Rotating Shelving System

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by

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# TABLE OF CONTENTS

TABLE OF CONTENTS...........................................................................................................II
LIST OF FIGURES ........................................................................................................... III
LIST OF TABLES ............................................................................................................. III
ABSTRACT ......................................................................................................................... IV

1.0 INTRODUCTION .......................................................................................................... 1
  1.A CURRENT INDUSTRIAL USES ............................................................................. 1
  1.B CURRENT HOUSEHOLD USES ........................................................................ 2

2.0 TECHNOLOGY .......................................................................................................... 2
  2.A ROTATION ............................................................................................................ 2
  2.B MOTOR ................................................................................................................ 3
  2.C BALANCE ............................................................................................................. 4

3.0 SAFETY ..................................................................................................................... 4
  3.A ABILITY TO BE CLOSED .................................................................................... 5
  3.B NOISE .................................................................................................................. 5
  3.C EASE OF USE ..................................................................................................... 6

4.0 MAINTENANCE ......................................................................................................... 6

5.0 RESEARCH CONCLUSION ....................................................................................... 7

6.0 SURVEY CONCLUSION ............................................................................................ 8

7.0 PROJECT FEATURES & OBJECTIVES ..................................................................... 8

7.0 DESIGN CONCEPTS AND SELECTION .................................................................. 10
  7.A CONCEPTS ......................................................................................................... 10
  7.B SELECTION ......................................................................................................... 10

8.0 DRAWINGS .............................................................................................................. 12

9.0 LOADING CONDITIONS ............................................................................................. 12

10.0 DESIGN ANALYSIS ................................................................................................. 13

11.0 FACTORS OF SAFETY ............................................................................................ 14

11.0 CALCULATIONS ..................................................................................................... 15

WORKS CITED ............................................................................................................... 16

APPENDIX A: SURVEY ................................................................................................. 17
  SURVEY CHARTS ....................................................................................................... 18

APPENDIX B: QFD ......................................................................................................... 19

APPENDIX C: SCHEDULE .............................................................................................. 20

APPENDIX D: BUDGET .................................................................................................. 21

APPENDIX E: DESIGN CONCEPTS .............................................................................. 22

APPENDIX F: SELECTED DESIGN 3D MODEL ............................................................ 26

APPENDIX G: DRAWINGS .............................................................................................. 27

APPENDIX H: CALCULATIONS ..................................................................................... 35
LIST OF FIGURES

Figure 1: Survey.................................................................................................................. 18
Figure 2: Average Factor Rating........................................................................................ 18
Figure 3: Maximum Spending Survey.................................................................................. 18
Figure 4: Concept 1............................................................................................................. 22
Figure 5: Concept 1 cont..................................................................................................... 22
Figure 6: Concept 2............................................................................................................. 23
Figure 7: Concept 3............................................................................................................. 23
Figure 8: Concept 4............................................................................................................. 24
Figure 9: Concept 5............................................................................................................. 24
Figure 10: Concept 6.......................................................................................................... 25
Figure 11: 3D Final Model ................................................................................................. 26
Figure 12: Exploded View Drawing..................................................................................... 27
Figure 13: Ball Bearing Drawing........................................................................................ 28
Figure 14: Belt Drawing...................................................................................................... 28
Figure 15: Frame to Wall Drawing....................................................................................... 29
Figure 16: Floor Frame Drawing......................................................................................... 29
Figure 17: Short Shaft Drawing.......................................................................................... 30
Figure 18: Short Shaft 2 Drawing....................................................................................... 30
Figure 19: Main Shaft Drawing.......................................................................................... 31
Figure 20: Motor Drawing.................................................................................................. 31
Figure 21: Main Pulley Drawing........................................................................................ 32
Figure 22: Shelf Exploded View Drawing.......................................................................... 33
Figure 23: Shelf Assembly Drawing................................................................................... 33
Figure 24: Shelf Attachment Drawing................................................................................ 34

LIST OF TABLES

Table 1: Quality Function Deployment
Table 2: Schedule
Table 3: Budget
ABSTRACT

This project began with a visit to my grandparent’s house. While doing yardwork, I went into the shed to look for a tool. The shed was in disarray, and the floor space was very limited. There were high, unreachable shelves, with tools covered in dust on them. It was clear the space needed a more efficient way to store things, and an easier way to reach the higher up tools. This experience led to my problem statement: Maximizing the space in a shed or garage can add a huge amount of storage capability. However, the higher you store items, the more difficult and dangerous it is to retrieve them. An automatic vertical carousel would allow the maximum amount of space to be used, while granting a easier and safer way to retrieve items.

In order to solve this problem I wanted to make an automatic, cheap, but capable shelving system. In order to keep costs down I designed the system to be manufacturable with home tools (table saw, grinder, power drills, etc). To further keep cost down I had the goal of purchasing as many materials as possible from a typical home improvement store. The system is designed to be variable, and to be able to fit any application. The goal was to have a system that could go infinitely high, have high capability per shelf, and be able to rotate the high items down right to you.

I was able to build a successful product by using a steel frame, wooden pulleys, steel shelves, steel ball bearings, steel water pipe shaft, nylon belt, ¼ HP motor, pulleys, and a lot of nuts and bolts. Every item was purchased at a typical home improvement store besides the motor, pulley and ball bearings. The system was
also 100% manufactured only using home tools. These helped keep the cost down. In
the end the project ended up costing about $600 which was dead on the budget
allotted for the project. The system was capable of holding 40 pounds per shelf and
was 8.5 feet high, 4.5 feet wide, and 3 feet deep. The system only required a 115V
outlet to operate.

In conclusion the product created was a great proof of concept product, but
most likely not sellable. Further design and troubleshooting could help improve the
product. Possible improvements would be to use a chain drive train over a pulley
drive train, to use plastic shelves rather than steel to reduce weight, and to use plastic
pulleys instead of wooden. Doing these things will further reduce the cost and
increase the quality of the product. If the product is reduced to around $400, which I
believe is feasible; it would be a sellable and successful product.
1.0 INTRODUCTION

Home storage shelving systems consist mainly of stationary shelving that goes from the floor to a designated height. These are most common due to their simplicity and relatively low cost. However, such shelving systems bring some major difficulties. Items stored near the top and bottom shelves are often hard to reach and can lead to injury retrieving them. Often you cannot store heavy items on the top shelves, thus limiting the space you can store them to the bottom. Items are often stored in random because it is too difficult to match alike items on the hard to reach shelving. These difficulties often arise to a lack of organization, possible injuries, and frustration from the users. A new storage rotating shelving system, that can rotate each shelf to the desired height, while maintaining a low cost for home use, can be the solution.

1.A CURRENT INDUSTRIAL USES

Vertical rotating shelving systems are already readily available, but only mainly in an industrial setting. These enormous, complex systems can be purchased from companies such as Bastian Solutions, Cisco Eagle, and Shelf Plus. These systems are robust and powerful. These systems can hold up to 800 pounds on one shelf, can reach over thirty six feet tall, automation controlled, and fully enclosed (5). Vertical shelving systems have been proven to save 70% on floor space and increase productivity “search time” but 2.5 times (4). These systems are highly effective for those willing to invest the $45,000 to $90,000 each. The effort of this research is to discover a way to take these concepts, and scale it down to a typical household system.
1.B CURRENT HOUSEHOLD USES

There are very little vertical rotating shelving systems in the household market. In fact, through research, I have only found one current system, the AutoPantry (2). The AutoPantry is a vertical rotating shelving system that is designed for food items in the kitchen. The system can be purchased in three different sizes, and is automated. However, there are some drawbacks to the design. Each shelf can only hold at maximum 20 pounds. This severely limits its usability to smaller, lightweight items. Also, each shelf must be balanced in order for the rotation to operate. This could cause frustration from the end user. One more drawback is the items on the shelves must be no taller than the back of the shelf. The shelves are tightly compact and any excess height will result in a jam. Overall, this system can work well for its desired purpose of food items, but is lacking in its universal ability. By taking the complex industrial vertical rotating shelving systems and comparing them to the AutoPantry, we see a large difference in capability. The purpose of this research is to find a happy medium between the two.

2.0 TECHNOLOGY

2.A ROTATION

The first requirement in creating a rotating shelving system is how to get the shelves to rotate. This can be done thru gears, chains, belts, or other means. When deciding which drive system to use, one must compare many factors. These factors include cost, installation, lubrication required, speed, weight capacity, efficiency, and
others (11). One of the most important factors to consider is the balancing of the shelves. The shelves must remain balanced even around the curve of the rotation. Also, in current use this rotation is done automatically using a motor, but a crank system is also viable for low weight applications.

2.B  **Motor**

In most applications a motor is used to automatically rotate the shelves. In industrial use, these motors are very strong to accommodate heavy weight and a large amount of shelves. In current household use, the motors are small and quiet, in order to work inside and accommodate a low weight and number of shelves. When selecting a motor many things need to be taken into account. First, you must know the load characteristics of the motor. Will the motor be constant torque, torque that changes abruptly, or torque that change over time? For a rotating shelving system, our motor would fall into the torque changes abruptly. The motor must be capable going from rest, to moving the max weight in a fraction of a second. Secondly, we must get a handle on the horsepower required. In this the rule of thumb is to select only what you need. Thirdly, you need to consider the power required to get the motor moving from rest. Inertia for a rotating shelving system will be high due to the weight on each shelf that must be moved from rest. Fourthly, one must look at the duty cycle. Duty cycle is the load the motor must handle from start, running, and stopping. In our application, the duty cycle will be intermittent duty. This means the motor will not run continuously, but rather on a needs basis. Lastly, the environment the motor runs in. We must look at things like temperature, altitude, humidity, and other factors to make sure the motor can run efficiently. (6)
2.C  *BALANCE*

Likely the largest issue to solve in rotating shelves is balance. The shelves must be able to hold its items weight, and keep it balances as it rotates from side to side. The shelves must be balance when rotating vertically, as well as around the curve to the opposite side. This poses many problems. If the shelves are balanced the items will fall off and could damage the items and more importantly the operator. The best solution to this issue has been a non-rigid approach. The shelves need to be hung at their center of gravity. Once they are suspended at their center of gravity, then gravity can balance the shelves throughout the rotation. This can be successful in balancing the shelves through the rotation, but still has issues that need to be solved. First, the shelves can lose their center of gravity by the loads and placement of the items put on the shelf. Therefore the shelf must have a way to limit the maximum movement of the self. This movement of the shelves, no matter how slight, can lead to less safety to the operator.

3.0  *SAFETY*

Safety is one of the paramount factors to consider in a rotating shelving system. If the system is not safe to use in a household, it will not be successful. In industrial use the system is made safe by its ability to be closed. Closing the system while it is in progress would guarantee that nothing can fall onto the operator. The same concept is used in household applications through the use of a door in front to the system. Another factor to consider is the noise. The system must not be overly loud to make sure it does not damage the operator’s ears. For household use, the
system must be quiet in order not disturb anyone near. One other factor to consider for safety is the ease of use. Rotating shelves can be done using a motor or crank system. A hand crank system can lead to a less safe environment due to the human force required. Also the ability to rotate a shelf to the ideal height for pickup, usually waist height, can lead to much less stress put on the operator retrieving objects.

3.A ABILITY TO BE CLOSED

The ability for the rotating shelves to be totally enclosed is key to a safe system. Closing the system can benefit safety two fold. First, the operator is no longer in danger of falling objects. Since the shelving system is enclosed, any possibility of a falling object will be contained within the system. Secondly, enclosing the system can protect the objects within to external hazards. By being enclosed the system can be locked and protect the objects from thievery. Also, being enclosed can protect the objects from environmental factors to a degree. (10)

3.B NOISE

Noise is an important factor of safety in both industrial use and household use. For industry, the system must not exceed certain decibel levels consistently over a long period. Per OSHA requirements noise levels cannot exceed 90 decibels for all workers for an 8 hour shift (3). For households you want the system to be quiet as possible. A household is supposed to be a relaxing and stress free place. Adding loud noise to consumers daily lives will not sell the product.
3.C **EASE OF USE**

Ease of use is a very broad factor but regardless is one of the most important. A shelving system would not be successful if it is complicated to use. The whole purpose of a rotating shelving system is to save time and energy for the consumer. Both of these goals fall into the ease of use category. A rotating shelving system brings the object into the operator’s power zone, typically at waist height. This rotation is beneficial in many ways. First it reduces the strain on the operator’s body. It reduces awkward postures, repetitive motions, forceful exertions, pressure points, and static postures. All of these cause in a significant reduction in injury possibility in workers (8). Also, an automatic system powered by a motor can increase the safety of the operator. By using a motor, we remove the required physical capability of the operator. If the system required manual rotation is could cause physical exertion on the operator. Having a motor can allow anyone to operate the system. This further adds to the ease of use and can be very appealing to a large consumer base.

4.0 **MAINTENANCE**

Maintenance is very important in both industrial and household uses. Industrial maintenance is a priority because the business requires their systems to be running at all times in order to keep productivity. If a rotating shelving unit was to fail, it would be extremely difficult to retrieve the materials inside. Many industrial rotating shelving systems help this possibility by adding a manual crank to the system if it goes down. When a system goes down it costs the company time and money to get it back up. The system must be fixed, and is not operating the entire time it is
down. Therefore preventative maintenance, the ability for quick fixes, and extended life are paramount in the shelving design. (7)

For the household systems maintenance is a much less of a factor. Household consumers will want the rotating shelving system to work as long as possible without any maintenance. Household consumers are often not skilled to complete preventative maintenance on a system. Therefore the life cycle and ease of fix of the system are paramount in this situation. The ability to simply replaced parts rather than fix them is also important. Household consumers would much rather buy a needed replacement part, rather than manually fix the broken area.

5.0 RESEARCH CONCLUSION

Through this research I was able to determine the current uses for rotating shelving systems, the technology required to create such a system, the factors of safety that must be addressed, and the importance of maintenance in the product. In its current use, rotating shelves are used on an industrial scale. Vast and robust designs are incorporated to save time, space, and energy. In household circumstances, rotating shelves are a lot less common and used in lightweight situations. The technology required to create such a system involves gears, chains, material, motor, crank, and a balancing system. The most difficult part of the design will be able to get the shelves to balance with any type of load applied. There are many factors of safety to account for including noise, containment, rotation balance, electrical, and others. Through research I was able to determine the best way to create the safest product was to have the ability to enclose the system. With an enclosed system, the operation can occur
without any risk to the operator. Maintenance is an important factor in both industrial and household uses, but is very different between the two. Industry wants a system that can be fixed continuously and last a lifetime. Household users want a system that requires no maintenance, last a long time, and can be replaced when it does eventually break. Household users look more into replicability rather than to opportunity for continually maintenance. For this my design will focus on robustness that does not require regular maintenance.

6.0 SURVEY CONCLUSION

Please refer to Appendix A for figures and data related to survey. As my project revolves around household rotating shelving systems, the surveys main participants were those with families. The results of the survey were expected for the most part. From the survey I gathered that the areas to focus my design are low cost, safety, and ease of use. While they cannot be ignored areas such as maintenance, style, size, and load do not require as much focus. The survey also shows the max that the participants were willing to spend on this technology. The results overwhelmingly express to keep the cost under $750. From this information I will focus my design to be under $750, and safe and easy to operate for all ages.

7.0 PROJECT FEATURES & OBJECTIVES

Through my research, survey, and quality function deployment (QFD) I have the data and analysis to lay the foundation of my product’s features and objectives. To view data from survey, see Appendix A; to see data from QFD, see Appendix B).
Through my research I have decided to make my product a household use item that can hold a medium amount of weight. The household market is extremely vast and a successful system could thrive in it. Through my customer survey I was able to determine that low cost, safety, and ease of use are the most important factors to my potential customers. By combining the survey data with the quality function deployment, I was able to arrive at the most important features. These features include a caged shelf, automatic rotation with a hand crank backup, and a closable door. These features will maximize the safety of the system as well as its ease of use. Some possible features that I will no longer be pursuing is a modular and adjustable system. These two features had a majority of negative effect on the key features. The goal is to be able to implement these key features and keep the cost under $750. The $750 max was the overwhelming selected requirement on the survey. Some features that could be included as extras, like color or design, could be implemented depending on budget availability.

For a budget I will like to keep the initial investment to below $1000. A budget below $1000 will keep the aim to have the final product be under $750. I would like to keep labor under $300 which includes lab tech work, assembly, transport, and welding. I would like to keep the material cost below $700 which includes sheet metal, gears, chains, motor, and hand crank. The goal is a product sellable for $750.
7.0 DESIGN CONCEPTS AND SELECTION

7.a Concepts

The main goal when creating concepts for a design of the vertical shelving system was cost. With a low budget, a low cost system is a must. When coming up with concepts, I started with a more traditional style approach and then broadened my ideas as I went. This gave me a large range of concepts and ideas to go through and ultimately help me choose the one I thought best. Going through many concepts also helps generate ideas, even if you end up not going with that certain concept. For example, some of my first concepts inspired ideas that went into my later concepts. Also, when choosing my final design I was able to choose and combine items I liked in different concepts, rather than just choosing one as a whole. In all my concepts I had two constraints. These constraints were low cost and automatic rotation. These two constraints were paramount because they defined my capabilities for the project. I didn’t have the budget to create a marvel of engineering but I wanted my most important feature to be paramount, the automatic rotation. While going through my designs these are the two things I kept always in the back of my head. These concepts included designs such as hydraulic lifted shelves, vertical and twist rotation, wall and ceiling mounted system, guide rails, and more. To see all concepts, in detail, please see Appendix E.

7.b Selection

For my project I went with a combination of my different concepts. To remove cost, I went with a floor and wall mount. This removes the need for extra material for a frame in order for the system to stand upright. Instead, the system will
be bolted into the ground and wall with brackets. This, as a plus, also saves on space, which is a huge benefit as well. The frame used will be a recycled shelving frame from a library, which was no longer being used due to upgrades. This also saves on the cost of purchasing material to make a frame. The frame is made from steel, and will be plenty strong for my required loads. Next, we have the ball bearings. In order for the whole system to rotate, we need 4 ball bearings to hold the shafts. These ball bearings are made 52100 chrome steel, have a 1” bore diameter, and 2 bolt holes to be bolted to the frame. These ball bearings will be supporting two 1” hollow shafts, made of galvanized steel, one top and one bottom. This shaft will be strong enough to hold the max weight, but is also hollow, which allows us to more easily attach our pulleys. On the shafts we will have our main pulleys holding the load, and also one pulley for our drive train. The main pulleys will be made of cuts of plywood bolted together to create a 2.25” thick and 18” diameter pulley. The pulleys are 18” in diameter in order to allow enough room for the shelves to rotate around the shaft. The pulleys are 2.25” thick in order to hold our belt, which is 2” thick. Our two belts will be made of nylon and have a 4000 pound capability, which is plenty over our max. The belts will have bolt holes burned through them, and a small shaft attached. Burning holes instead of drilling holes through the nylon will help keep its integrity, as the fibers will not be frayed. The attached shaft to the nylon belt is what the shelves will rest on. This shaft will be made of steel. The shelves will be also made of recycled materials from the library shelving system, saving costs once more. The shelves are made of 4 pieces, a bottom, backrest, and two sides that will be bolted together. The shelves will also have a thin piece of metal on the front, making sure
items do not slip off the front during rotation. The shelves rest on the shaft attached to the pulleys by having a hole drilled in the sides. The shaft goes through this hole and is balanced by gravity. As the shelves rotate through the system, they are constantly balanced by the force of gravity pulling down on them. This brings us to the motor powering the system. My goal rotation speed for the system was to go around twice in one minute. With this in mind I was able to select a 1/4 HP 12 RPM 115V Dayton AC Parallel Shaft Gear Motor. This motor is capable at meeting my required max torque, but the system will be slightly slower than the goal. I determined this acceptable, as it was the best fit for my system. To allow the motor to drive the shaft, I used a 2:1 gear ratio pulley drive train. The motor will be bolted to the frame and held near the shaft. To see the 3D model of the selected design please see Appendix F.

8.0 DRAWINGS

The final design has 17 unique parts with 2 subassemblies. The shelves themselves are made up of 4 parts, a bottom, backside, and two sides. The shelf assembly is then a part of the overall assembly. The system will mostly attach together with bolts in order to make the whole system modular. For a detailed view of the drawings for every part please see Appendix G.

9.0 LOADING CONDITIONS

This system has a few torques and loads that must be met. By design, the system is to hold 50lbs per self, with eight shelves in total. This means that the max torque condition is 4 shelves fully loaded on one side of the system, and a factor of safety. Including a factor of safety of 2, and the 18” diameter pulley, this gives us a
maximum torque of 300 ft*lbs. The system also needs to support the full weight of all the shelves on the shaft. This is 800 lbs of free weight that the shaft must be able to hold. The weight will also be distributed on the frame, which then will apply it to the floor it is mounted on. The wall mount will also carry a load, but this load will be very small. This load is simply to keep the system perfectly vertical during rotation.

10.0 DESIGN ANALYSIS

So how does the system operate? First, let’s look at the shelves. The shelves operate by having a gravity fed rotation. The shelves are suspended by putting a shaft through a hole on the sides of the shelves. The shaft is loose in the hole. As the system rotates, and the belt moves, the shelves move with it. Once at the top the shelves will go around the pulley, but will stay gravity fed upright. The key for this to work is a balancing of the weight on each shelf. Each shelf must have its weight as balanced as possible. Two things that will help with balancing are guard rails and a ridge on the front of the shelf. The ridge will keep items from slipping off of the front of the shelf. The guard rails will help keep the shelf balanced on the straight path of the pulley. They will keep the shelf from tilting too much in one direction. With all of these features and considerations in place, we can create a smooth and safe rotation.

The shelves will be attached to the nylon belt, which is being moved by the pulleys, which are being rotated by the shaft, which is being rotated by the drive train and motor. The motor is able to lift the worst case for my design, 400 lbs on one side. However, this situation should never arise. The shelving should be balanced throughout the system. This means, that the weight of the system should be spread out amongst the eight shelves. The better spread out the weight is, the better the system
will operate. For example if there is 200 pounds on one side of the pulley, and 200 pounds on the other side as well, the system is in balance and the motor will have a much easier time. This will add life to the motor and system as a whole.

The motor can be run by a typical 115v house outlet. For the sake of budget there will be no forward and reverse direction added to the motor, although it is capable if an add-on is wanted. Therefore, for the system to start its rotation it needs to be plugged in. There is no on-off switch. For my design, the motor will be plugged into an outlet controlled by a light switch. If you want the system to turn on, you simply flip the light switch.

11.0 FACTORS OF SAFETY

For this system the balancing of weight is the most important aspect. Without weight being balanced, the shelves could tilt too far and spill the things being stored. Two features are added to help ensure this will not happen, the guard rails and shelf ridge. While these features will help, the most important thing to do is balance the weight on the shelf.

Another important factor is the weight per shelf. The weight per shelf is designed to be a max of 50lbs per shelf. Now, usually people do not know the exact weight of items they are storing, and we want a buffer zone for safety. Because of this I designed the system to withstand loads to a safety factor of 2. This means the system is built to withstand a maximum of 100 pounds, even though it is listed as a 50 pound max.

Another important safety item is the openness of the system to its surroundings. Because the system is wall and floor mounted, it is not enclosed and is
easily accessible. While this is good for functionality, it adds a risk factor. For this risk factor, however, only a warning can be used. My design does not include and enclosed system, and therefore, with a warning in the instructions, I believe it will be safe to operate as long as the operator uses car.

11.0 CALCULATIONS

For this project the main calculations revolve around the max torque the system may face and the rate I want the system to rotate. First, I calculated the max torque condition, which is with 400 pounds on one side of the pulley, and no weight on the other side. For this I arrived at a max torque of 300 ftlbs. Next, my goal was to have the system rotate 2 times around in one minute. To solve for this I needed the length of the belt in the system. The belt is a loop with two half circles, and two straight lengths. I calculated this by adding the circumference of the main pulley and the two straight lengths together and arrived at around 192 inches. Next, I needed to calculate how many times the pulleys must rotate to cover this distance twice in one minute. I arrived at 6.78 rpm to achieve this goal. Next I needed to solve for the size motor I would need for this worst case scenario. I solved this using the torque and rpm just calculated, and arrived at .371 horsepower. Unfortunately, I had a .25 horsepower on hand and ready to use. Therefore, I had to re-solve for the RPM that would allow me to lift the max torque load. After resolving for RPM, I arrived at the pulleys rotating around 4 RPM rather than 6.5 RPM. I decided that this was an acceptable speed, and proceeded with the .25 HP motor. The .25 HP ran at 12 RPM, so I needed to solve for the gear ratio required to have the motor at 4 RPM. For this I arrived at a 3:1 gear ratio. To see detailed equations and math please see Appendix H.
WORKS CITED


APPENDIX A: SURVEY

Below is the customer survey that was sent out to 20 potential consumers, 15 responded.
The results of the survey are shown in the two figures below:

**Figure 2: Average Factor Rating**

**Figure 3: Maximum Spending Survey**
## APPENDIX B: QFD

### Quality Function Deployment Template

<table>
<thead>
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<th>Technical Requirements</th>
<th>Current Rating</th>
<th>Planned Rating</th>
<th>Importance Rating</th>
<th>Sale Point</th>
<th>Weighted Scale</th>
<th>Percentage of Total</th>
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**Correlations:**
- Positive
- Negative

**Relationships:**
- Strongest = 10
- Strong = 7
- Fair = 4
- Weak = 1
# APPENDIX C: SCHEDULE

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Table 2: Schedule
## APPENDIX D: BUDGET

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Table 3: Budget
APPENDIX E: DESIGN CONCEPTS

Figure 4: Concept 1

Figure 5: Concept 1 cont.
Figure 6: Concept 2

Figure 7: Concept 3
Figure 8: Concept 4

Figure 9: Concept 5
Figure 10: Concept 6
Figure 11: 3D Final Model
Figure 12: Exploded View Drawing
Figure 13: Ball Bearing Drawing

Figure 14: Belt Drawing
Figure 15: Frame to Wall Drawing

Figure 16: Floor Frame Drawing
Figure 17: Short Shaft Drawing

Figure 18: Short Shaft 2 Drawing
Figure 19: Main Shaft Drawing

Figure 20: Motor Drawing
Figure 21: Main Pulley Drawing
Figure 22: Shelf Exploded View Drawing

Figure 23: Shelf Assembly Drawing
Figure 24: Shelf Attachment Drawing
APPENDIX H: CALCULATIONS

Required Torque = \( F \times D \)
\[ = 4(100\text{lbs}) \times 0.75\text{ft} \]
\[ = 300 \text{ ft} \cdot \text{lbs} \]

Belt Distance = \( 2(\text{Straight Length}) + 2(\pi r) \)
\[ = 2(67.52) + 56.56 \]
\[ = 191.6 \text{ inches} \approx 192 \text{ inches} \]

RPM Goal = 2 times around per minute = \( \left( \frac{\text{Belt Distance}}{\text{Pulley Circumference}} \right) \)
\[ = \left( \frac{2 \times 191.6}{56.56} \right) \]
\[ = 6.78 \text{ rpm} \approx 6.5 \text{ rpm} \]

Horse Power Required = \( \frac{\text{Torque} \times \text{RPM}}{5250} \)
\[ = \frac{300 \text{ ft} \cdot \text{lbs} \times 6.5}{5250} \]
\[ = 0.371 \text{ Horse Power} \]

RPM required for \( \frac{1}{4} \) HP motor = \( \frac{\text{HP} \times 5250}{\text{Torque}} \)
\[ = \frac{0.25 \text{HP} \times 5250}{300 \text{ft} \cdot \text{lbs}} \]
\[ = 4.375 \text{ RPM} \approx 4 \text{ RPM} = \text{acceptable} \]

Gear Ratio = \( \frac{\text{Motor RPM}}{\text{Goal RPM}} \cdot \frac{12 \text{ RPM}}{4 \text{ RPM}} \)
\[ = 3:1 \text{ ratio} \]