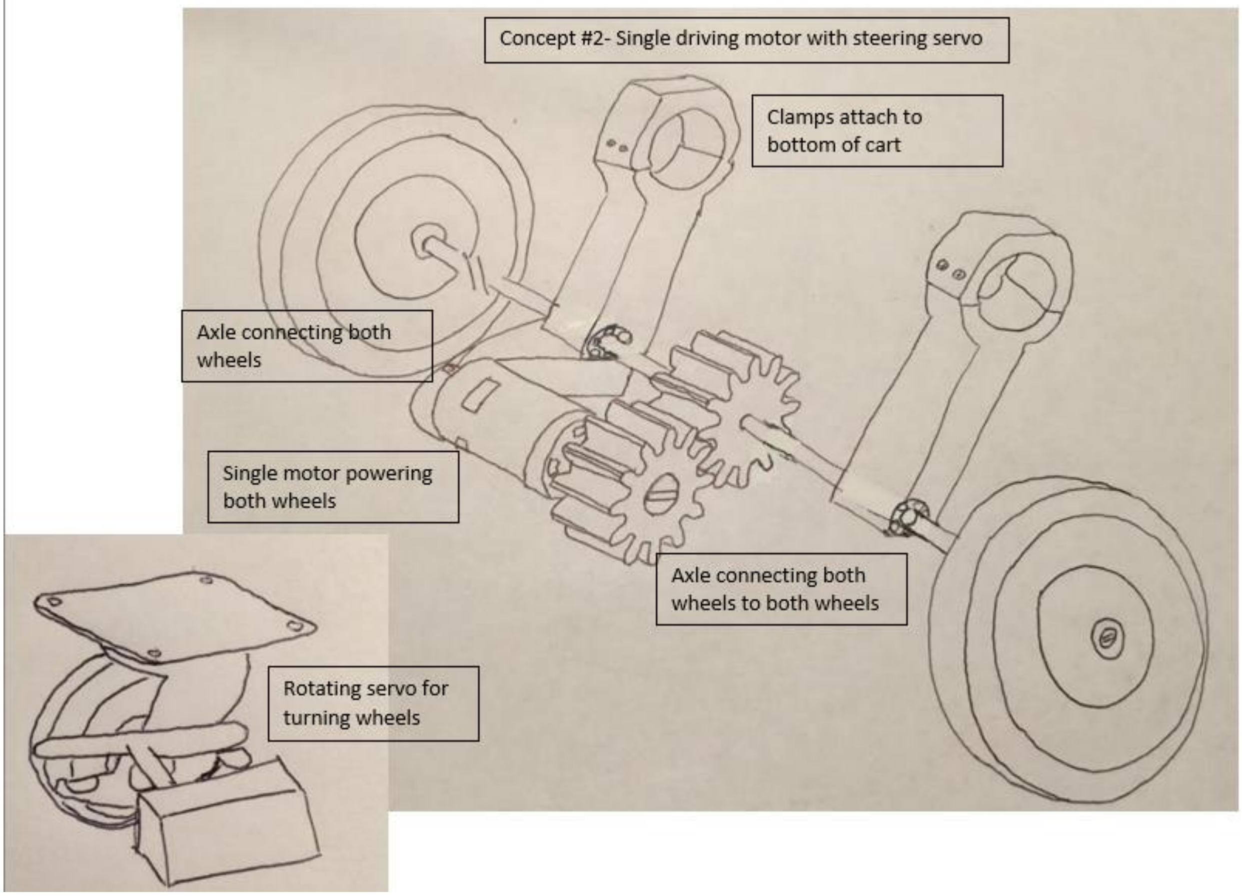


Figure 3.3.2 Single driving motor design

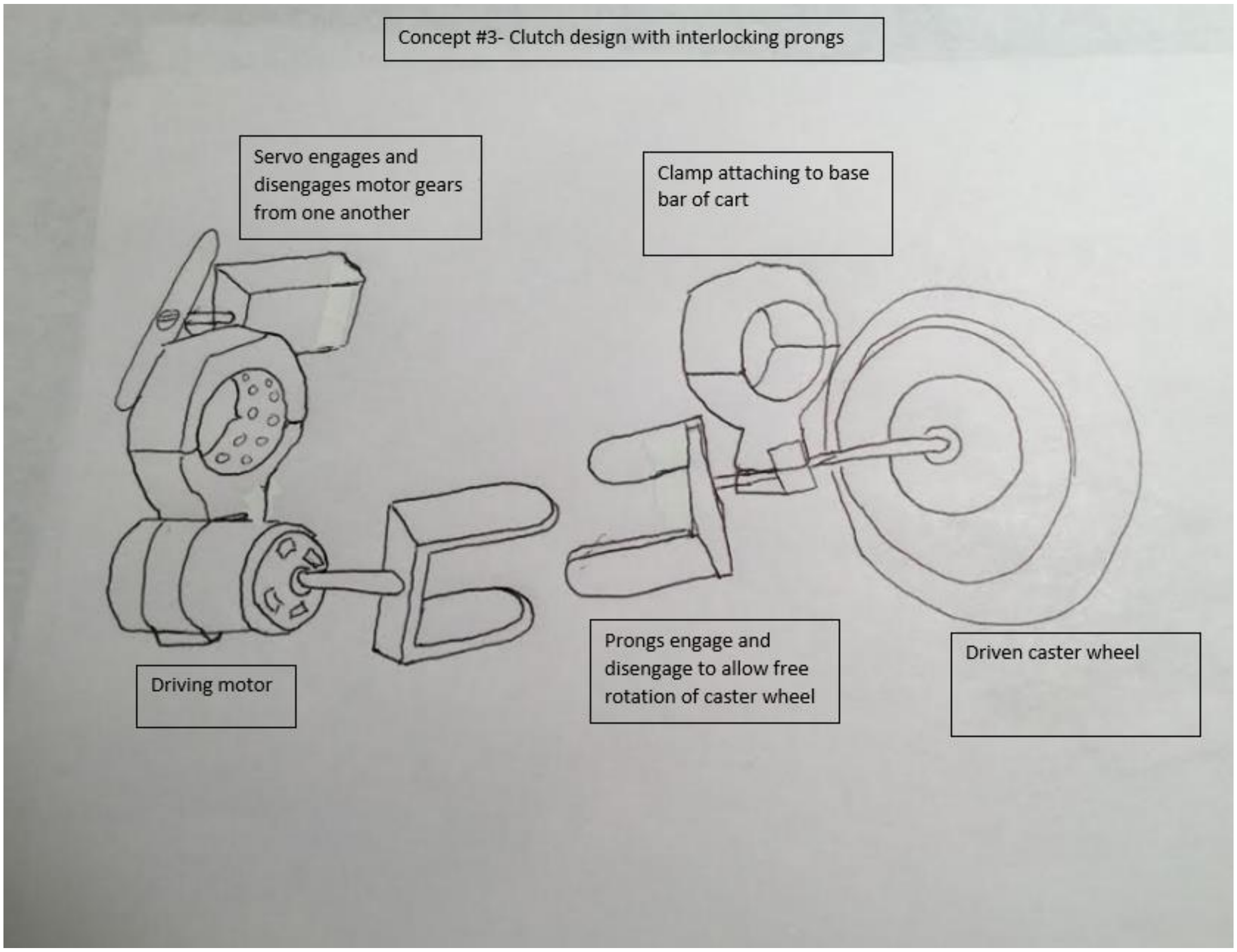


Figure 3.3.3 Clutch Design

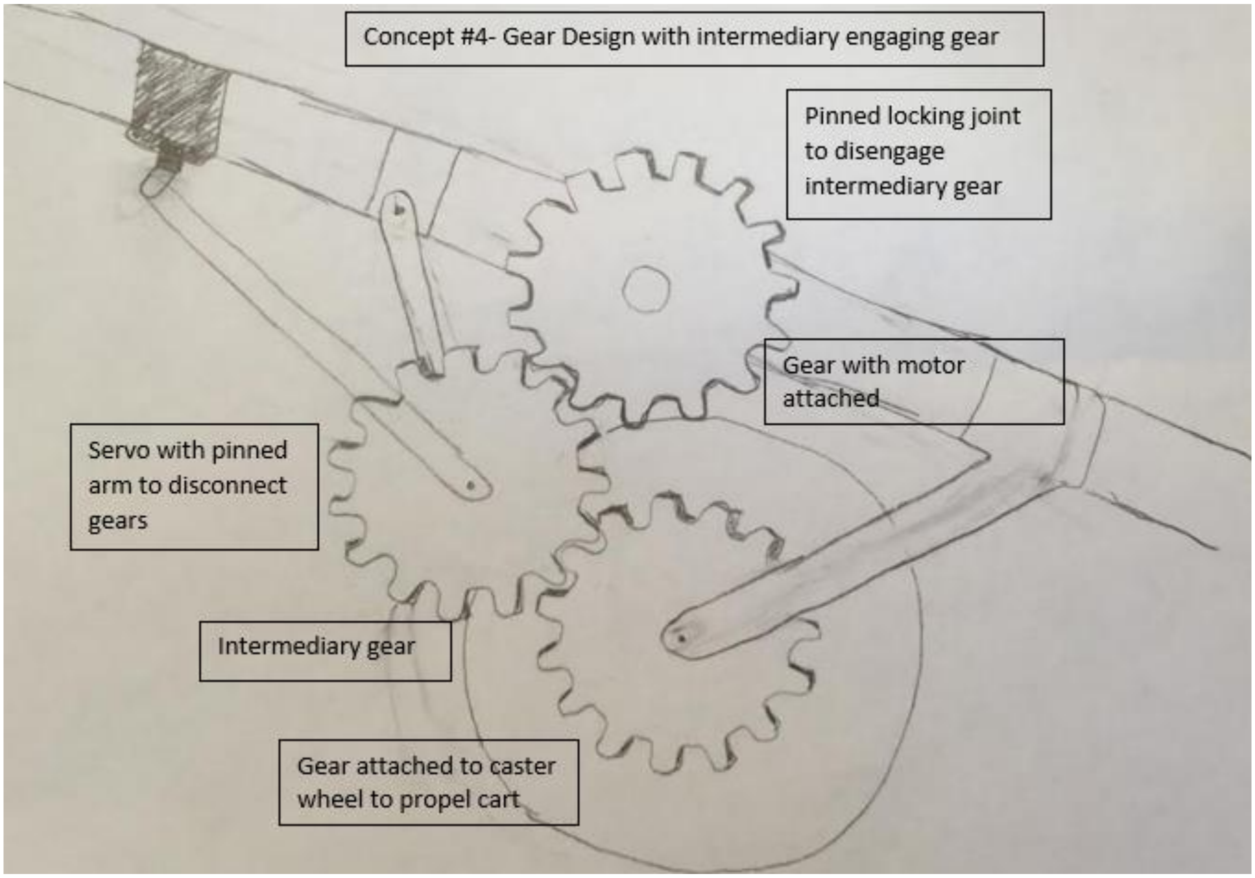


Figure 3.3.4 Gear Design

3.4 CONCEPT SELECTION PROCESS

3.4.1 Preliminary analysis of each concept's physical feasibility based on design requirements, function allocation, and functional decomposition

Concept #1 Belt Driven Motor

The shortcomings of the gear driven motor are mainly constrained to the lack of durability of the model and the concerns of weatherproofing it. These concerns are present because the chain can wear out, rust out, or become disengaged due to a variety of factors. The chain system would also require more extensive maintenance. Despite this, it is a reliable and durable design within the 5 years that is required of the cart. It also gives enough ground clearance to be used safely while maintaining the ability to be stacked with other carts. It can be installed cheaply and replaced cheaply, and it requires the fewest number of sensors in order to operate safely.

Concept 2: Single driving motor with steering servo

The singular driven motor performed the worst in concept scoring. This is because it ruins the most important aspect of the shopping cart, which is its stackability. There is not enough room for unstacked shopping carts in stores, which makes the design the most infeasible. Some of the advantages to the break design are its durability. The single steering wheel also gives the cart a larger turning radius than the other designs, as it cannot pivot around a stationary back wheel. It is the only design with an actual breaking mechanism, giving it a small stopping advantage over the other designs, which rely on motor friction to stop the cart. The two required Servos make the application a more expensive option than the belt and gear driven motor. This design is easily weatherproofed and versatile, and could still be useful to other autonomous cart application, just not shopping carts.

Concept 3: Clutch Design with interlocking motors

The clutch design was found to be the second most attractive after the belt. The disadvantages are the Servo requirement to move the entire motor and prong mechanism, which is unnecessary for the gear design. It also requires a servo to engage and disengage, making it more expensive than the belt, but still competitive with the other designs. The prongs are also cheaper and easier to manufacture than gears will be because the tolerances will be very large. The clutch will require more torque than the gear design, as the prongs make it harder to gear the motor up and down. A major advantage of the prongs over the gear is that they will take up less room on the bottom of the cart, and will allow for more clearance. This will make them more durable, but does not make up for its deficiencies in performance.

Concept #4 Gear Driven by Motor

The advantages of the gear driven motor mechanism are mainly derived from the durability of the design. It is the most reliable of the designs when working. Its motor does not requires much power, so a small battery can operate it. It is very compact, and its high ground clearance makes it safe from damage due to scraping against the ground. At the same time, it is not very easily weatherproofed, so it is not expected to last very long. It would be the most expensive of all of the designs, and the build process would be complicated. Furthermore, maintenance on the device would not be easy and would require much knowledge about the device. These factors make it a poor option compared to others.

3.4.2 Concept scoring

Need Number	Need	Importance
1	Module is autonomous	4
2	Charging must be automatic	4
3	Must avoid obstacles	5
4	Operate only when desired	5

5	Battery Storage Placement	2
6	Ability to nest	4
7	Safe to use in rain	5
8	Paint application must be durable	3
9	Module must be durable	3

Table 3.4.2.1 Concept scoring

Chain Driven Design

Metric Number	Associated Needs	Metric	Units	Worst Value	Max Value	Actual Value	Normalized Value
1	2, 3, 7, 9	Clearance	cm	3	8	5	0.400
2	1, 3	Number of Floor Sensors	integer	8	4	4	1.000
3	1	Battery Size	mAh	8000	3000	4000	0.800
4	9	Expected Work Life	Years	0.5	5	5	1.000
5	6	Nest Ranking	integer	0	3	3	1.000
6	9	Required Motor Power	Watt	1000	350	450	0.846
						TOTAL	5.046

Table 3.4.2.2 Score for Chain Driven Design

Gear Driven Motor

Metric Number	Associated Needs	Metric	Units	Worst Value	Max Value	Actual Value	Normalized Value
1	2, 3, 7, 9	Clearance	cm	3	8	3	0.000
2	1, 3	Number of Floor Sensors	integer	8	4	6	0.500
3	1	Battery Size	mAh	8000	3000	6000	0.400
4	9	Expected Work Life	Years	0.5	5	0.5	0.000
5	6	Nest Ranking	integer	0	3	1	0.333
6	9	Required Motor Power	Watt	1000	350	650	0.538
						TOTAL	1.772

Table 3.4.2.3 Score for Gear driven motor

Single Driven Motor

Metric Number	Associated Needs	Metric	Units	Worst Value	Max Value	Actual Value	Normalized Value
1	2, 3, 7, 9	Clearance	cm	3	8	8	1.000
2	1, 3	Number of Floor Sensors	integer	8	4	8	0.000
3	1	Battery Size	mAh	8000	3000	8000	0.000
4	9	Expected Work Life	Years	0.5	5	2	0.333
5	6	Nest Ranking	integer	0	6	0	0.000
6	9	Required Motor Power	Watt	1000	350	1000	0.000
						TOTAL	1.333

Table 3.4.2.4 Score for Single driven motor

Clutch Design

Metric Number	Associated Needs	Metric	Units	Worst Value	Max Value	Actual Value	Normalized Value
1	2, 3, 7, 9	Clearance	cm	3	8	4	0.200
2	1, 3	Number of Floor Sensors	integer	8	4	6	0.500
3	1	Battery Size	mAh	8000	3000	3000	1.000
4	9	Expected Work Life	Years	0.5	5	3	0.556
5	6	Nest Ranking	integer	0	3	2	0.667
6	9	Required Motor Power	Watt	1000	350	350	1.000
						TOTAL	3.922

Table 3.4.2.5 Score for Clutch Design

3.4.3 Design requirements for selected concept

The chain driven rear mounted motor is the clear “winner. The cart should not have more than 4 infrared distance sensors. This will keep the load down on the signal processing and will allow for a fast program execution. Fewer than 4 infrared sensors will impede the carts ability to check its surroundings and avoid interference with traffic or customers. The distance sensors need to detect static objects at least 1 ft away from the cart and dynamic objects 8 inches away. The battery on the cart needs to allow the cart to operate continuously for two hours. The cart motors will never run continuously for more than two hours, but a large battery will allow other features to be added to the cart, like a credit card reader and screen for in store navigation. A small battery risks running out of power while in use, leaving it vulnerable to theft. The cart should have an expected working life of 5 years or greater. The carts are assumed to last for five years according to our interviews. Customers of the product will not want to refit an old cart with a new module because the module does not last five years or more. The fear of creating a module that lasts more than five years is the general idea of over engineering a solution. If the module is built to last 100 years, it will cost too much, weight too much, and sacrifice critical metrics unnecessarily. One metric that is of utmost importance is the carts ability to nest. The module must not impede a carts ability to nest within another cart. This allows for compact storage. If this is not achievable, the carts would take up too much space. The mechanism for the cart cannot increase the amount of space taken by stacked carts by more than 15%, and it will ideally not increase the space used at all. The final metric is the required motor power. The cart is intended to move between 1 mph and 5 mph. This design should not use more than 2 450 Watt motors. Higher power motors can be considered unsafe and would require far more regulations if the carts still allowed for a baby to ride in the cart while the cart is equipped with such motors. Higher power motors will also draw on battery power more heavily and increase the chances that a cart dies before returning to the building. With these concerns in mind, the cart must be empty and ready to return when the module is activated. Elderly or infant people rely on the carts and activating the motors while they are using it could lead to potential hazards. Another important consideration is in the paint application. The parking lot will need to be painted for the cart to return. This paint can be invisible or visible, but in both cases it must be very durable. The expected lifetime of the paint must be at least 5 years, so that the paint application need only be checked when the modules are checked or applied to the new carts. Lastly, the module must be able to initiate charging autonomously. This must happen every time, with a confidence of at least 98%.

3.4.4 Final summary

Four designs were considered for the driving mechanism of the automatic shopping cart module. These were a gear drive, a chain drive, a clutch mechanism, and a brake drive. To evaluate the efficacy of each of these mechanisms, several design criteria were chosen. First, as the module will need to be in use for many years to be considered viable, the reliability of the design is important. It will also need to run outdoors in all weather conditions without failing. At the same time, the drive will need to deliver enough torque to move the cart at a fast enough speed. The mechanism needs to be compact enough to not significant affect the ground clearance of the cart in order to minimize the impact the module will have on the maneuverability of the cart.

The brake design would involve a single motor powering both rear wheels and would turn by braking one of the front wheels. This design would be the most compact and would have minimal impact on ground clearance. It would be reliable, durable, and would deliver enough torque to power the cart. It is an expensive design, however, and it would not be highly maneuverable. At the same time, the brakes in the front would prevent the cart from stacking, making the design unattractive to stores. This means that the brake drive must be excluded from further consideration.

The final designs in consideration were the gear drive and the clutch drive. The gear drive will use a system of gears that will engage and disengage in order to deliver power. The clutch would use a "U" design to lock the wheels to the motor. They are both superior to the belt design as they are stronger, more reliable, more durable, and more compact than the belt design. The clutch is cheaper than the gear design; the gear, however, surpasses it in all other metrics. It can deliver more power, more reliably. The design is more easily weatherproofed and will operate longer than the clutch design. The gear design's greatest advantage over the clutch is its ability to stack carts more easily. It is not without any drawbacks, however. It is the most expensive design as well as the most complex. If it breaks down, it would be the most difficult to repair.

The chain drive would have two separately driven wheels with the motor transferring power through a belt. This design will provide the easiest steering solution of the cart, as it uses differential power to steer. It excels in all the cart metrics, and will not impede stacking at all, as the motors will be mounted on the outside of the cart. Because the motors protrude on the outside of the cart, they are more exposed than on the other designs. This might lead to a slightly lower working life than the other designs, and will require the motors and chain to be encased. Overall, the rear mounted motors are the optimal design in terms of cost and performance.

3.5 PROPOSED PERFORMANCE MEASURES FOR THE DESIGN

The autonomous shopping cart's performance will be measured by the following criteria:

1. Dynamic and static infrared sensor detection success and distance required for detection

2. Cart Battery Life
3. Speed of Cart

3.6 DESIGN CONSTRAINTS

3.6.1 Functional

The design could not impede a carts ability to nest with other carts. To achieve this, all hardware must be placed in non-nesting areas, and must not be large enough to interfere with the carts under carriage. The motors must be substantial enough to power the cart, the battery must be large enough to power the motors for a minimum of 2 hours, and the cart must move at a safe speed.

3.6.2 Safety

The cart must check for an infant onboard and must be able to detect objects in front and behind it. The cart must also be able to withstand substantial rain, snow, or other elements, as well as the rough surface of the parking lot.

3.6.3 Quality

Because infants can ride in the cart, the cart must remain non-motorized while a child is in the cart. The motor module must also last as long as the lifetime of the cart, 5 years.

3.6.4 Manufacturing

The components of the cart must not be expensive, and the tolerances of the manufactured parts must not be too high. The module must be able to be assembled and maintained by the average grocery store employee.

3.6.5 Timing

The module must be small enough to transport hundreds of modules at a time. The modules must be able to be safety tested before they are implemented in the store.

3.6.6 Economic

The module must not cost more than the initial cart. The tools and labor of the installation and maintenance must not cost more than 1/3 of the cost of the module over the 5 year life of the product.

3.6.7 Ergonomic

The module must not add more than 1/10 the weight of the cart. The gear ratio must not provide more than 5 times the current resistance of pulling the cart backwards

3.6.8 Ecological

All materials must be sourced sustainably and recyclable. The unit must not be gas powered or put off harmful or volatile fumes. The lubricant used on the chain must not be derived from seal fat.

3.6.9 Aesthetic

The cart must not produce a foul odor from the module. The cart must be pleasant to the eyes and be able to be painted to the owners liking.

3.6.10 Life cycle

The cart must be wholly recyclable and it shall not impede on the quiet atmosphere of the shopping center.

3.6.11 Legal

The cart must comply with all regulations. A sticker must be present detailing the user of the cart assumes full responsibility for damages occurred during use.

4 EMBODIMENT AND FABRICATION PLAN

4.1 EMBODIMENT DRAWING

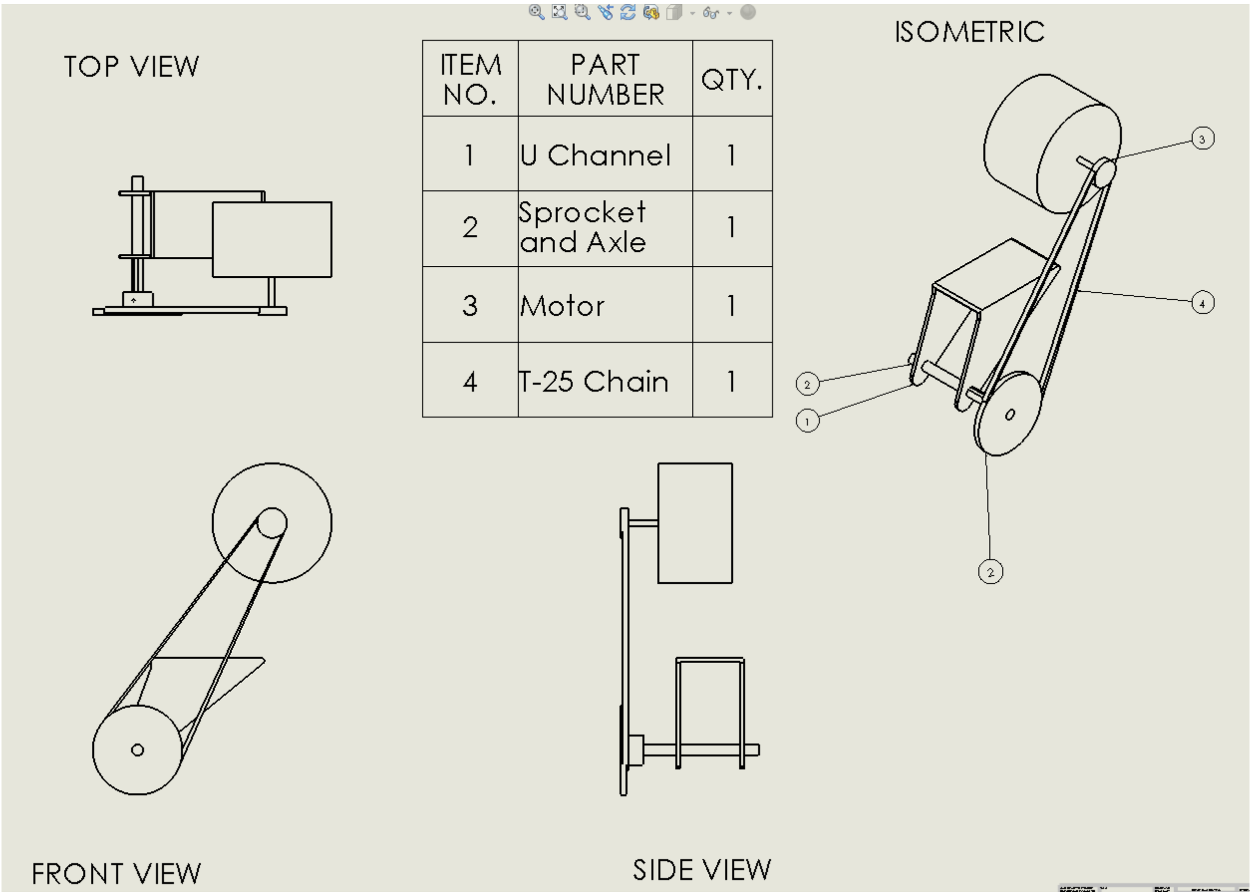


Figure 4.1.1: Embodiment Drawing

4.2 PARTS LIST

Part	Source	Model No.	Quantity	Unit Cost (USD)
LAMPHUS LED Off-Road Light Horizontal Bar Clamp Mounting Kit 1"	Amazon	Lamphus	2	15.5
Donghua Standard #25 Single Strand Roller Chain 10 Ft(480 Links)	Amazon	25-1x10FT-2CL	1	18.8
Roller Chain Sprocket, Reboreable	Amazon	Type B Hub, Single Strand, 25 Chain	1	21.19
4 AmpFlow P40-250 Brushed Electric Motor,	Amazon	250W, 12V, 24V or 36 VDC, 3400 rpm	2	50.9

FORCE SENSING RESISTOR,1.5 INCH SQUARE,1oz-22LBS,2 LEADS,0.1 INCH	Amazon	1645	2	14.99
IR Sensor for Arduino	Amazon	GP2Y0A21YK0F	2	17.99
Infrared reflective Photoelectr Switch IR Barrier Line Track	Amazon	TCRT 5000	1	6.98

Table 4.2.1 Parts List

4.3 DRAFT DETAIL DRAWINGS FOR EACH MANUFACTURED PART

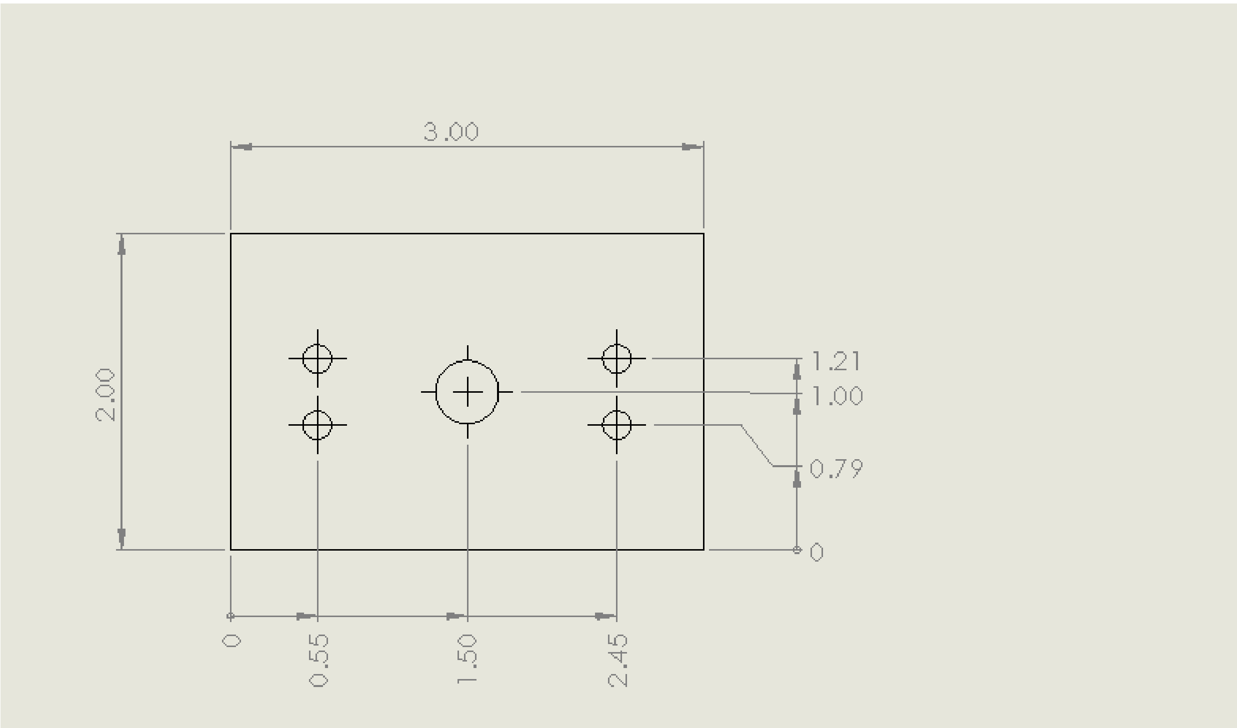


Figure 4.3.1: Rectangular mounting plate for motor

4.4 DESCRIPTION OF THE DESIGN RATIONALE FOR THE CHOICE/SIZE/SHAPE OF EACH PART

To provide power for the selected motors for an extended period of time, the battery must have a large capacity and a high allowable current. Given the customers' lack of concerns for space, and the large cavity that we have to mount the module, the size of the battery must be less than

12x6x4. Also, given the weight of an average cart compared to the relatively light weight of a lithium polymer battery, the weight of the battery was not of high importance.

The electronic speed controller was chosen because of the high consistent current rating and the on board fan. The selected motor runs a maximum current draw of 122 amps. With the circuit we will use, the maximum current will be far less than this, but for safety concerns we must use an esc with a current of at least 110A. Also, we need it to stay cool, so the on board fan will help us achieve this.

The sharp distance sensor was selected for its small size and range. We need a sensor for detecting vehicles, customers, and carts far enough away that it provides a safe and comfortable environment for customers.

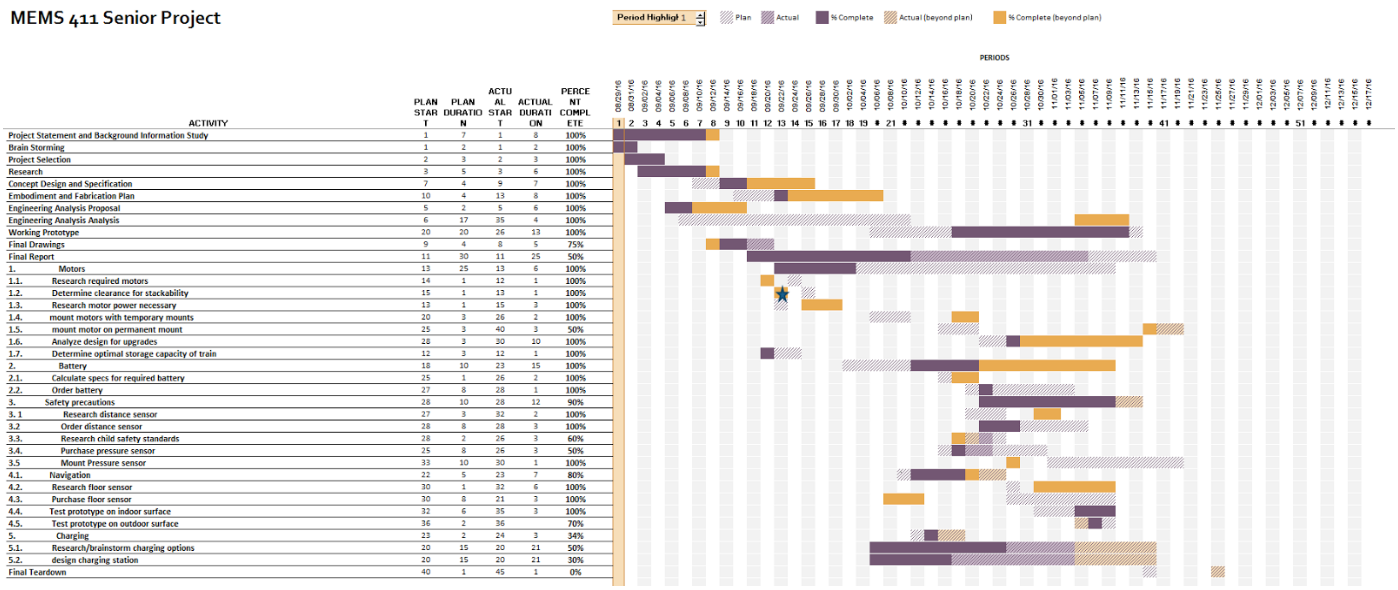
The line tracking sensor must be strong enough to detect a line that may have potential flaws or difficult lighting situations. The sensor we chose can handle both of these scenarios while still remaining small and unobtrusive to nesting.

The motor was chosen because of its maximum power output of 2700 W, which is equal to 3.6 horsepower. The desired speed of the cart is 5 mph, which was calculated to be 46.8 revolutions per minute with a 3 inch diameter wheel. The torque produced by the motor is related to the horsepower and the rpm of the motor. At maximum rpm the torque was found to be .37 lbf-ft.

The stackable clamping hangar was chosen from the McMAster catalog because of its easy and convenient mounting to the servo. There is a threaded hole in the bottom of the clamp where the square plate above the servo must attach. The clamp is 1 inch in diameter but can be adjusted to fit larger or smaller bars, so the module will be compatible with different cart versions.

The line sensing trackers will be used to detect the track painted onto the parking lot. They will be mounted onto the bottom of the cart, and must only detect the painted line so the cart is not steered off course. Because the line sensors are mounted under the cart and are too small to affect the clearance of the wheels, the size was not a factor. The Redbot sensor was chosen for its simple design and low cost.

4.5 GANTT CHART



ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Project Statement and Background Information Study	1	7	1	8	100%
Brain Storming	1	2	1	2	100%
Project Selection	2	3	2	3	100%
Research	3	5	3	6	100%
Concept Design and Specification	7	4	9	7	100%
Embodiment and Fabrication Plan	10	4	13	8	100%
Engineering Analysis Proposal	5	2	5	6	100%
Engineering Analysis Analysis	6	17	35	4	100%
Working Prototype	20	20	26	13	100%
Final Drawings	9	4	8	5	75%
Final Report	11	30	11	25	50%
1. Motors	13	25	13	6	100%
1.1. Research required motors	14	1	12	1	100%
1.2. Determine clearance for stackability	15	1	13	1	100%
1.3. Research motor power necessary	13	1	15	3	100%
1.4. mount motors with temporary mounts	20	3	26	2	100%
1.5. mount motor on permanent mount	25	3	40	3	50%
1.6. Analyze design for upgrades	28	3	30	10	100%
1.7. Determine optimal storage capacity of train	12	3	12	1	100%
2. Battery	18	10	23	15	100%
2.1. Calculate specs for required battery	25	1	26	2	100%
2.2. Order battery	27	8	28	1	100%
3. Safety precautions	28	10	28	12	90%
3. 1 Research distance sensor	27	3	32	2	100%
3.2 Order distance sensor	28	8	28	3	100%
3.3. Research child safety standards	28	2	26	3	60%
3.4. Purchase pressure sensor	25	8	26	3	50%
3.5 Mount Pressure sensor	33	10	30	1	100%
4.1. Navigation	22	5	23	7	80%
4.2. Research floor sensor	30	1	32	6	100%
4.3. Purchase floor sensor	30	8	21	3	100%
4.4. Test prototype on indoor surface	32	6	35	3	100%
4.5. Test prototype on outdoor surface	36	2	36		70%
5. Charging	23	2	24	3	34%
5.1. Research/brainstorm charging options	20	15	20	21	50%
5.2. design charging station	20	15	20	21	30%
Final Teardown	40	1	45	1	0%

Figure 4.5.1 Gantt Chart

5 ENGINEERING ANALYSIS

5.1 ENGINEERING ANALYSIS RESULTS

5.1.1 Motivation

The stress analysis is a stress test on the one piece shaft that fits through the wheel, C-channel, and large sprocket. We determined that the shaft and sprocket connection was the most likely component to fail because the sprocket connects on the thinnest point of the shaft. The sprocket and chain rotate as one unit, so it is critical that the sprocket does not spin on the shaft.

Carrying forward, the SolidWorks analysis will determine the best material from which to construct the shaft. The weight of the shaft is negligible, so the only factors are the time required to machine a harder shaft, and the cost of the material. All the metal used on the prototype comes from the machine shop, but the selected material would have cost implications in the mass production of the mechanism. There was a SolidWorks analysis conducted and real experimentation with an aluminum shaft. As aluminum is lighter and cheaper than steel, it would have been the optimal material to construct the shaft with.

5.1.2 Summary statement of analysis done

The parts were all created on SolidWorks. The sprocket and shaft assembly were subjected to a torque from the motor, which was calculated by finding the normal force on the wheel and the friction coefficient between concrete and rubber. The torque experienced by the shaft is given by the equation

$$T = Fn * k * r$$

Where F_n is the normal force of the wheel, k is the friction coefficient between the wheel and ground (from engineering toolbox) and r is the radius of the wheel. Plugging the values into the equation, the torque was calculated to be 1.57 ft-lb. The figure below shows the free body diagram of the wheel.

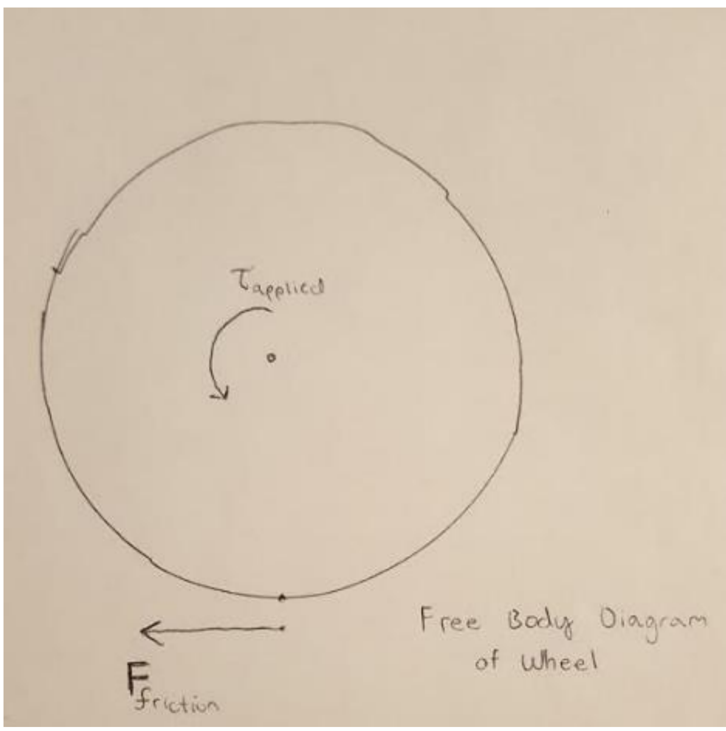


Figure 5.1.2.1: Free body Diagram of Wheel

It is important to note that this is the required power to drive the shopping cart at a constant speed. The average friction coefficient could vary greatly due to obstacles in a given parking lot, and exert much more force on the shaft than this equation might predict.

The calculated force was applied to the shaft in SolidWorks and a static stress test was selected. This showed a stress distribution on the aluminum shaft, shown in the figure below

.

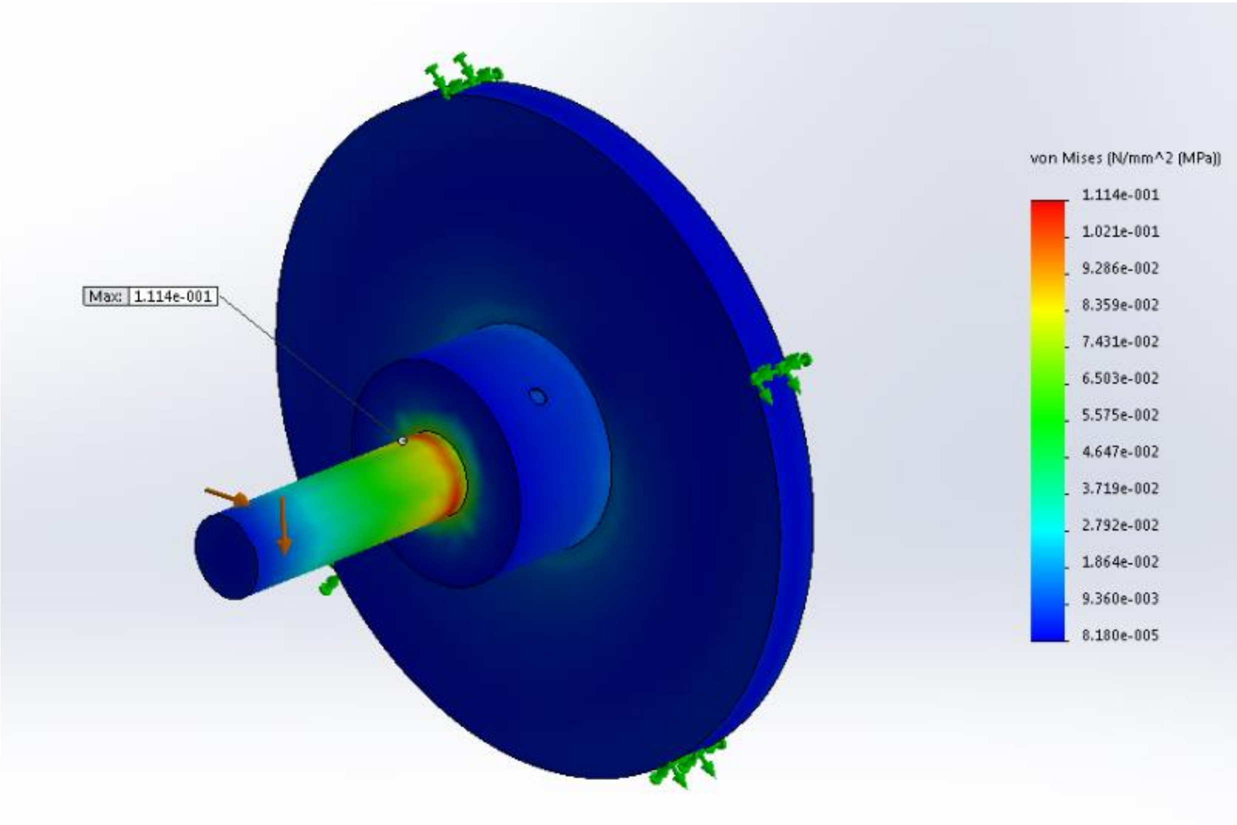


Figure 5.1.2.1: Von Mises Stress Analysis of Aluminum Shaft.

5.1.3 Methodology

The SolidWorks analysis was done by creating the sprocket, shaft, and force fitted set screw. The sprocket was made out of cast iron and the set screw was made out of steel. As we were unable to determine the exact type of aluminum from the machine shop, we stress tested with several common forms of aluminum. The analysis was done by setting the shaft and sprocket into a motor and conducting a stress test.

The torque of 1.57 ft-lb were applied to the shaft.

Experimentation was not required to conduct the SolidWorks test, but an aluminum shaft was conducted to verify the results of the analysis. To allow for drilling and easier mounting of the set screw, the top of the aluminum shaft was filed down flat. The shaft was mounted in the C-channel, and then force fitted onto the sprocket with a set screw drilled through the sprocket and shaft. The Motor was run at low speeds without a load inside the cart.

5.1.4 Results

The SolidWorks results, as shown in the figure below, show that the stress experienced by the aluminum was 16.05 Mpa, and the yield strength of aluminum 1066 is 276 MPa. So the aluminum should not have been close to yielding.

When the product was actually tested on the cart however, the aluminum shaft had clearly failed. After removing the aluminum shaft from the sprocket, the aluminum shaft was shown to have sheared a channel through the shaft. The shear force applied by the set screw had cut through the shaft enough to clearly weaken its structure, even though the sprocket never actually slipped on the shaft. One reason the aluminum failed is that in reality the set screw had a pointed tip and was not sunk deep enough into the shaft, so it chewed through it.

This was based on the actual material from which shopping carts are constructed, steel. Since the shaft takes more of a load than most other parts of the cart, it wouldn't make sense for it that part to be made out of a weaker, softer material. The SolidWorks test show that steel and stainless steel have very high factors of safety, so neither have any reasonable chance of failing during the lifespan of the cart.

5.1.5 Significance

The analysis was a very important step in determining the best material for the shaft. Aluminum is very easy to machine, but an unrealistic prospect if the mechanism is to last the average lifespan of a shopping cart, which is about 4 years. Because of the tests, not only were the shafts made of stronger, harder material, the mounting holes in the C-channel were widened, so the shaft could be made thicker where it bears the load of the cart. Widening the sprocket hole would have allowed the shaft to be thickened at that contact point as well, but it was not worth drilling into the cast iron. The diameter of the shaft was widened from .375 inches to .4 inches. The designed shaft is shown in the figure below.

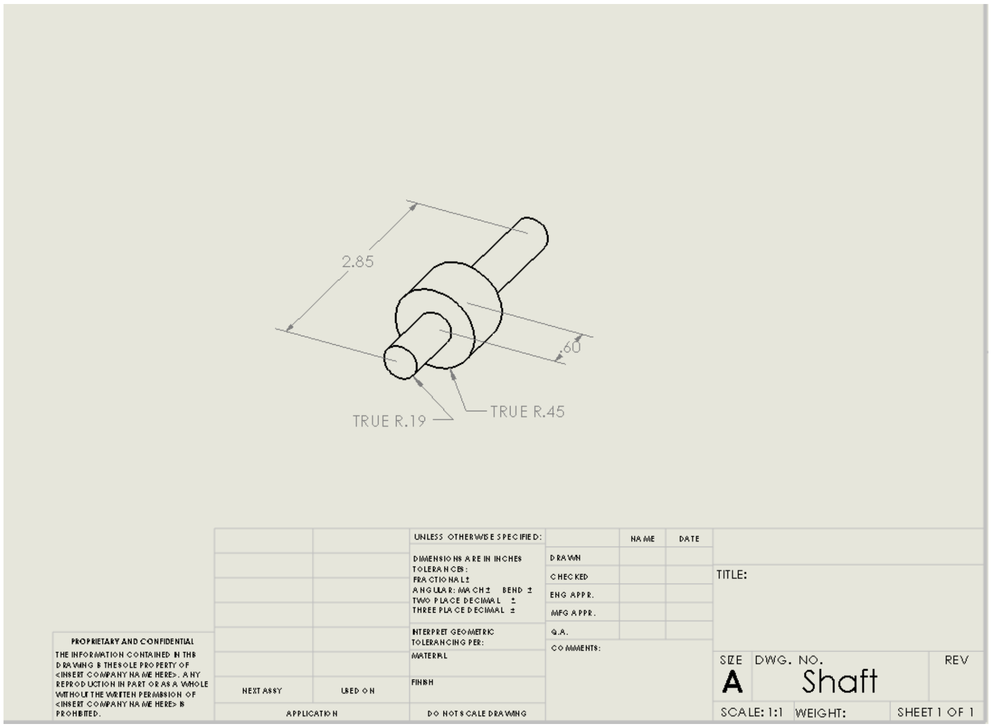


Figure 5.1.5.1: Embodiment drawing of steel shaft.

5.1.6 Summary of code and standards and their influence

The Standard Consumer Safety Performance Specification for Shopping Carts outlines the necessary requirements of a cart to protect a child riding inside. The standard states that a shopping cart should be designed to safely accommodate a child of up to 35 lbs in the seat. While the motor will not run with a weight inside the children's seat, it should be designed not to fail if there is a load in the cart. Because the set screw shearing the shaft will significantly impact the cart's ability to brake, it was important to increase the factor of safety of shaft. The high consequence of shaft failure (decreased braking with a child on board) led to the material choice of stainless steel for the shaft, which provides an ample safety factor for all aspects of use.

5.2 RISK ASSESSMENT

5.2.1 Risk Identification

Our risk assessment process can be summarized with the following heat map.

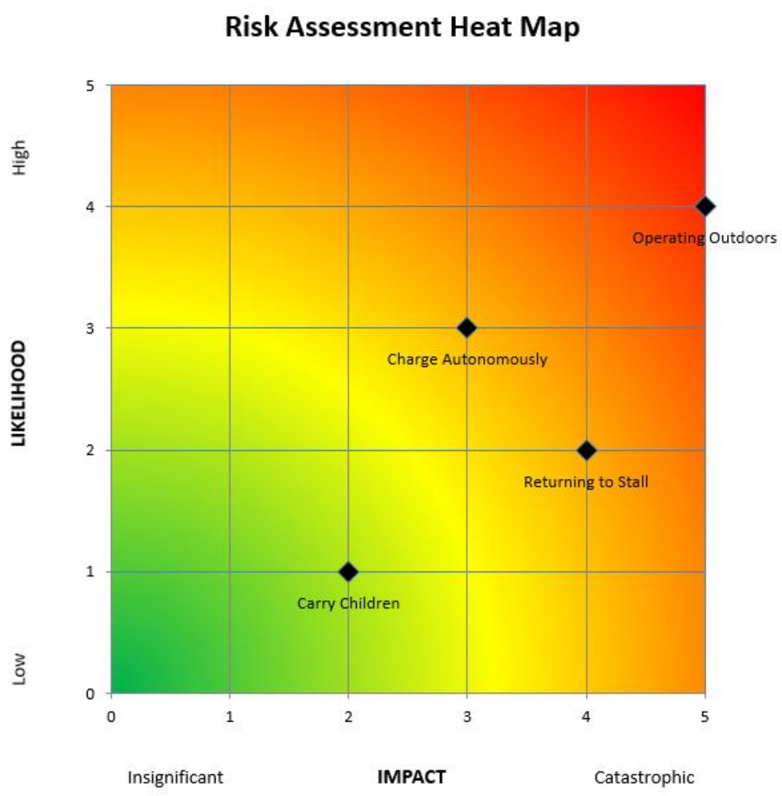


Figure 5.2.1: Heat Map of Risks

5.2.2 Risk Impact or Consequence Assessment

1. Operating Outdoors: The cart will be operating entirely outdoors because the motors are only engaged when the cart is being driven to the return stall in the parking lot. It would have to deal with uneven surface terrain, varying temperatures, and different types of precipitation. Testing has shown the cart to work on several types of surfaces, but dealing with pot holes and large cracks may require more testing. Temperatures are not likely to affect our components much as they are not being stressed very hard. Our design as it exists now, however, is not waterproof. A more final design would be encased to ensure that it is fully waterproof. It would be rendered useless if it came into contact with water from rain. It would be able to drive in snow because the motors can deliver much more torque than they normally do. This risk is medium-high in likelihood and catastrophic in impact.

2. Returning to Stall: The first purpose of out cart is for it to return itself to the stall without damaging itself, any property, or any people. To prevent this from happening, the cart has been fitted with infrared distance sensors that would allow to avoid obstacles. The cart will follow a prescribed path to minimize the risk of collision. The impact of this risk is significant, but the likelihood is low-medium.

3. Carrying Children: The cart is expected to be able to carry children onboard while it is operating in the store, but it most not cause any harm to them while it is carrying out its function in the parking lot. To prevent an absent minded parent from engaging the motors of the cart while their child is still onboard, the cart has been fitted with a pressure sensor on the child seat. This sensor prevents the motors from running when there is a weight on the seat. The impact of this risk is mild, and its likelihood is low.

4. Charge Autonomously: The final design of the cart would charge its batteries automatically when it parks itself in the return stall with no input from employees. This technology has not be implemented in the prototype. An eventual system would utilizes brushes in the stall to contact surfaces on the cart in order to charge the batteries.

5.2.3 Risk Prioritization

1. Operating Outdoors (most critical)

2. Returning to Stall

3. Charge Autonomously

4. Carry Children (least critical)

6 WORKING PROTOTYPE

6.1 DIGITAL PHOTOGRAPHS OF PROTOTYPE

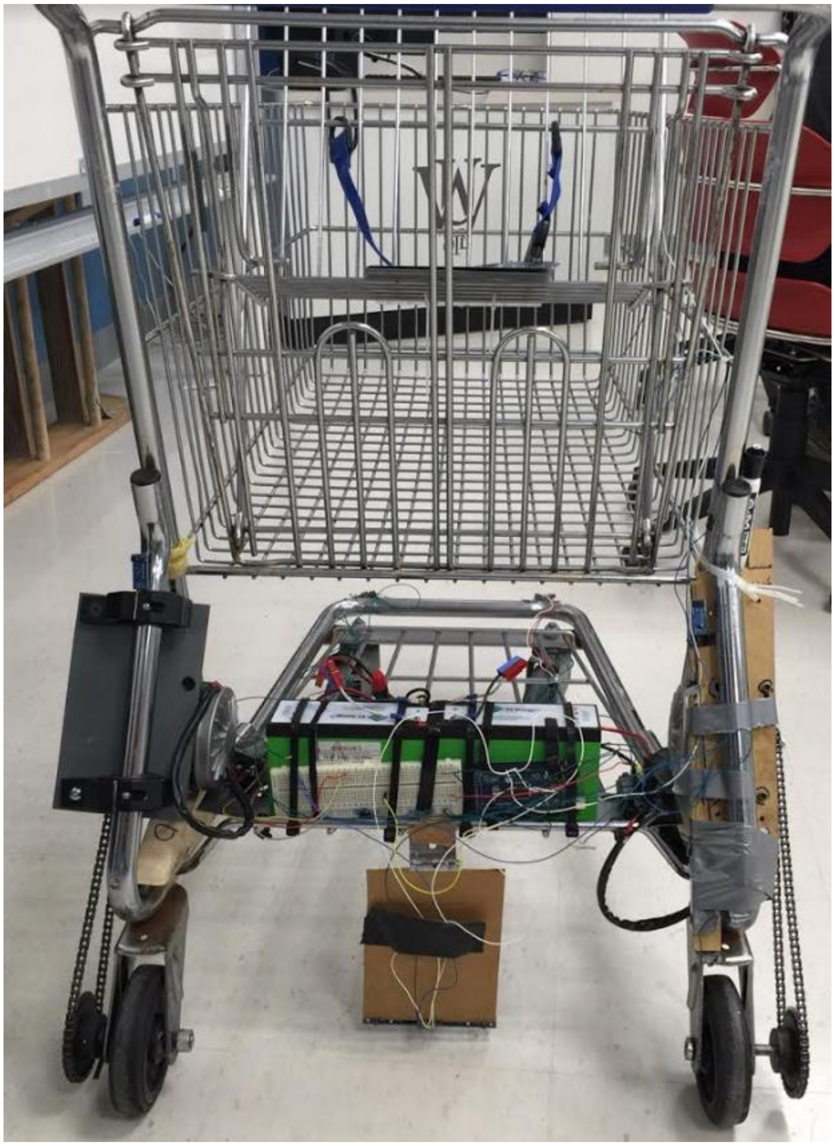


Figure 6.3.1: Back view of the autonomous shopping cart.

The left motor is attached to a sheet metal plate that is clamped onto the back of the cart. The motors protrude into the inside of the cart, but not enough to imped stacking of the cart in any way. The motors connect to two electronic speed controllers, which control the motor after receiving input from the aduino. The motors are also connected to the 9.6 Amp batteries. Beneath the cart the color sensor is attached on a hinge which will flip up into the cart when a cart is stacked behind it. The right side motor (on the picture) is mounted on a wooden mount. For the next step of the prototype, the hinge at the bottom will be made out of sheet metal, making it more durable, as its low hangoing position makes it one of the most vulnerable places on the cart. The right side will also be mounted on a stiff sheet metal plate. We would also like to change the rubber inserts on the mounting plates, as they rotated slightly around the bar at high motor rpm.

Figure ffee

Figure 6.3.2: Isometric view of the completed cart.

This view shows the infrared distance sensors mounted on the front of the cart. The wire connecting to the pressure sensor in the baby seat runs from the top of the cart into the breadboard, which is connected to the Arduino. The wires connecting to the front sensors, as well as all the wires on the back, will be encased to avoid snagging on debris on the ground. The entire battery assembly will also be enclosed in a waterproof case. The chains will also be guarded for both the longevity of the cart and safety of the customer.

6.2 A SHORT VIDEOCLIP OF FINAL PROTOTYPE PERFORMING

Two videos of the cart performing its designated tasks can be found at the following links

Video of the cart following a colored Line:

http://www.youtube.com/watch?v=g-SaGoJWKVo

Video of the cart's moving object detection:

http://www.youtube.com/watch?v=qMunfakc8uI

6.3 4 ADDITIONAL DIGITAL PHOTOGRAPHS WITH EXPLANATIONS

Figure 6.3.3: Warped Aluminum Shaft.

The left side of the shaft has been bent and twisted significantly from the pressure applied to it by the cart. The aluminum shaft was predicted to work with a high factor of safety based on the theoretical moment applied to it by the motor. We predicted that in certain instances, especially while testing the autonomous cart, a large acceleration from the cart would put a much higher moment on the cart. As we expected, the force applied to the shaft over a series of tests severely warped the aluminum. This physical test complemented the engineering analysis performed in SolidWorks, and is a good example of the importance of having a large factor of safety.

Figure 6.3.4: Aluminum shaft set screw hole

This is the aluminum shaft that was originally tested in the wheel of the cart. Aluminum was the preferred metal because its low hardness made it the easiest metal from which to fashion the shaft. The hole on the right side of the shaft was created to insert a set screw, to ensure the shaft and sprocket rotated together. Evident from the picture, the force from the set screw have begun to bore into the shaft. The actual test of the shaft complemented the engineering analysis, and lead to the material decision of using stainless steel in our final design. Stainless steel has a much higher hardness than aluminum, and gave the shaft an appropriate factor of safety, suitable for an estimated five year lifespan of the cart. The sheared channel created by the set screw prompted us to use stainless steel, which has a higher yield strength and hardness than aluminum.

Figure 6.4.5: Stainless Steel Shaft

This picture shows the second shaft machined after testing the aluminum shaft. It has the same shape, and is made out of stainless steel. The end of this shaft also contains a set screw hole to lock with the sprocket, but there is no sheared channel as with its aluminum counterpart. The stainless steel shaft is still in perfect condition, and contains no shear channel in the set screw hole. The shaft remains in the wheel because a hole was drilled vertically through the wheel and shaft and dropped in to ensure the two parts rotated together. This was done under the suggestion of Professor Jakiela. The pin that was forced into the shaft is visible in the bottom left of the wheel’s inner hole.

Figure 6.3.6 Stainless steel shaft other side

This picture shows the other side of the wheel. The nuts and bolts holding the shaft to the wheel started to abrade the rubber, which would have eventually resulted in the shaft spinning freely inside the wheel. This side of the shaft was also kept from sliding within the u-channel with a collar mounted on the shaft outside of the u-channel. The top of the shaft was filed down to drop a set screw through the collar and shaft. Overall, stainless steel was a tremendous improvement from aluminum.

7 DESIGN DOCUMENTATION

7.1 FINAL DRAWINGS AND DOCUMENTATION

7.1.1 Engineering drawings

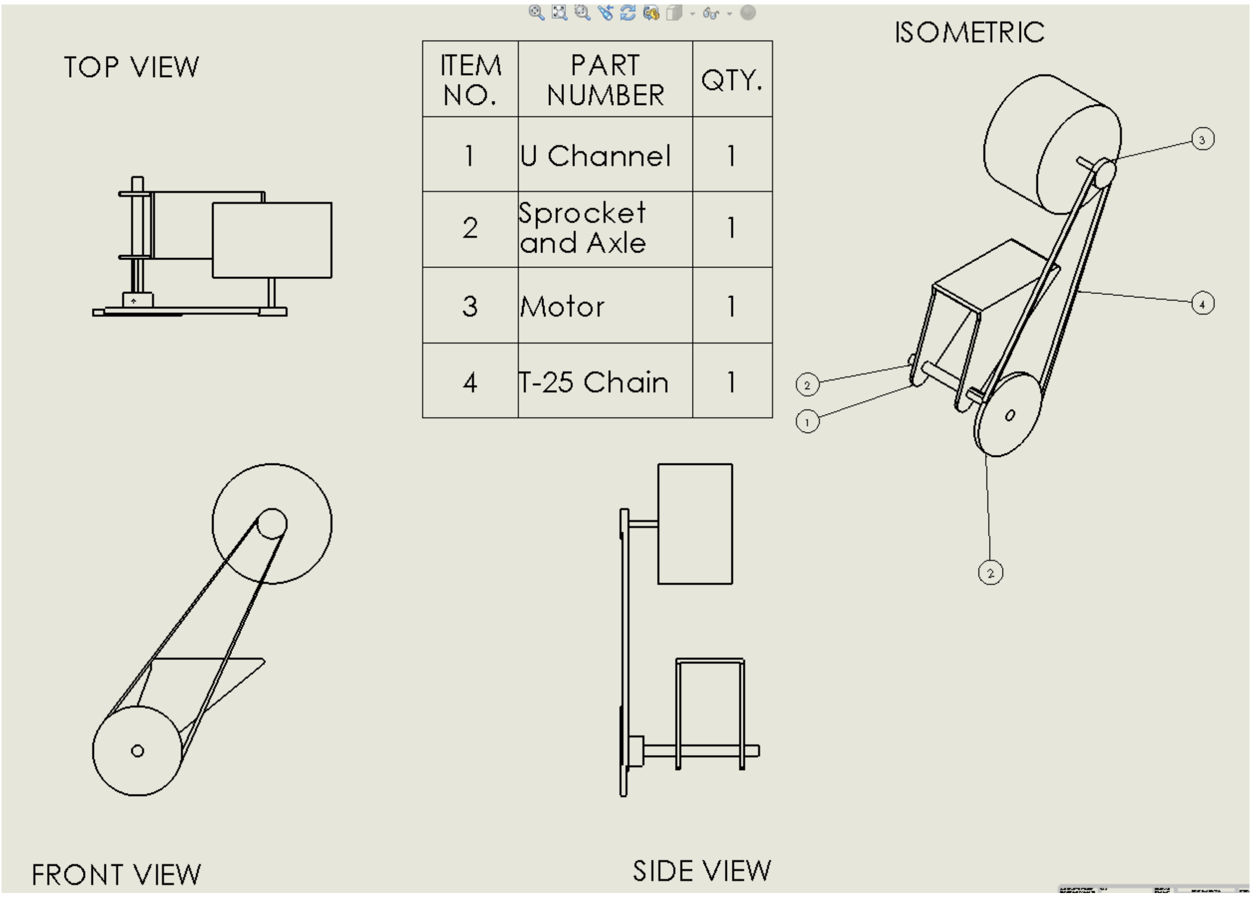


Figure 7.1.1 Final Assembly View Drawing

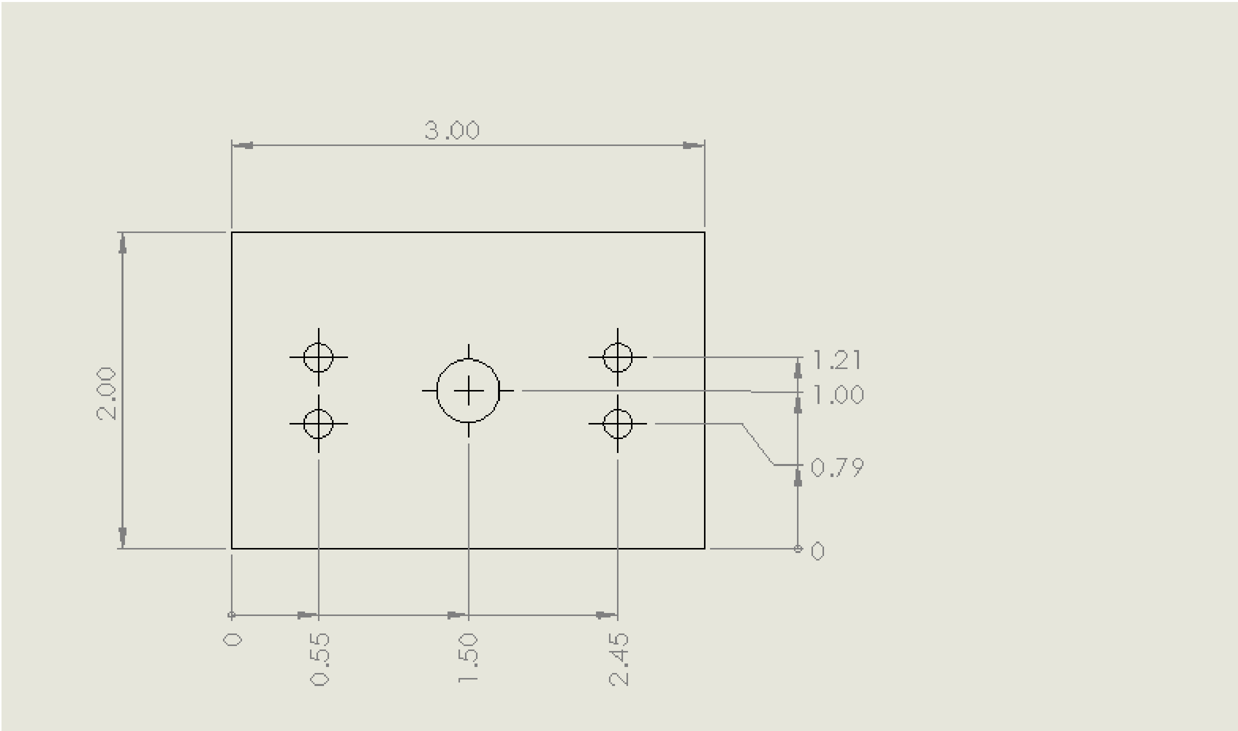


Figure 7.1.2 Drawing of Square Mounting Plate

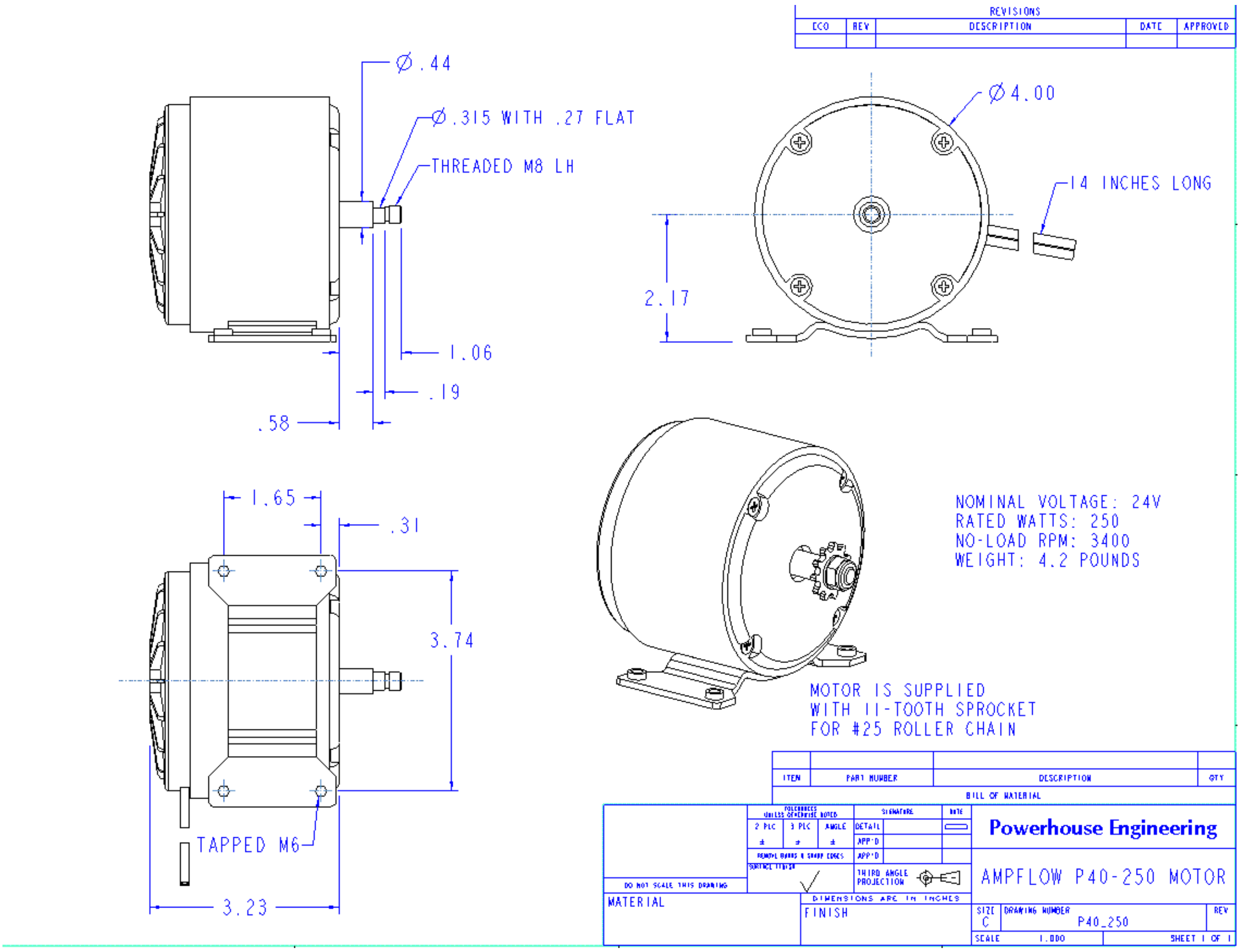


Figure 7.1.3 Drawing of Motor from Powerhouse Engineering

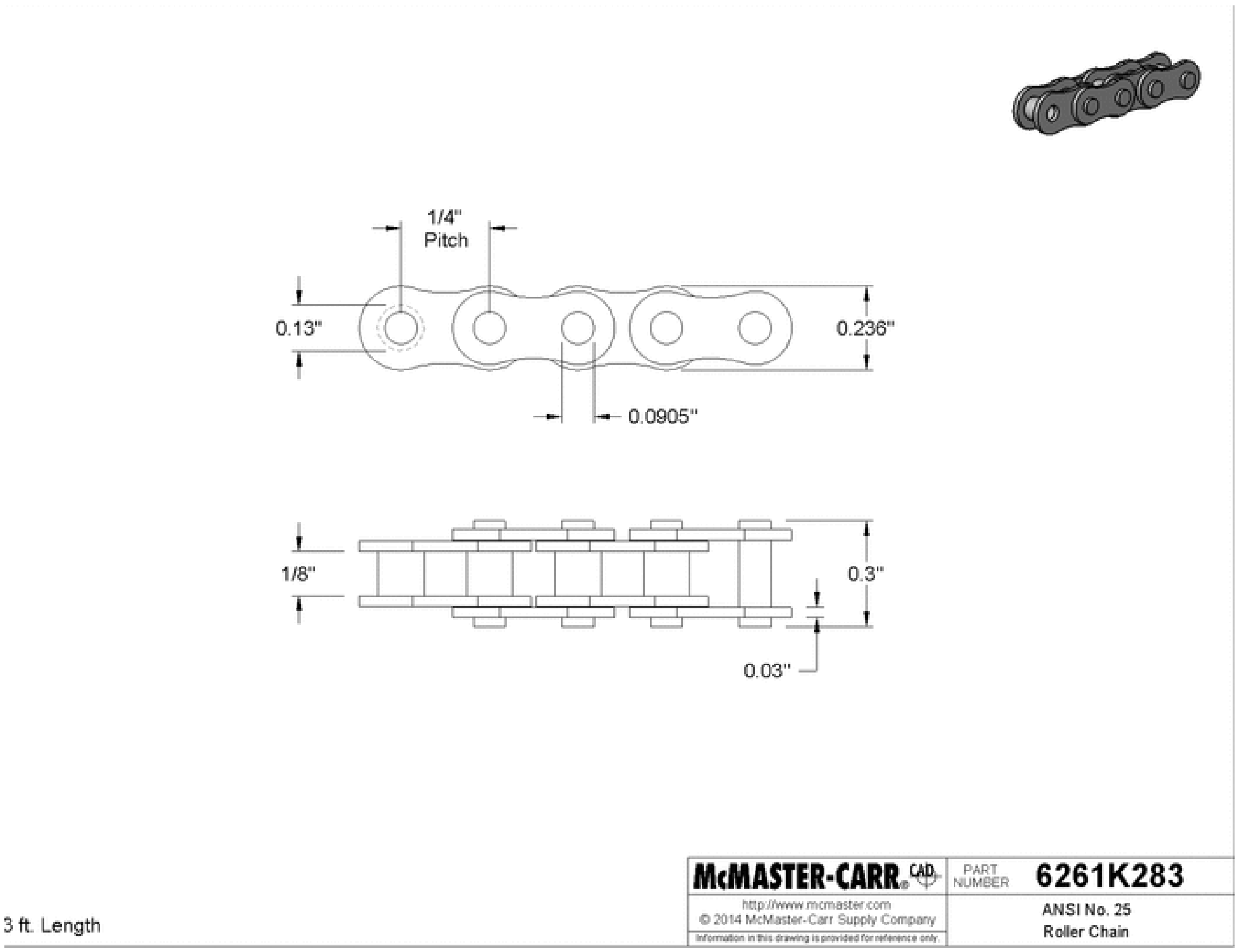


Figure 7.1.4 Drawing of Chain from McMaster-Carr

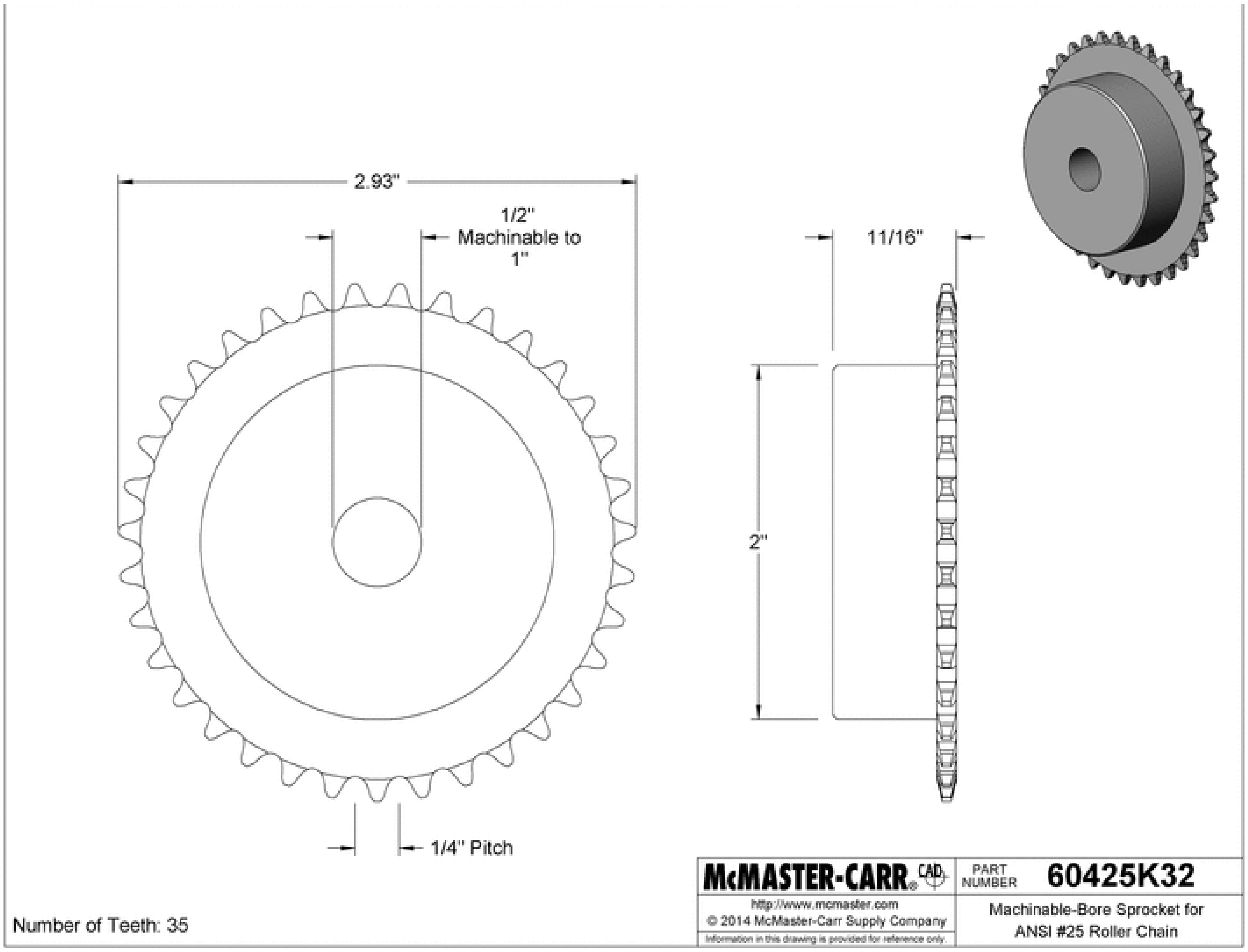


Figure 7.1.5 Drawing of Sprocket From McMaster-Carr

7.2 FINAL PRESENTATION

7.2.1 A link to a video clip

A video presentation and demonstration of our project can be found at the link:

https://www.youtube.com/watch?v=62ZlYbL7aRU&index=18&list=PLpaIgTgYdmcJ-6mZULCZl73bxzSJODK80

7.3 TEARDOWN

TEARDOWN TASKS AGREEMENT

PROJECT: Autonomous Shopping Cart

NAMES: John Gutsch, Steven Taschner, Asim Zaidi

Instructors: Professor Malast, Professor Jakiela

The following teardown/cleanup tasks will be performed:

Remove all wires from sensors and breadboard

Remove and save sensors from cart

Remove clamps from cart with hex key

Detach chain from sprocket and motor

Remove force fitted sprockets from shaft (2)

Remove shaft and wheel assembly from u-channel (2)

Detach and save batteries from cart

Remove and save motors from mounting plate with screwdriver

Remove sprocket from shaft

Remove force fitted shaft from wheel assembly

8 DISCUSSION

8.1 USING THE FINAL PROTOTYPE PRODUCED TO OBTAIN VALUES FOR METRICS, EVALUATE THE QUANTIFIED NEEDS EQUATIONS FOR THE DESIGN. HOW WELL WERE THE NEEDS MET? DISCUSS THE RESULT.

Our cart met or exceeded the design requirements of every part of the cart. The infrared distance sensors were able to detect static and dynamic objects up to two feet away with ease. The cart was tested to approach 20 mph, and could easily travel between one and five miles an hour. The most important design requirement, the space taken by two stacked carts was not reduced at all. However, the motor does add to the width of the cart, which will slightly increase the amount of space that multiple stacks of carts will consume. However, with smaller, more appropriately sized motors, the cart will not be made larger in any direction. For safety, the distance sensors were required to detect objects with 85% accuracy. On testing they were found to detect objects of any color with 99% accuracy. Overall, the performance of the cart was excellent.

8.2 DISCUSS ANY SIGNIFICANT PARTS SOURCING ISSUES? DID IT MAKE SENSE TO SCROUNGE PARTS? DID ANY VENDOR HAVE AN UNREASONABLY LONG PART DELIVERY TIME? WHAT WOULD BE YOUR RECOMMENDATIONS FOR FUTURE PROJECTS?

We were able to use Amazon prime for most of our parts, so the delay time for ordering parts was not a huge issue. We also had excellent experiences with all of our vendors over the course of this project. The batteries and electronic speed controllers were taken from another robot to save on costs. The only time we were ever forced to “scrounge” for materials was miscellaneous metal parts in the machine shop. However, if we had to redo the project we would have finished the design phase earlier in the course, which would have allowed a more relaxed build schedule for the prototype. These were unforeseen circumstances on our part, as we had to change our design relatively late in the course.

8.3 DISCUSS THE OVERALL EXPERIENCE:

8.3.1 Was the project more of less difficult than you had expected?

Building the cart was significantly more difficult than anticipated. The project underwent two approved design changes throughout the process. Our first design consisted of an exposed gear, which was deemed to technically difficult to machine, and could not be bought. The front steering power design was changed when it was replaced by the rear mounted motor, which offered more power and a simpler, more elegant steering solution.

8.3.2 Does your final project result align with the project description?

The project solves all the problems outlined in the project description. The goal was to modify a shopping cart so that it would drive autonomously, which the motors and navigation program achieved. The sensors on the front of the cart accomplished all our safety precautions, and the line sensor achieved our navigation objectives. Our main concern was making sure the carts stacked as normal, which was critical in keeping the project viable, which was also accomplished.

8.3.3 Did your team function well as a group?

Yes. There was very good team chemistry, and our skills complemented each other. Through working together we were able to teach each other Solidworks and hands on prototyping in the machine shop. The main problem was disagreements about the scope of the problem, and the amount of commitment each group member wanted to commit to the project. In the end, we compromised on the scope of the project, but the work required exceeded our expectations anyway.

8.3.4 Were your team member’s skills complementary?

Yes. Each person brought a different amount of theoretical knowledge and technical knowledge to the project. Steven had the most machine shop and design experience, and was able to teach the rest of the group.

8.3.5 Did your team share the workload equally?

Yes. The majority of the project was done as a group. Work was only split when we were physically separated by distance. Even then there was strong communication between the group members at all time. Of course, whoever had the most expertise in a particular program or technical task put the most time into that part.

8.3.6 Was any needed skill missing from the group?

Not significantly. While the technical skills were all there previously, none of us had every worked on a project exactly like this before. This project was very multidisciplinary, and required us to trust in the other group members when the project required their area of expertise. We were thankful to receive significant technical assist with the electronic component from Alex Herriot, a friend and electrical engineering student here at Washington University in St. Louis.

8.3.7 Did you have to consult with your customer during the process, or did you work to the original design brief?

No. There was an initial interview conducted with the manager of a Home Depot in Chesterfield Valley, which is included in the report. While we did not consult again with shop owners, there was extensive consulting done with the ultimate end user of the product, the shopper. Both Professor Jakiela and Professor Mallast offered their perspectives as shoppers, and we obtained multiple informal interviews with friends. The original design was followed very closely in this regard.

8.3.8 Did the design brief (as provided by the customer) seem to change during the process?

The design brief changed only minimally. The main criteria provided by the customer were all used as guiding principles that the project was designed around. The biggest example of this was the temptation to integrate a power button to help the customer push the cart. Our customer interviewed was adamant that the cart should run with the motor, so everything was designed to that specification.

8.3.9 Has the project enhanced your design skills?

Yes. All three of us gained significant experience designing a prototype, modeling and conducting engineering analyses in Solidworks, and anticipating potential problems. It has significantly enhanced our ability to completely plan out a project before building, which was forced by the significant delay time required by ordering parts.

8.3.10 Would you now feel more comfortable accepting a design project assignment at a job?

Yes. All three of us would like the opportunity to apply what we have learned in the class on another project. While we surprised ourselves with what were able to accomplish, there were several hard lessons learned over the course of the semester that set us back on our schedule. Having worked through every step of a design process also helped sharpen our estimation of our own abilities, which were overvalued is

8.3.11 Are there projects that you would attempt now that you would not attempt before?

Yes. This project comprised a great deal of hands on experience, which was new and challenging for two of three of the group members who had limited experience in this regard. We would like to continue the project next semester as an independent study, something we wouldn’t have considered given the option at the beginning of the semester.

9 APPENDIX A - PARTS LIST

See Section 4.2

10 APPENDIX B - BILL OF MATERIALS

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	U Channel		1
2	Drive Mechanism		1
3	Motor		1
4	finalchain		1

Figure B.1 Bill of Materials

11 APPENDIX C - CAD MODELS AND DRAWINGS

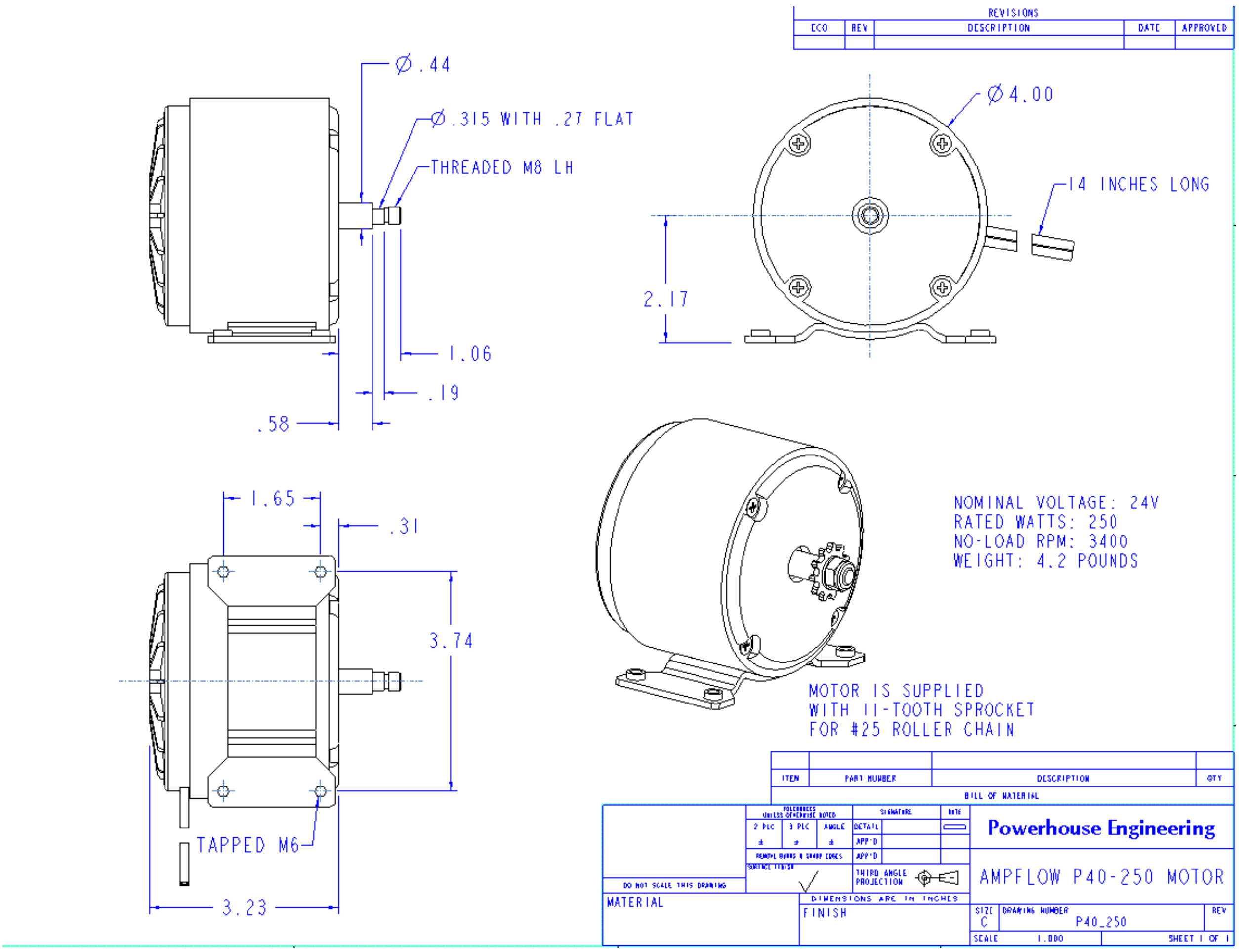


Figure C.1: Motor Drawing

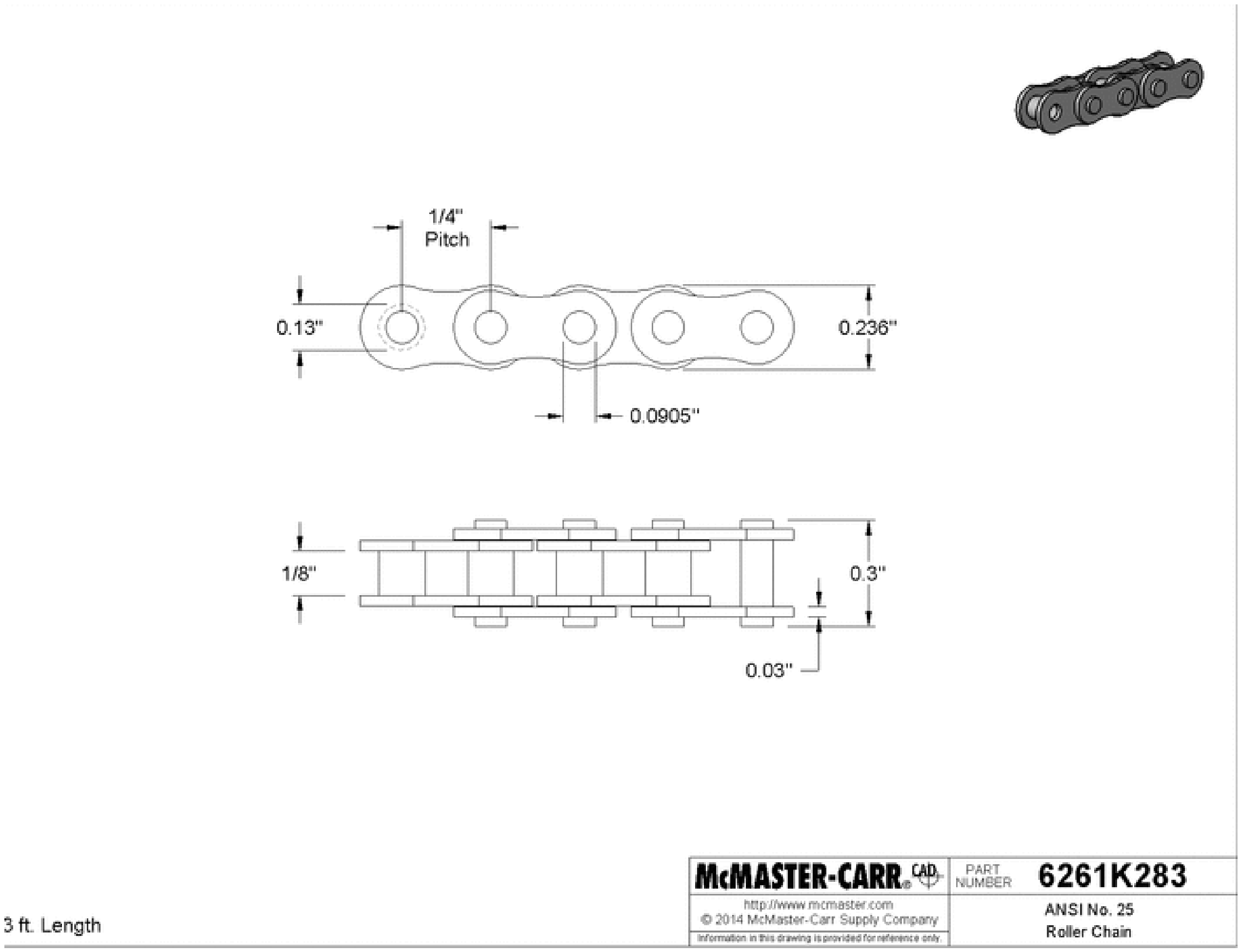


Figure C.2 Chain Drawing

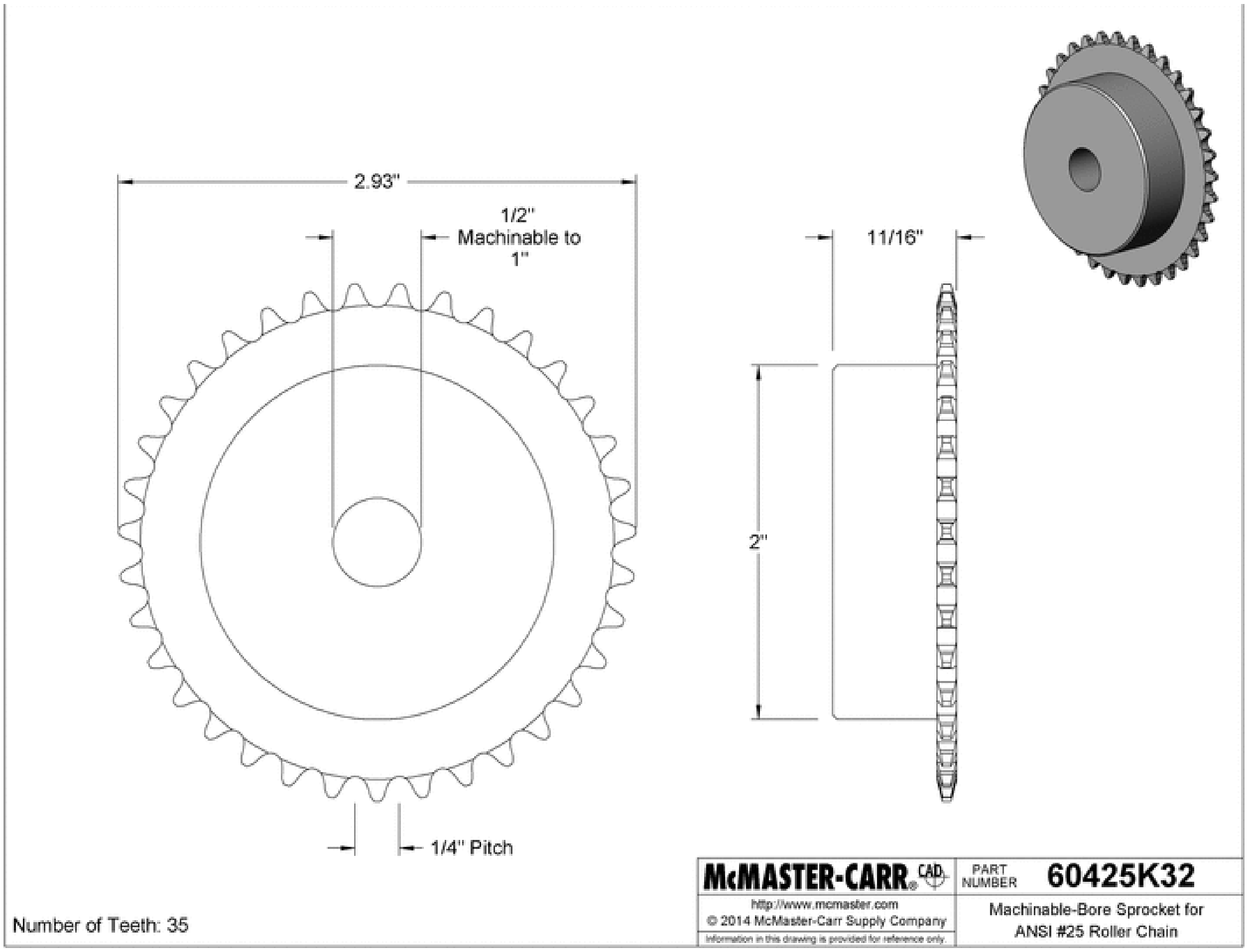


Figure C.3 Sprocket Drawing

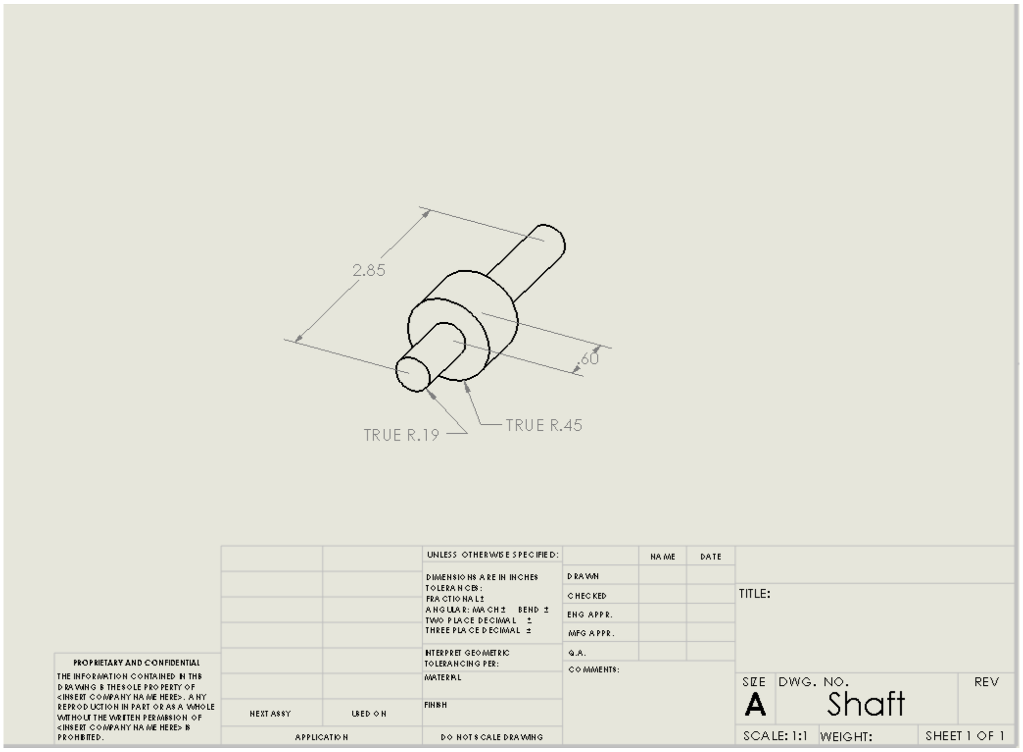


Figure C.4 Shaft Drawing

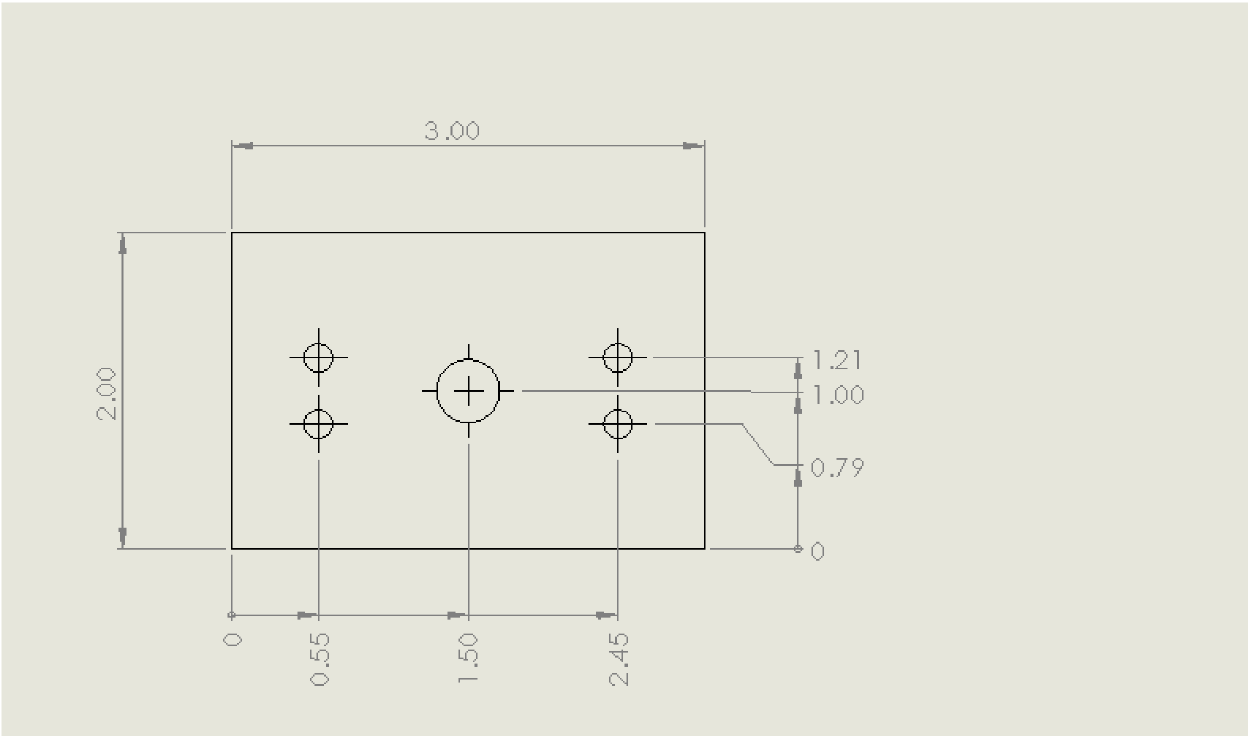


Figure C.5 Plate Drawing

Figure C.6 Assembly Model

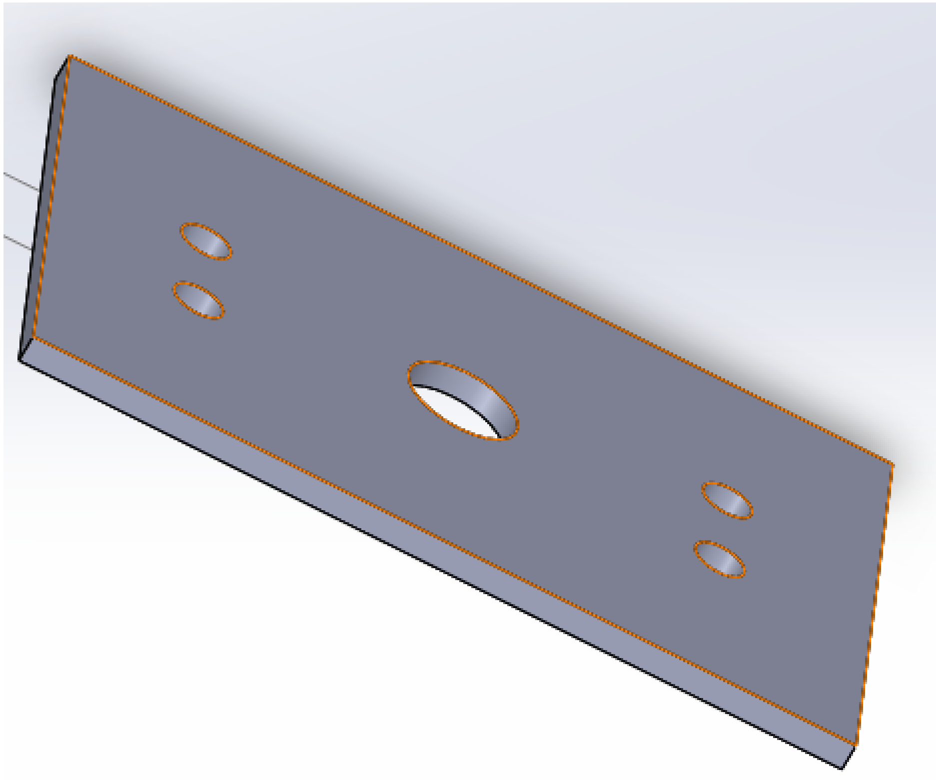


Figure C.7 Mounting Plate Model

12 APPENDIX D -ANNOTATED BIBLIOGRAPHY

Walker, Diane. “On Your Side: Walmart denies negligence after cart damages customer's car,” NBC 12 News. 7 April, 2015.

This article was used to help demonstrate a need for our product. Stores like Walmart across the country have to deal with legal cases like these on a regular basis. They would want to be free of the hassle and cost of litigating these cases, and the customers would want to be free from the risk of hitting other cars or having their own cars hit.

Losego, Martine. System for Motorizing a Shopping Cart or Trolly, or the like. Martine Losego, assignee. Patent US5064012 A. 12 Nov. 1991. Print.

This was a patent that we found in our patent search. It represents an early attempt to motorize a shopping cart. This design, however, was severely limited in both its scope and by the technology of its time. The inventors conceived of a motorized cart that could follow customers in the store. However, there is no demand from the customer or the store for this. Also, because microprocessors were not as cheap and available as they are now, this patent could not take advantage of programming a path for the cart to follow and sensors to protect it from hitting objects or being run when it should be stationary.

Electric Shopping Cart/burden Carrier. Tudek Arthur L, Arthur Paul Tudek, assignee. Patent US20080041644 A1. 21 Feb. 2008.

This was another patent that was found early in this process. It also represents what we believe to be a misguided attempt at motorizing a shopping cart. A motorized cart following a shopper could be a hazard to shoppers if a failure caused it to drive when it is not supposed to.

Standard Consumer Safety Performance Specification for Shopping Carts, ASTM Standard F2372, 2015.

This is the ASTM standard that exists for shopping carts. It mainly focuses on the safety of the shopping cart as it pertains to a child in the seat of the cart. This led us to focus on making safety measures to ensure a child's safety in the case that they were left in the cart. The standard exclusively applied to non-motorized carts, so it does not directly apply to our design.

13 APPENDIX E- SOLIDWORKS STUDY

Simulation of Drive Mechanism

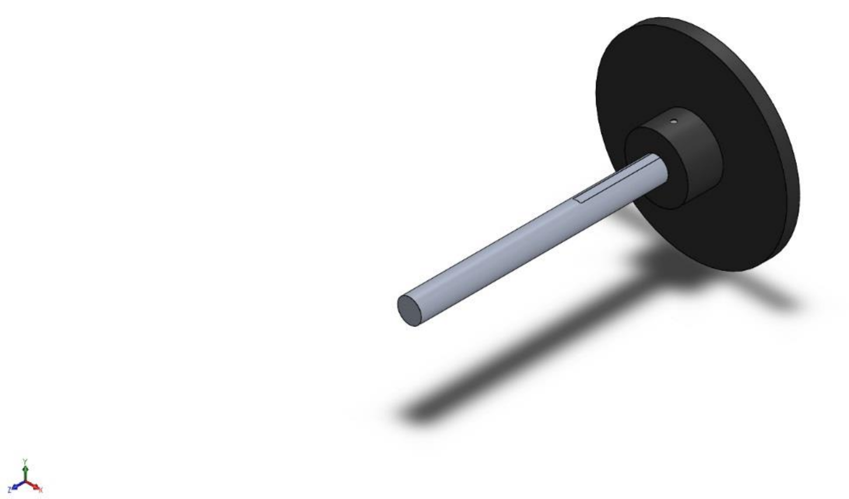
Date: Sunday, December 11, 2016
Designer: Solidworks
Study name: Static 1
Analysis type: Static

TABLE OF CONTENTS

14 DESCRIPTION

No Data

15 MODEL INFORMATION



Model name: Drive Mechanism
Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Boss-Extrude2 	Solid Body	Mass:0.0225032 kg Volume:8.33452e-006 m^3 Density:2700 kg/m^3 Weight:0.220531 N	\\warehouse2.seasad.wustl.edu\home\john.gutsch\winprofile\desktop\Senior design project\Solidworks files\Axle.SLDPRT Nov 16 01:58:27 2016
Cut-Extrude1 	Solid Body	Mass:0.207808 kg Volume:2.88622e-005 m^3 Density:7200 kg/m^3 Weight:2.03651 N	\\warehouse2.seasad.wustl.edu\home\john.gutsch\winprofile\desktop\Senior design project\Solidworks files\Sprocket.SLDPRT Nov 15 00:59:52 2016
Boss-Extrude1 	Solid Body	Mass:0.000329276 kg Volume:4.22148e-008 m^3 Density:7800 kg/m^3 Weight:0.0032269 N	\\warehouse2.seasad.wustl.edu\home\john.gutsch\winprofile\desktop\Senior design project\Solidworks files\set screw.SLDPRT Nov 15 00:59:51 2016

16 STUDY PROPERTIES

Study name	Static 1
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (\\warehouse2.seasad.wustl.edu\home\john.gutsch\winprofile\desktop\Senior design project\Solidworks files)

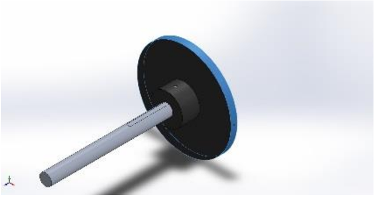
17 UNITS

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

18 MATERIAL PROPERTIES

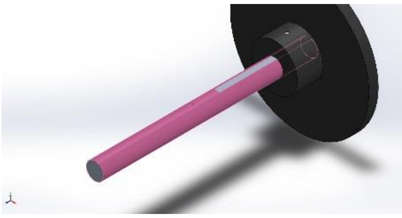
Model Reference	Properties	Components
	Name: **1060 Alloy** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Yield strength: **2.75742e+007 N/m^2** Tensile strength: **6.89356e+007 N/m^2** Elastic modulus: **6.9e+010 N/m^2** Poisson's ratio: **0.33** Mass density: **2700 kg/m^3** Shear modulus: **2.7e+010 N/m^2** Thermal expansion coefficient: **2.4e-005 /Kelvin**	**SolidBody 1(Boss-Extrude2)(Axle-1)**
Curve Data:N/A		
	Name: **Gray Cast Iron** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Tensile strength: **1.51658e+008 N/m^2** Compressive strength: **5.72165e+008 N/m^2** Elastic modulus: **6.61781e+010 N/m^2** Poisson's ratio: **0.27** Mass density: **7200 kg/m^3** Shear modulus: **5e+010 N/m^2** Thermal expansion coefficient: **1.2e-005 /Kelvin**	**SolidBody 1(Cut-Extrude1)(Sprocket-1)**
Curve Data:N/A		
	Name: **Plain Carbon Steel** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Yield strength: **2.20594e+008 N/m^2** Tensile strength: **3.99826e+008 N/m^2** Elastic modulus: **2.1e+011 N/m^2** Poisson's ratio: **0.28** Mass density: **7800 kg/m^3** Shear modulus: **7.9e+010 N/m^2** Thermal expansion coefficient: **1.3e-005 /Kelvin**	**SolidBody 1(Boss-Extrude1)(set screw-1)**
Curve Data:N/A		

19 LOADS AND FIXTURES

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** **1 face(s)** **Type:** **Fixed Geometry**

Resultant Forces

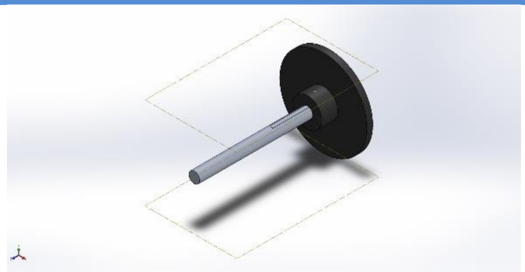
Components	X	Y	Z	Resultant
Reaction force(N)	22.0831	-0.0267167	0.000554942	22.0832
Reaction Moment(N.m)	0	0	0	0

Load name	Load Image	Load Details
Torque-1		**Reference:** **Face< 1 >** **Type:** **Apply torque** **Value:** **-18.9 lbf.in**

20 CONNECTOR DEFINITIONS

No Data

21 CONTACT INFORMATION

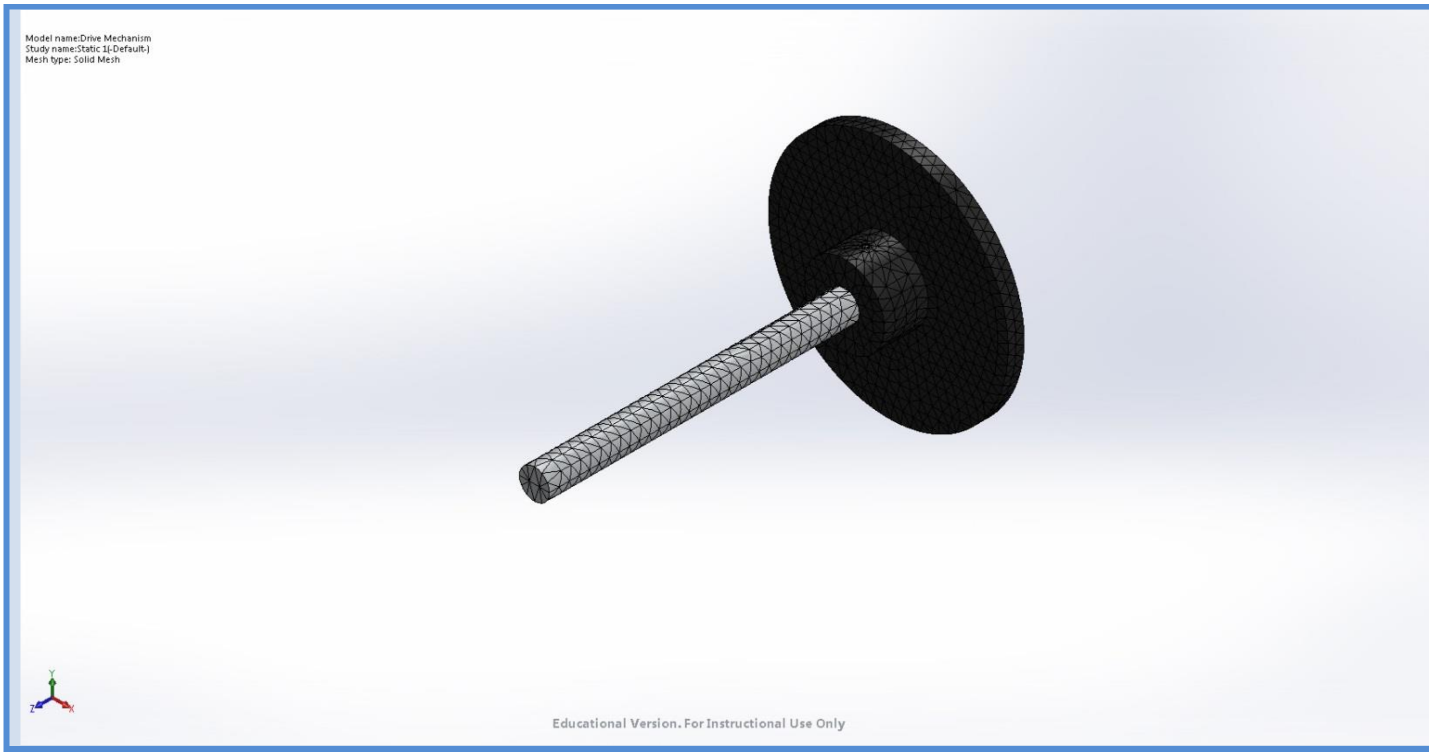
Contact	Contact Image	Contact Properties
Global Contact		**Type:** Bonded **Components:** 1 component(s) **Options:** Compatible mesh

22 MESH INFORMATION

Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Element Size	0.125656 in
Tolerance	0.00628279 in
Mesh Quality	High
Remesh failed parts with incompatible mesh	Off

22.1 MESH INFORMATION - DETAILS

Total Nodes	16715
Total Elements	10121
Maximum Aspect Ratio	22.947
% of elements with Aspect Ratio < 3	96
% of elements with Aspect Ratio > 10	0.336
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:02
Computer name:	URB222-16



23 SENSOR DETAILS
No Data

24 RESULTANT FORCES

24.1 REACTION FORCES

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	22.0831	-0.0267167	0.000554942	22.0832

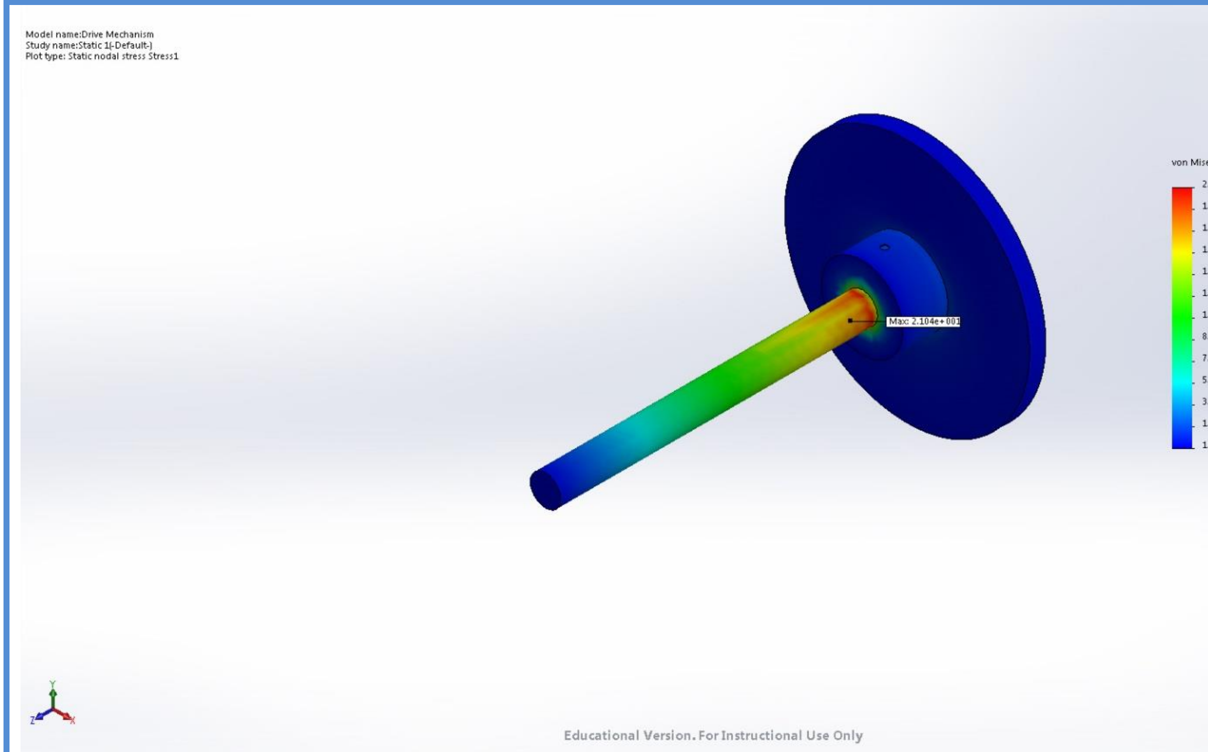
24.2 REACTION MOMENTS

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

25 BEAMS
No Data

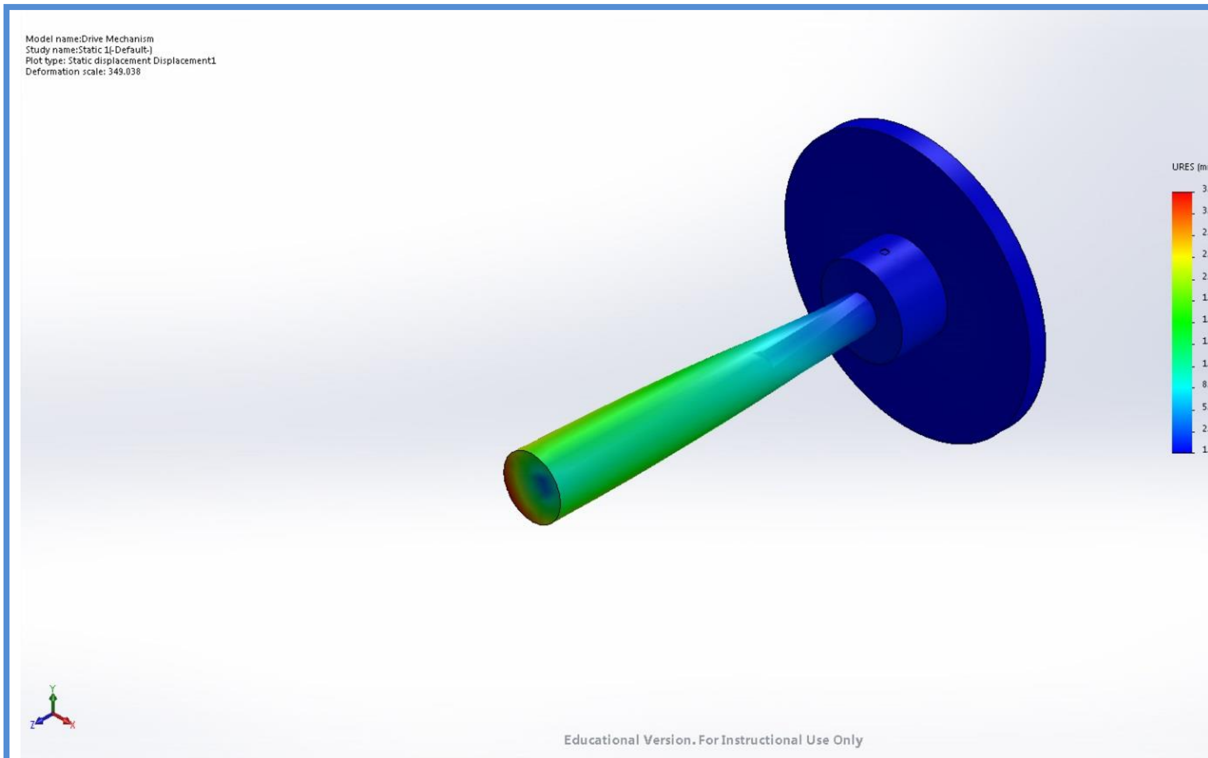
26 STUDY RESULTS

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.00155737 N/mm^2 (MPa) Node: 4948	21.044 N/mm^2 (MPa) Node: 3669



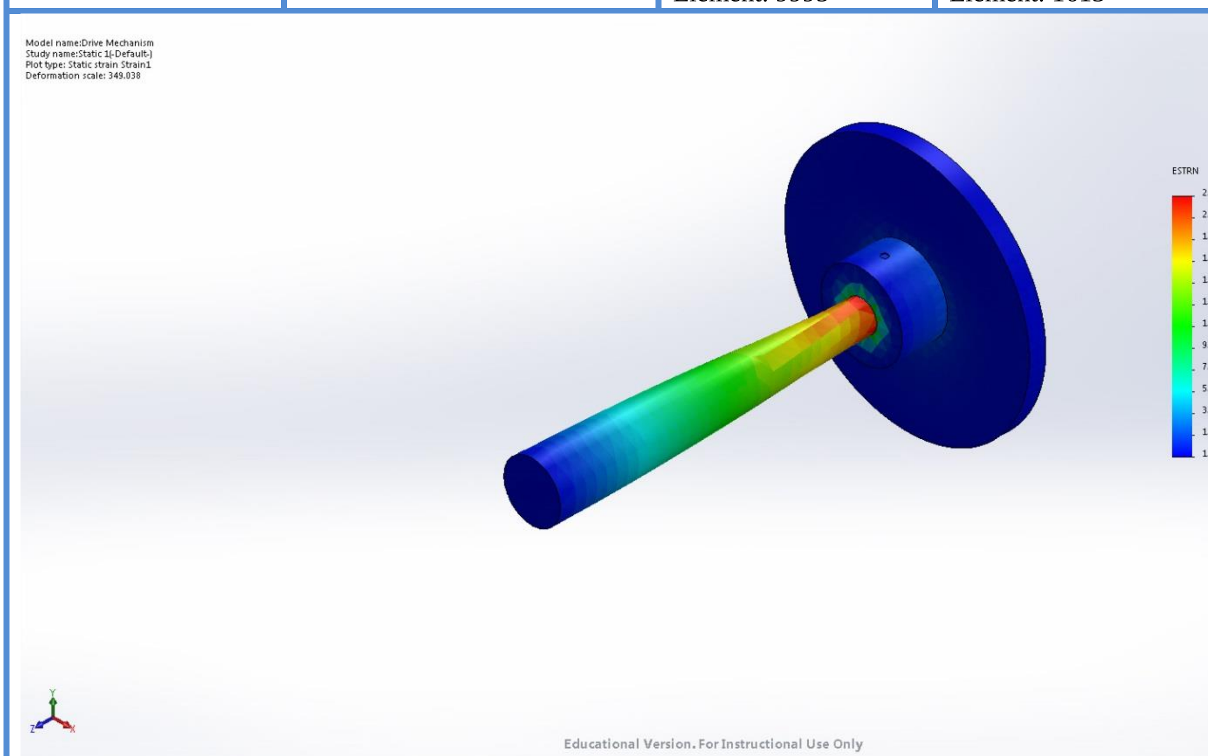
Drive Mechanism-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 3993	0.0336962 mm Node: 341



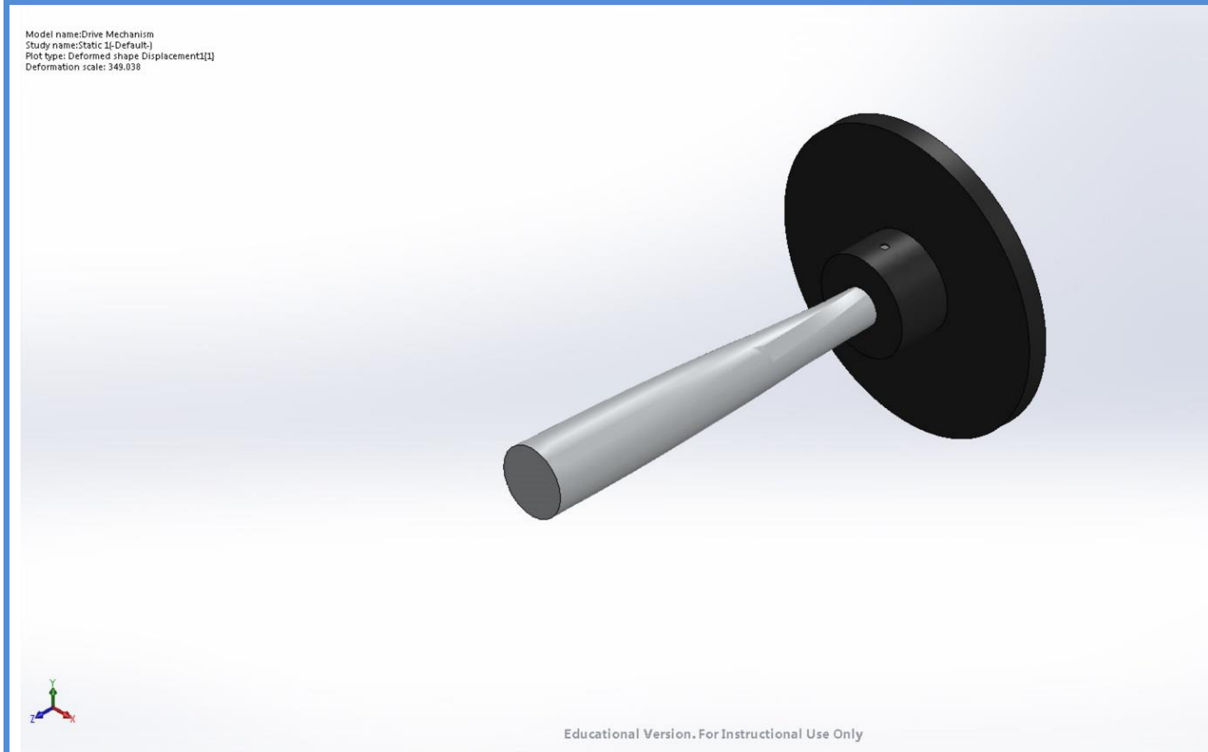
Drive Mechanism-Static 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1.38616e-007 Element: 9995	0.00022193 Element: 1613



Drive Mechanism-Static 1-Strain-Strain1

Name	Type
Displacement1{1}	Deformed shape



Drive Mechanism-Static 1-Displacement-Displacement1{1}