Team 1

return;

Robot Entity That Uses Rfid Indexing

Luke Griffioen, Chris Rozema, Theo Voss, Josh Vroegop

Fall 2011, Calvin College ENGR339
Copyright 2012, Luke Griffioen, Chris Rozema, Theo Voss, Josh Vroegop
and Calvin College
Abstract

Libraries are wasting hundreds of thousands of dollars a year on sorting books when an automated system could do it for much cheaper. The challenge is that designing such a system for libraries on an individual basis is prohibitively expensive. This school year at Calvin College our team is designing an automated system to sort returned books for small libraries in such a way that our design can be scaled up to accommodate a wide range of libraries.

The basic design will receive books and store them in a queue until the second stage is ready to process. The second stage will determine the location of the spine by lifting the cover of a book and detecting which way it tilts. Once the spine is located the book will be rotated and loaded into the third stage, another queue, with its spine facing out. The second queue will be picked up by a drone robot (stage 4) designed to navigate to the re-shelving carts and fill them with books. The sorting will be done by the drone putting a book in the right section of the carts.

The book handling motors throughout the process will be controlled by two micro-controllers: one to control the stationary motors (stages A through C) and one to control the drone (stage D). The micro-controllers will communicate with a dedicated Windows computer for integration with the library’s main systems. Our estimated price at production is $15,000 which will be payable on a 5 year payment plan. Costs for manufacturing are estimated at $1,500. The additional price is for business costs, our profit margin, and to finance a research and development team to develop new products. Our design will be saving a typical target library (book returns between 1,000 and 40,000 books a week) $50,000 or more a year. A market survey shows that libraries are willing to spend up to $5,000 a year for such a sorting device and would look for a 30 to 35 level sort.

Our team has divided the project into four main technical areas: mechanical (covered by Chris), software (covered by Luke), controls (covered by Theo) and power (covered by Josh). Each team member has decision authority over their section but has to talk to other team members to figure out requirements for their section.

We believe that this project is feasible in the time allotted. Currently the mechanical design is the furthest along as it drives requirements for much of the electrical design. The additional work on the Electrical and Software designs will be accomplished because both Luke and Theo have more available time during interim and spring semester to dedicate to the project. Also, our market research shows that our estimates on price and functionality are right for the target market.
Table of Contents

1  1Introduction.................................................................6
   1.1Senior Design.........................................................6
   1.2Problem Statement..................................................6
   1.3Customer Operations..............................................6

2  2Team Organization....................................................8
   2.1Non-team members:...............................................8
   2.2Team Members......................................................8
   2.3Team Interactions: problem resolution and team leadership....10

3  3Requirements............................................................11
   3.1Problem Definition.................................................11
   3.2Customer Requirements.........................................11

4  4Method of Approach..................................................13

5  5System Design..........................................................14

6  6Programming Architecture........................................17
   6.1Stage A controls....................................................17
   6.2Stage B flow........................................................18
   6.3Stage B computer programs:....................................18
   6.4Stage B controls....................................................20
   6.5Stage D computer.................................................21

7  7Design Work.............................................................21
   7.1Mechanical Designs...............................................21
   7.2Electrical Design..................................................32
   7.3Power Supply.......................................................36
   7.4Software Design...................................................40
   7.5Possible Issues.....................................................42

8  8Testing.................................................................43
   8.1Incremental Tests..................................................43
   8.2Module Testing.....................................................43
   8.3System Testing.....................................................48
   8.4Tests Completed...................................................48
   8.5Arduino PWM Test...............................................50
   8.6Optical Character Recognition Test............................51
   8.7Book Recognition Test..........................................51

9  9Prototypes Built........................................................52
   9.1Stage B Proof of Concept Build.................................52

10 10Budget Management...............................................54
    10.1Tools .............................................................54
    10.2Cost Estimation..................................................55
    10.3Key Numbers.....................................................56

11 11Marketing Study....................................................57
    11.1Competition......................................................57
    11.2Patents............................................................59
    11.3Market Survey...................................................60

12 12Business Plan........................................................61
12.1 Executive Summary

12.2 Mission Statement

12.3 Vision

12.4 Industry Profile and Overview

12.5 Business Strategy

12.6 Products and Services

12.7 Marketing Strategy

12.8 The library market is not shrinking or growing much as libraries tend to be financially stable and an increase in demand for renting books can be accommodated by current libraries.

12.9 Location and Layout

12.10 Competitors

13 Plan of Operation

13.1 Legal Form Operation

13.2 Decision Making Authority

14 Financial Forecasts

14.1 Loan or Investment Proposal

15 Feasibility

15.1 WBS summary

15.2 Feasibility Statement
1 Introduction

1.1 Senior Design
Senior design at Calvin College is a year-long class broken into ENGR 339 and ENGR 340 during which engineering students break out into design teams, pick a project, design to meet specific requirements and build a prototype when possible.

1.2 Problem Statement
Our team is designing a sorting solution targeted at smaller libraries with book returns in the range of 1,000 to 50,000 books a week. Our design will be receiving books through a book drop and be delivering books to a re-shelving cart. It must be able to receive books at a rate of 1 book per second and process them fast enough that a line of people dropping off books doesn’t get held up.

1.3 Customer Operations

Hekman Library
Calvin College’s Hekman Library has a staff size of 30 employees, including full-time librarians, support staff, and student workers. Hekman has several mediums in their collection, such as books, electronic documents, reference materials, journals, and government documents.¹ Our project focuses on sorting books. The circulation desk in the library currently has student employees who perform daily tasks, which includes checking books in from the drop box at the entrance. The Hekman Library would likely not buy our sorter as it unwilling or unable to eliminate the two students staff members who handle sorting tasks and only gets overwhelmed a few days a semester. The Hekman Library was initially considered as a customer but as they would not buy such a device we have changed our customer to Grand Rapids Public Library (GRPL) because they have a much higher throughput rate and are moving towards incorporating new technologies.

Grand Rapids Public Library
GRPL is researching and working to implement an RFID system in their collection of reading materials, within the next two years. Another goal they would like to meet is to be able to “optimize the use of current facilities while exploring opportunities for future expansion”. Our team would like to be able to implement an automated, RFID driven system in libraries like GRPL whose books are going to

support RFID. The integration of RFID and their interest in new technologies makes GRPL a near-ideal client for our team’s project.

GRPL would find use for our design in their facilities for several reasons; the main reason is that they are currently researching the best way to incorporate a RFID check-in system. They have shown interest in the design and are willing to help us narrow down requirements and do a cost-benefit analysis for us to see if it would be a financially feasible product for their libraries. Our contacts at the GRPL are seen below.

---


2 Team Organization

2.1 Non-team members:

Advisor:
Steve VanderLeest is the team advisor. If there are overall design issues that affect the scope of the project, the team has to describe the problem and proposed solution for the design. VanderLeest also has the privilege of reading weekly team reports and grading all material handed in.

Library Contact:
Maria Ehlers is the team’s contact at the Grand Rapids Public Library (GRPL). She has agreed to organize tours of the circulation sections of all library locations the GRPL operates. She has also agreed to a design meeting to talk about requirements for the overall system as well as a cost/benefit breakdown of the system to determine how much GRPL would be willing to spend on it.

Industrial Consultant:
Mr. Tim Theriault is our industrial consultant. We have had one meeting with him where we described our design and asked questions about the design process. He was able to give us a few alternatives for controlled motor design and measuring the position of a rotating axle.

2.2 Team Members:

Luke Griffioen

Bio:
Luke is a senior at Calvin College studying Electrical and Computer Engineering. He is also a 4-year member of the Calvin Swim team and is currently having his best season ever. He began writing software in high school on his TI-83+ calculator. He later expanded to desktops, writing in Java, and into mobile writing iOS apps. His skills have earned him a job at TechSmith corporation in Okemos, MI and a position on team Return as a programmer for this library book sorting robot.

Tasks:
Luke is the lead programmer in charge of integrating all of the software pieces together and writing code for sorting and signal processing. He is also responsible for testing and integrating the RFID scanner chip and integrating our software system with the libraries, should we get that far.
Theo Voss

Bio:
Theo is a senior at Calvin College studying Electrical and Computer Engineering. In his spare time he enjoys reading, programming, playing games and sports, and watching TV. He also enjoys writing and has even been employed as a student writer at Calvin. Theo has happily accepted a job offer for after graduation at DornerWorks where he was an intern last summer.

Tasks:
Theo is in charge of integrating the micro-controllers with higher level languages for full system control. Theo is also charged with helping Chris Rozema create the control systems for the various motors throughout the system. He also is the Webmaster for team 1.

Chris Rozema

Bio:
Chris Rozema grew up building and tinkering. Throughout his childhood Chris has enjoyed a continued hobby of design and construction from Legos and K'nex to RC planes, model rocketry, and eventually, robotics. Chris plans to enter the workforce after Calvin, hopefully, to pursue a career in manufacturing and automation where is recently found love of robotics will become his full-time job.

Tasks:
Chris is in charge of the mechanical design of the machine. He will perform the spacial, static, dynamic, stress, failure, and energy requirement analysis primarily alone. He will also be working alongside Theo Voss on integrating the mechanical system with the control system and programming the BASIC stamp micro-controllers. Chris' power requirement information will be passed on to Josh Vroegop who is expected to design the machine's power distribution system.

Josh Vroegop

Bio:
Josh Vroegop, is from Kalamazoo, MI and is a senior engineering major with a concentration in Electrical and Computer Engineering. He plans to find a job after school in an entry level position anywhere in the Midwest, primarily one that involves analog circuit design, work for a couple years, and possibly consider applying to graduate school for further education.

Tasks:
Josh is in charge of designing the analog circuits for the machine. This includes the overall power supply that will provide necessary levels of power to specific components such as motors, micro-
controllers, and the drone. He will also be designing the printed circuit boards (PCB) that will hold the power supply, the micro-controller, and the necessary intermediate stages that allow power to be provided at necessary voltage and currents levels needed for other components.

2.3 Team Interactions: problem resolution and team leadership

Team members are given specific subsections of the project to head and are responsible for researching and finding solutions to any problems, issues, or delays that fall under their subsection. Design decisions that affect the overall system are debated and decided on by the whole team, with the team member most affected by the design choice having the deciding vote in case of deadlock.

If a team member has an issue with the quality of work of another team member, they should address the team member they have an issue with first one on one. If they are not satisfied with the results of that meeting they must tell the team of their issue. The team will then help resolve it. In extreme cases, the team adviser may be brought in to help resolve team interaction issues. If, at the end of the semester, any member is still considered to have not contributed equally to the team effort, their lack of productivity will be noted in the team member evaluations.
3 Requirements

3.1 Problem Definition

The automation industry today is focused primarily on projects which must be designed on a case-by-case basis for each customer. Local companies like Dematic, J&R Automation, and Emhart Teknologies will typically obtain contracts to design automation solutions for customers at large, high volume libraries such as the one at Grand Valley State University. Designing the solutions to be customer specific means extreme costs to cover professional labor expenses.

Our team hopes to develop a proof-of-concept for a scalable, manufacture-able, inexpensive, automation solution for libraries with book circulation volumes in the range of 1,000 to 40,000 books a week with a sort division ranging from 23 (Hekman Library) to 35 (GRPL) or even as high as 63 (Holland Public Library). Therefore we will take close to the low-end of our target design. The resulting base-case product will constitute a single unit of which multiple units could be purchased based on a specific libraries needs.

3.2 Customer Requirements

While our problem definition gives our team an excellent qualitative basis for our design optimization goals, it does not provide us with nearly as good a quantitative basis for our design requirements. Every Library we would potentially market our product to will have unique situations in terms of staff, floorspace, and book volume. To simplify our analysis and provide a reasonable metric for success, we will take the Hekman Library as our base case customer (i.e. a customer who would likely be interested in a single unit system). Although the Hekman has a large collection of books (______) their book circulation volume in close to our lower end of our target market (______) with comes down to around 63 books/min or about 1 book/sec.

Using the Hekman as a base case we apply the following design requirements to the return; automation solution:

1. The machine must be able to handle a worst-case book return rate of 1.13 books/second.
2. The machine must be able to sort books to at least a 23 level sort.
3. The machine must fit within the 1.71 [m] X 0.84 [m] X 1.21 [m].
   1. The machine must be able to receive books from the users at a height no less than 1.08 [m].
4. The machine must be able to operate fully on the power drawn from two standard U.S. Outlets.
or $120 \text{ [V]} \times 20 \text{ [A]} = 2.4 \text{ [kW]}$

1. The machine cannot draw more than 20 [A] of current (typical circuit breaker).

5. According to our market research, the libraries constituting the lower-end of our market in terms of book volume would not be either willing or able to afford an automation solution priced higher than $5000 \text{ U.S.}$. Therefore, our target manufacturing cost will be $1260. See the business section for the details on this calculation

In addition to our quantitative requirements based on the Hekman, it is important to recognize the qualitative goals our design will strive to achieve to fill as large a potential market as possible

1. **Size**: The Hekman provides us with a basis, but the smaller the machine can be made, the larger a market we can reach.

2. **Flexibility**: Our machine will have the greatest market potential with a design that allows the system to be easily fitted to a wide variety of different floor spaces. The capability for our system to be usable in a wide range of floor layouts should be clear to the average observer.

3. **Scalability**: Our machine is intended for libraries in as great a range of circulation volumes and collection sizes as possible. The ease at which the system can be scaled up by using multiple units should be clear to the average observer.
4 Method of Approach

The goal for the functionality of the device, as previously stated, is to receive books from a library book drop-off slot and place it for recirculation on either a re-shelving chart or on an inter-library load book shelf. Each of the individual stages will have varying degrees of complexity, cost, size etc.

By using this general design approach as opposed to designing the entire machine as a whole, our team is now able to examine the beginning function of the machine (stage 'A'); then, suggest, develop, and optimize design alternatives for that section independently on the basis of our design constraints and goals.

Once a given stage has been designed and optimized, the output conditions of that stage can be used as the inputs for the following stage. This allows our team a greater degree of creativity when considering design alternatives. Also, it allows our team to consider a greater number of total design alternatives given the same amount of time to work. Consider the following: If we decided to design the machine as a whole we would probably have time enough to consider two or three alternatives. Any one of these alternatives could have a fatal flaw existing in only one component early on in the machine's functional cycle. By splitting the machine into sections we can evaluate the feasibility of an idea before subsequent portions of the machine are designed around it.

The disadvantage to this strategy is that we risk over-constraining the design of the final stage. By having the final stage receiving constraints both at its input and output. There is a possibility that the final stage may be impossible to perform. However, there will still be some leeway will be intentionally designed to alter previous stages in response to “backward constraints” that appear towards the end of the project.
5 System Design

The Team's general design strategy is to break down the machine into four separate tasks the machine must perform in sequence to fulfill its desired function. The four tasks specified are:

A) Stage 'A' will queue (Figure # 1) and separate books as they are dropped off by library patrons into the library's drop-off book slot prior to organization. This step is important because the machine's response time, the time allowed between individual book insertions, has already been determined to be at least 1.0 seconds (see Requirements section) and the second stage, because of its complexity, is expected to have a high cost-to-response time ratio (i.e. The increase in cost for decreasing the response time of stage 'B' is expected to be much higher than any other stage). Finally, Stage 'A' must provide some method of passing the books on to stage 'B'.

Stage 'A' will need to send information about which queue slots are full to the main computer to be stored. This information will then be referenced when another book comes in so that it knows which queue slots are empty and can house a book. This transfer must be fast, so as not to slow down the 1.0 second latency limit.

B) Stage 'B' will use some method of determining books orientation, more specifically, the direction the book's spine is facing. Once the machine has determined the book's orientation it must align the books' spine in a consistent direction. At this point in the process the actual direction of the

Figure 1: Stage 'A' Queue Design
orientation can be considered arbitrary. However, the books must end their journey with the spines facing upward so they can be easily seen by library staff for re-shelving purposes. Finally, stage 'B' must provide some method of passing books on to stage 'C'.

Stage 'B' will recognize the dimensions and placement of the book optically, using a photograph and some custom image processing software. A mechanical measurement system could also work here, but it could possibly cause some damages to soft-cover books. This stage will also use RFID to scan the book and identify what it is. This information needs to be passed to the main computer for sorting later, and so that it can be automatically checked back into Evergreen. The micro-controller will send PWM signals to the motors to orient the book correctly and send the RFID scans to the main computer. Figure # 2 shows an overall diagram of this stage.

**Figure 2: Stage 'B' Component Flow Chart**
C) Stage 'C' will provide a means of storing the book prior to being placed on the re-shelving carts or inter-library loan shelves. Note: the need for this stage is really dependent on the general method of re-shelving. For the time being, our team considers some form of independent 'Drone', physically separate from the rest of the machine, to be the only feasible solution to the re-shelving stage of the machine. This stage will also need to communicate information to the main computer about which slots are vacant.

D) Stage 'D' will provide a means of placing books onto the appropriate re-shelving cart or inter-library loan handling device. This machine stage is expected to be the most complicated and expensive of the four. Meeting our goals of minimum noise, and minimum interference with library staff will be the driving forces behind the design of this section. As a general design strategy, we are hoping to allow ~40% of the total budget to be available for this stage of the design. Stage 'D' will require information from the main computer about which books are in the queue and where they need to go. The computer will tell the drone which book to fetch and which sorting bin to place it in. The drone will know where said bin is, travel there, drop the book in, and then return to the queuing area for its next book.

Design alternatives will be developed and analyzed for each stage of the machine. Each stage design will have to be developed with the overall design requirements and goals in mind.
6 Programming Architecture

Since we have broken up the mechanical design, we have also broken up the programming aspects into what needs to be calculated in each stage and what is needed to control each stage. As we build incremental prototypes with Vex parts we will test our control systems and programming aspects. Our project will require a computer running Microsoft Windows. An Arduino will handle the control functions at each stage. Currently, we plan to use two Arduino's, one for stages A through C and one for stage D.

6.1 Stage A controls:

void RotateWheelOneSlot(int *ptr); 2 pins
This function returns nothing and receives nothing. When run, it outputs a PWM signal that needs to be amplified to drive the rotation of the wagon wheel. It also receives a signal from a sensor to determine how far the wheel has turned. Initial design call for this sensor to be an ir sensor reading a track of alternating white/black squares taped onto the wheel. The function also stores which slot is next to receive. Once this function is done, the next line in main should call openSlot(int *ptr)

Void ReadSlotHasBook(int *ptr); 3-number of slots
This function reads sensors that will be in each slot to determine which slots have books in them. The function then stores the information in an array in memory.

Void openSlot(int *ptr); 3 pins
openSlot will use 3 pins to send signals to open one of the 4-7 motors which control the slots that keep the books in Stage A while it rotates. The three pins will be filtered by digital logic or a mux. This will be used to open a slot that will be receiving the next book and to drop a book into stage B when it is ready.

Void closeAllSlots(); 3 pins, same as openSlot
This function closes all slots. This is to keep books in the wagon wheel while Stage A rotates. Since there are not 8 slots for books, one of the unused 3 pin combinations will feed the reverse transistors in each of the H-bridges.
6.2 Stage B flow:

A book comes in and a picture is taken by a stationary camera. The Computer will analyze the photo to determine the book’s dimension and position. It will then this information to the Arduino which moves the spine recognition system over the book then lifts the cover to determine where the spine is. The Arduino then rotates the book and reads the RFID tag which it proceeds to send back to the computer. The computer then checks the book back in and determines sorting information from the evergreen database. The sorting information might then be sent back to the Stage B micro or stored in the computer depending on how we decide to communicate with the Stage D Arduino.

Notes:

- the picture of a book requires that the background be a different color than the book. We are currently looking into which color would be best to use.
- Motor and sensor functions can be work at the same time, not because the Arduino can dual-process, but because the physical systems take time to respond and we can switch between functions fast enough that they appear to be working at the same time. All functions that are work at the same time will be wrapped in a loop until their end criteria are met.

6.3 Stage B computer programs:

void takePicture(*ptr, string fileName);
This function will make the Stage B camera take a picture and store the picture in memory for processing.

void calculateDistance(string fileName);
since the camera is stationary, we can count the number of pixels from one side until we encounter the edge of a book. Currently edge recognition is working. The function then calls calculateWidth and passes the number of pixels counted.

void calculateWidth(string fileName, int pixels);
This function will count the number pixels from one edge of the book to another. It will add half of this
value to the variable 'pixels' that it is passed. This should be the center of the book in the x direction. The function also needs to store the width to a global variable so it can be later logged in the database. It then calls calculateHeight and passes the the distance calculated along with the filename for the picture.

```cpp
void calculateHeight(string fileName, int pixels);
```

This function is used to calculate the height of a book which will be stored to a global variable and saved to a database later. It then calls convertPixelsToDistance and passes the number of pixels counted as an array: first value width, second value height.

```cpp
void convertPixelsToDistance(int data[]);
```

This function converts the number of pixels into a distance that the Arduino will understand. This distance should be as precise as the controls can be. It then calls sendData and passes the calculated distance.

```cpp
void sendData(int data[]);
```

This function is used to send data back to the Arduino. It's used to pass the distance calculation, book width calculations, and possibly to pass the sorting information.

```cpp
queryDatabase(string RFIDtag);
```

This function will be used to query the database to determine what book it is. It will receive at least the books call number (the one on the spine). Next it will call the function calculateSortedLocation and pass the call number.

```cpp
calculateSortedLocation(string callNumber, *ptr);
```

This function will calculate which shelf the drone should put the book on. It will then either call sendData or a function that communicates directly to the Stage D drone and pass the shelf number. Shelves will be numbered 1 – number of carts*shelves on a cart. The number will be decoded to a location by the Stage D micro. The shelf number will be stored in an array in memory either here or in the stationary Stage A-C micro.
Void checkBookIn(string RFIDtag);
This function will check a book in given the RFID tag.

6.4 Stage B controls:

void tellComputerToTakePicture(int go);
This function communicates to the computer that it should take the picture and calculate the position. It then calls listenToComputer.

void listenToComputer(*locationArray);
This function will be listening to the computer after it drops a new book into stage B. It will receive the location of the center of the book. It will then return this value to the main function which will then call the control functions used to move the spine sensor around.

Void moveXDirection(int x); 2 pins
This function moves the spine sensor to the correct x coordinate. It will receive some sensor input (likely ir and black/white method) to measure how far it's gone.

Void moveYdirection(); 2 pins
This function moves the spine sensor to the correct y coordinate. It will receive some sensor input (likely ir and black/white method) to measure how far it's gone.

int moveDown(); 2 pins
This function will move the suction device down to contact with the book. Have two sensor inputs: 1 to tell how far down it's gone, and one to determine when it has contacted the book. It will return the distance down it has gone which will tell us how thick the book is.

Void createSuction(); 1 pin
This function will actuate the solenoid to create the suction to the books cover.

Void liftUp(); 1 pin
this function will lift the suction device up.
int tiltSensor(); 1 pin
this function will be listening to the tilt sensor as the liftUp function is working. It will determine when
the tilt of the device is sufficient enough to know where the spine is. When it's sure it knows the tilt, it
will call releaseSuction and return the tilt.

Void rotate(int direction); 2 pins
this function will be used to rotate the book to the correct orientation. It will receive an integer which
will correlate to 45, 90, or negative 45 degree rotations. It will also have a sensor to control it to make
sure it has rotated the correct amount.

Void rollBookOffB(); 1 pin
This function will turn on the wheels that will be used to move the book off of stage B.

6.5 Stage D computer:

void passBookArray(int [] book array);
This function will pass the shelf on which a book should be placed.
* as Stages C and D are not designed Mechanically yet, we are not designing controls for them yet.

7 Design Work

7.1 Mechanical Designs
The following sections outline the teams progress on each of the machine's functional stages A-D. It
also explains our design process both quantitatively and qualitatively and highlights our final design
choices for each stage.

For the machine as a whole we consider the following to be our major constraints

Stage 'A' Design: Queuing Book Drop-off
The first stage of the machine will perform the task of receiving books from the library patrons via the
drop-off slot and/or window.
For this segment of the design we considered our constraints to be:
1. Size: The volume of space given to us for the total design which is approximately 8ft X 5ft X 5ft taken from the available corner space behind the Hekman circulation desk next to the drop-off slot.
   1. \( \text{Height}(h)=5[\text{ft}]=1.56[\text{m}] \)
   2. \( \text{Length}(L)=8[\text{ft}]=2.50\text{m} \)
   3. \( \text{Width}(\text{i.e. Distance from the wall})(W)=5[\text{ft}]=1.56[\text{m}] \)

2. The height of the drop-off slot itself measured to be:
   1. \( H_{\text{dropoff}}=1.05[\text{m}] \)

3. Height: The minimum height stage 'B' is expected to require at the bottom of stage 'A' is estimated using the worst-case major dimension for a book returned through the slot (.396 [m]) angled at 60° from the horizontal. Using a spacial safety factor of 1.5
   1. \( H_{\text{stageB, max}} = 1.5*l*\sin(60^\circ) \)

4. Weight: The weight of stage 'A' is not considered a major concern at this point. The overall balance of the machine will have to be taken into consideration once the the weight and location for each stage can be estimated.

5. Response Time/Power: The worst-case rate for one-by-one book drop-off that the machine has been estimated via experimentation around 63 books/minute or about 1 book every 2-3 seconds. Stage 'A' must be able to cope with this rate of book return queuing up the returned books until the second stage has time to catch up with the book flow. Secondarily the maximum time taken by stage 'A' to deliver a book to stage 'B' must not be greater than the response time of stage 'B'
   1. \( t_{\text{responseA}} \leq 1.13 \text{ second}(s) \)
   2. \( t_{\text{delivery}} \leq t_{\text{responseB}} \)

   *Note: It is also possible to use constraint 5.2 in the other direction. That is, using the maximum delivery time of stage 'A' as the response time constraint for stage 'B'.

In addition to the constraints already listed, other design criteria to be considered during design alternative evaluation process will include:

1. Complexity: The more complex a given stage, and by association the machine as a whole is, the more difficult it will be to ensure reliable operation in the finished prototype. We will evaluate the complexity of this stage as the sum of all its moving parts and rotating axis.

2. Cost: Our team is limited by an overall expected budget of ~$1000. The relative cost for each stage design alternative must be considered. For stage 'A' we expect 20% or $200 of the total
Design Alternatives:

Our team considered three possible alternatives for the general mechanical design on stage 'A.' Two of the alternatives utilize a rotating wheel that holds the books in side separate slots. The other uses a series of parallel shelves angled along a common drop chute with opening and closing flaps on either side to control the books movement through the stage.

For the rotating wheel approach two different possibilities were considered. The first involves the use of a wheel where the book slots are oriented towards the center of the wheel. Books are rejected below the wheel to the second stage. The second is a slightly arranged along the sides of the N-sided polygon and exit on the other side after a 180° rotation.

From this point forward we will refer to the first option at the “center -spoke” design, the second as the “n-gon” design, and the third as the “slotted-shelf” design. We will step our analysis bases of our constraint hierarchy for stage 'A'. We will analyze the starting with a general size analysis to ensure that a given design can fit within the specified area before time is wasted on more complicated analysis.

![Illustration 1: Slotted-Shelf design concept](image1)

![Illustration 2: Reference Diagrams for the spatial analysis for the center-spoke design alternative for stage 'A'](image2)

![Illustration 3: Reference Diagrams for the spatial analysis for the center-spoke design alternative for stage 'A'](image3)
We begin with the spatial analysis for the center-spoke design with the goal of determining the radius of the part. Using the radius, given a number of books 'N', as the key dimension in the machine we can then determine the angle the wheel would have to accept books at to fit within the maximum 1.0 meter drop-off height.

First we define the angle \( \theta_{\text{wheel}} \) as the angle which each of the book slots will make relative to one another.

\[
\theta_{\text{wheel}} = 360 \frac{[\text{deg}]}{N} \quad \text{Equation (1)}
\]

From the angle \( \theta_{\text{wheel}} \) we also can determine the additional length parameter 'b' which is can be added to the major book dimension 'l' to obtain the real length of the spoke.

\[
\tan(\theta_{\text{wheel}}) = \frac{a}{b} \quad \text{Equation (2)}
\]

We now find the effective distance between the farthest point on the wheel and the intersection of two spokes.

\[
\gamma^2 = (l - wh \sin(\frac{\theta_{\text{wheel}}}{2}) + b)^2 + a^2 \quad \text{Equation (3)}
\]

Likewise the angle which this dimension makes relative to the length dimension 'l' is:

\[
\theta_1 = \tan^{-1}(\frac{a}{l - 2h \sin(\theta_{\text{wheel}}/2) + b}) \quad \text{Equation (4)}
\]

And the angle the dimension 'h' makes relative to the same line is:

\[
\theta_2 = 180 [\text{deg}] - \frac{\theta_{\text{wheel}}}{2} \quad \text{Equation (5)}
\]

We can now use equations 1-3 to determine the radius 'r' via the Law of Cosines.

\[
r^2 = h^2 + \gamma^2 + 2h \gamma \cos(\theta_1 + \theta_2) \quad \text{Equation (6)}
\]

To calculate the distance the center of the wheel must be from the drop of window examine the geometry of the design to obtain:

\[
\text{Distance from Center to Drop-off} = -h \sin(1.5 \theta_{\text{wheel}}) + (b + l) \sin(\theta_{\text{wheel}}) \quad \text{Equation (7)}
\]

From here we move onto the weight and mass moment of inertia analysis for the center-spoke design. The general method of approach was to first divide the slots themselves into three separate sections with moments calculated about a central axis 'X', one for each pair of panels needed to build a slot. The combined moment about 'X' for these section will then be recalculated about the axis of rotation for the rotating wheel 'XX' using the parallel axis theorem with a distance \( D_{\text{offset}} \).
The mass moment of inertia for part 1 \( I_{x1} \) is:
\[
I_{x1} = 2\left(\frac{1}{12} m_1 \left(l^2 + a^2\right)\right)
\]
Substituting \( m_1 = \rho l t a \) we obtain
\[
I_{x1} = 2\left(\frac{1}{12} \rho l t a \left(l^2 + a^2\right)\right)
\]

The mass moment of inertia for part 2 \( I_{x2} \) is:
\[
I_{x2} = 2\left(\frac{1}{12} m_2 \left(F^2 + F\right) + m_2 d_2^2\right)
\]
Substituting \( m_1 = \rho l^2 t \) after simplification we obtain
\[
I_{x2} = 2\rho \left(F^2 + t^2\right) \left(\frac{1}{12} \left[ \left(l-t\right)^2 + F^2 \right] + a^2 / 4\right)
\]

The mass moment of inertia for part 3 \( I_{x3} \) is:
\[
I_{x3} = 2\left(\frac{1}{12} m_3 \left(t^2 + a^2\right) + m_3 d_3^2\right)
\]
Substituting \( m_3 = \rho t \left(l-t\right) a \) after simplification we obtain:
\[
I_{x3} = \rho t a \left(l-t\right) \left(\frac{1}{12} \left( \left(t^2 + a^2\right) + l^2 / 4\right)\right)
\]

To obtain the total mass moment of inertia for a single part about the x axis we must take the sum of the individual MMI's

\[
I_{xTotal} = I_{x1} + I_{x2} + I_{x3}
\]

We then use the total mass moment about the x-axis and change the axis of rotation from the axis 'x' at the center of the part to the axis X' about the center of our wheel using the parallel axis theorem.
\[
I_x = T_{xTotal} + m_{total} d_{ref}^2
\]
Equation (8)

Where
\[
m_{total} = \rho \left(t a \left(l-t\right) + t^2 \left(l+t\right) a\right)
\]
Equation (9)
and  
\[ d_{ref} = \left[ \left( \frac{a}{2} + h \cos \left( \frac{\theta_{wheel}}{2} \right) \right)^2 + \left( \frac{l}{2} - h \sin \left( \frac{\theta_{wheel}}{2} \right) \right)^2 \right]^{\frac{1}{2}} \]  
Equation(10)

By substituting equations 10 & 9 into 8 we obtain:

\[ I_x = N \left[ T_{xTotal} + \rho \left( t a(l-t) + t^2 l + t l a \right) \left( \frac{a}{2} + h \cos \left( \frac{\theta_{wheel}}{2} \right) \right)^2 + \left( \frac{l}{2} - h \sin \left( \frac{\theta_{wheel}}{2} \right) \right)^2 \right] \]  
Equation (11)

Where 'N' is the number of book slots in the design.

We then used the density and standard thickness for the considered materials (Figure # 3) to obtain the corresponding mass moment of inertia for the materials we are considering at this stage of the machine. The standard thicknesses are obtained from vendor websites and the densities have been obtained via a combination of engineering handbooks and wikipedia sources.

Finally we must determine the recommended power requirement for the wheel driving motor given the wheels material, the minimum response time, and number of book slots to be used.

We take the definition of rotational power:  
\[ P = T \omega \]  
Equation(12)

Also we know that:  
\[ T = I \alpha \]  
Equation(13)

and  
\[ \alpha = \frac{d\omega}{dt} \]  
Equation(14)

Using equations 12-14 we can write the first-order differential equation:

\[ P = I \omega \frac{d\omega}{dt} \]

\[ \frac{P}{I} dt = \omega d\omega \]

Integrating both sides respectively we obtain:

\[ P t = I \frac{\omega^2}{2} + C_1 \]  
Where \( C_1 \) is a constant  
Equation(15)

The question now is how to define our function for the angular velocity omega. In reality, the behavior of the angular velocity over time is a design variable. We know that omega must begin and end at 0 rad/sec with it's velocity likely peaking near the midpoint between slot positions. A sinusoidal function for omega seems to be the natural choice given the desired behavior. Therefore, for the purpose of preliminary analysis we define the function for omega to be:

\[ \omega(t) = A \sin \left( t - \frac{\pi}{t_{resp}} \right) \]  
Equation(16)
Where \( A \) is the maximum value for the angular velocity. In order to obtain a numerical value for the Power 'P' we must determine the amplitude 'A' for the angular velocity function. To do this we recognize that the change in angle \( \theta \) will be the definite integral \( \omega(t)dt \) from 0 to \( t_{\text{resp}} \). Therefore, we have:

\[
\theta_{\text{wheel}} = 2\frac{\pi}{N} = \int \omega(t)dt = \int A \sin \left( t \frac{\pi}{t_{\text{resp}}} \right) dt
\]

\[
\frac{2\pi}{N} = \frac{t_{\text{resp}}}{\pi} A \left[ \cos(0) - \cos(\pi) \right]
\]

\[
A = \frac{\pi^2}{t_{\text{resp}} N}
\]

Equation(17)

We now substitute equations 16 & 17 into equation 15 to obtain:

\[
P(t) = I \frac{\left[ \frac{\pi^2}{t_{\text{resp}} N} \sin \left( t \frac{\pi}{t_{\text{resp}}} \right) \right]^2}{2} + C_1
\]

Equation(18)

to solve for \( C_1 \) we know that our power function should be 90 degrees out of phase with our angular velocity function. In other words, the power coming out of the motor should be at its highest when the wheel is first rotated from rest and at it's minimum when the wheel is rotating at it's fastest. Thus:

\[
C_1 = \frac{\pi^2}{t_{\text{resp}} N} \sin \left( \frac{-\pi}{2} \right)
\]

Equation(19)

Plugging equation 19 back into equation 18 and simplifying yields:

\[
P(t) = I \frac{\left[ \frac{\pi^2}{t_{\text{resp}} N} \sin \left( t \frac{\pi}{t_{\text{resp}}} - \frac{\pi I}{2} \right) \right]^2}{2}
\]

Equation(20)

Where \( 0 \leq t \leq t_{\text{resp}} \)

Using equation 20 we then performed an analysis to predict the power level required from the motor over the specified time domain. Noting that at \( t = 0 \quad P = \infty \) we will begin our analysis at \( t = 0.1 \) seconds. (The fact that our analysis results in infinite power at \( t = 0 \) is likely an error we have not yet figured out). Using our minimum response time of 2.5 seconds we obtain the following power profiles.
After the initial analysis showed that our minimum response time allowed for an extremely low-power motor we decided to analyze the response time given a 1/10 hp motor driving a sheet metal wheel with a safety factor of 2 on the motors nominal power rating (i.e. 1/20 hp motor). We obtain the following relations:

If purchased commercially a 1/10 hp motor would cost the team nothing in terms of their project budget because a motor of the required nominal power rating has already been donated to the team. The cost of producing the first stage will likely be dominated by the materials cost associated with the wheel itself as well as the gears required for the reduction from motor to wheel.

After completing the preliminary analysis for the center-spoke design we turned our attention to the n-gon design concept. When both ideas for a wheel-based design were first suggested it what not immediately clear which one would be more efficient or practical. Thus, both designs were accepted for first-order analysis.
We begin the spacial analysis for the n-gon design alternative by examining the geometry again with the motivation of finding the equivalent radius for the wheel. Again we define our thickness corrected major and minor dimensions to be 'l' and 'a' respectively.

Again we define \( \theta_{wheel} = 360 \frac{\text{deg}}{N} \) Where 'N' is the number of books slots.

We also know that \( \tan(\theta_{wheel}) = \frac{l-t}{2g} \) Where g is distance from the center of the wheel to the inside corner of the wheel. Solving for 'g' we can derive a relationship for the radius 'r'

\[
r^2 = (g+l-t+a)^2 + \left[\frac{l-t}{2}\right]^2
\]

At this point we do a quick comparison between the expected size of the n-gon design in relationship to
the center-spoke design. Figure 7 below clearly shows that for no conceivable value 'N' will the radius of the n-gon design be smaller than the center-spoke design. Therefore, there is no foreseeable advantage to using the n-gon design over the center-spoke and we will abandon the design alternative before performing any more detailed analysis.

Stage 'B' Design: Orienting the Books

At this stage in the design process we have not yet developed alternatives for the book orienting stage. The general plan at this point is to have rotating surface (Figure 9) large enough to accommodate the largest possible book size 1 x 1 angled just below the center-spoke wheel. Books will be deposited onto the surface with gravity sliding them down.

Next, a suspended suction cup vacuum (Figure 8) will attach itself to the cover of the book and lift perpendicular to the book surface. Based on the direction of the suction cup system deflection, our machine will know the current orientation of the book. Currently we have no way to determine whether the book is right side up or upside down. However, both Hekman and Grand Rapids Public Library staff indicated that books placed onto re-shelving carts upside down would not be an issue in whether
or not to purchase a machine.

After that, the micro-controller will send the appropriate signal to reorient the book along a consistent direction. A linear actuator will then reject the oriented book onto stage 'C'.

Stage 'C' Design: Book Storage Prior To Placing

Stage 'C' will most likely be the least taxing of the four stages. The general concept for stage 'C' at the moment is to have a series of metal u-wire shelves angled coincident with stage 'B'. Stage 'C' will be able to slide linearly perpendicular to stage 'B' allowing for different books to be stored without requiring a conveyor system typical in larger material handling projects or any movement on the part of stage 'B'.

Stage 'D' Design: Placing the Books onto Re-Shelving Carts

Stage 'D' must now take the oriented books from stage 'C' and place them neatly on either the Hekman re-shelving carts or the inter-library loan shelved based on the information the computer will have stored on the book's title and location in the library.

The plan, as it stands right now, is to design a drone that will carry the shelved books from stage 'C' in the order that they were ordered. Using a line-following design with white duct tape providing a path for the drone to it's destinations the drone will drive up to a cart and place the book according to a coordinate system based on the books destined cart, shelf, and distance from the edge on that shelf. In order to do this the machine will need a method of measuring the thickness of a book and keeping track

Figure 9: Stage 'B' Turntable Concept

Figure 8: Stage 'B' orientation sensor concept
of the book already stored on a shelf.

The drone itself should be simple in concept. A chassis with four wheels and a linear actuating arm which can move up and down to separate shelves and slide the current book onto the shelf. The drone will rely only on the line-following aspect for navigation. Aside from that, however, the drone will need to be able to detect objects possibly hindering it's pack. Simple “whiskers” should provide a sufficient solution to this problem seeing as how our design will not attempt any navigation correction or object avoidance. The drone will let out an alarm when it cannot reach it's destination, letting library staff know the drone's path has been blocked.

7.2 Electrical Design

Book Recognition

There are three methods of recognizing a book that our team considered: Radio Frequency Identification (RFID), Optical Character Recognition (OCR), and barcodes. Optical Character Recognition was our first design choice because any library could use it without any modifications to their current books. Our machine would take a digital photo of the call number sticker, convert it into text, and look up the book in a database. We started with an open source tool called GOCR which handles scanned documents with near 100% accuracy. When we started testing, GOCR did not perform adequately. Of the 17 characters analyzed from a typical tag, 2.3% of the characters, on average, were recognized correctly. To improve performance, we wrote an image enhancer to process the photos before were analyzed by GOCR. Along with some optical enhancements, better lighting and a magnifying glass, we obtained images clear to the human eye, but still did not result in acceptable output from the OCR program. Figure 11 shows the original photograph, the pre-processed image, and the textual result from the OCR program.
The image enhancer converts the picture into pure black text on a clean white background. The image was processed by GOCR with a few source code modifications which limited it to capital letters and numbers to help improve recognition accuracy. This was our best result and, ignoring spaces, only half of the characters were correctly identified. This was also one of the better labels we found. Some were faded; others were handwritten. On top of all of this, all of the image processing is very slow, and process time is our main requirement. Because of the difficulties met and the limited time for the project, we abandoned the OCR option and began pursuing other alternatives.

Bar-code scanning was the considered next. Bar-codes are inexpensive and widely by libraries. However, bar-code locations are not standardized, requiring the system to open the book before scanning it. The process would be complicated if not impossible to perform and prohibitively slow if accomplished. The bar-code solution would work well if it were always in the same location on the outside of the book. Although our prototype will be using RFID, the design will be flexible enough to support using bar-codes instead.

![Figure 11: GOCR Image Processing Results](image)
Our chosen method of book recognition will be RFID. A number of libraries across the country are switching to RFID tags for tracking their materials. In an RFID system, each book has a unique transponder tag [a circuit that emits a signal when it receives one. Requires no batteries] which is read by a circuit (Figure 12) and converted into a 10 digit ID. The chip sends this signal out on a single data line at 2400 bits/second with 8 data bits, a stop bit, and no parity bits.\(^4\)

RFID provides accurate identification, unlike the OCR results. Individual books will not be mis-identified, but it does have a small detection range on only 2-3 inches. The problem of having multiple books within this range is explained in the Multiple Book Detection section. The proximity required for RFID to function is in the same range as OCR and bar-code options as well and the tags can be read through a book's cover. Using RFID will simplify the mechanical design, reduce cost, and speed up process time. We have ordered the part and the next step is to test it for accuracy, proximity, interference, etc.

We worked for a while on OCR and determined that it will not work for library book labels, so we were left with bar-codes and RFID. Although bar-codes are less costly for the libraries, the ones with the funding to switch to RFID technology are likely to be the ones with enough money to invest in our system. Also most large scale system material handling system we have researched\(^5\) utilize RFID technology, very few are still using bar-codes, and none have used OCR. This means that companies that are designing library sorting mechanisms already do not consider OCR to be feasible.

---

4  RFID Scanner Datasheet on website  
5  See section on large scale systems (marketing)
Motor Control

Controlling the speed of the motors will be done digitally, using pulse-width modulation (PWM) (Figure 13).\(^6\)

The micro-controller emits a series of pulses (V) with a positive or negative value. The resulting signal (B) at the motor rises, when there is a positive pulse and falls when there is a negative pulse. This allows us to tailor a signal for the motor at any amplitude and frequency we choose, using flexible software algorithms. This will allow us to move our motors more precisely than with straight DC values.

**Micro-controller**

The choice of micro-controller depends on a few different factors:

Compatibility – How well it integrates with our system. Most important factor is PWM capabilities.

Ease of Use – Include which programming language it uses.

Number of pins – More pins gives the capability to control more external devices such as motors and scanners.

Price – Must be low cost to fit our budget constraints.

Memory – Must be able to fit our software.

---


![Figure 13: PWM Example](image)
Table 1: Micro-controller Decision Matrix

<table>
<thead>
<tr>
<th></th>
<th>Weights</th>
<th>Basic Stamp</th>
<th>Arduino</th>
<th>Microchip PIC</th>
<th>Amtel AVR</th>
<th>Freescale</th>
</tr>
</thead>
<tbody>
<tr>
<td>I/O Pins</td>
<td>0.2</td>
<td>16</td>
<td>23</td>
<td>16</td>
<td>16</td>
<td>22</td>
</tr>
<tr>
<td>RAM</td>
<td>0.1</td>
<td>32K</td>
<td>16K</td>
<td>2K</td>
<td>1K</td>
<td>1K</td>
</tr>
<tr>
<td>PWM capabilities</td>
<td>0.1</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Limited</td>
<td>Yes</td>
</tr>
<tr>
<td>Ease of use</td>
<td>0.3</td>
<td>Easy</td>
<td>Medium</td>
<td>Hard</td>
<td>Hard</td>
<td>Unsure</td>
</tr>
<tr>
<td>Price (1)</td>
<td>0.1</td>
<td>44.1</td>
<td>3.8</td>
<td>1.7</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>Price (1000)</td>
<td>0.2</td>
<td>25.48</td>
<td>1.1</td>
<td>1.56</td>
<td>1.29</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1</td>
<td>0.7</td>
<td>0.9</td>
<td>0.7</td>
<td>0.6</td>
<td>0.5</td>
</tr>
</tbody>
</table>

The Basic Stamp and Arduino both come with sample code for processing the RFID scanner’s output, saving our team development time. We chose the Arduino (Table 1) because it was the least expensive option and did not sacrifice any essential functionality. It has the most pins, PWM capability, and is programmed in C, with which all team members are familiar. DornerWorks has also donated Arduino for prototyping, making it much more cost-effective for our prototype budget.

7.3 Power Supply

The design of the power supply is one of the most important aspects in the context of the design of the ‘return’ robot. The first consideration of this design is the decision of whether or not more than one power supply will be used. This is an important consideration because this design will require voltages at levels currently up to 24V and as low as 5V. These voltage levels will be applied to the motor rotating the book slots and powering the microcontrollers respectively. With this in mind, two power supply designs could potentially be implemented within the whole of the system. One design revolves around a single transformer, with two sets of secondary windings being output. Another design involves using two individual transformers, one to accommodate the higher voltages or currents, and another transformer for the smaller voltages and currents.

One benefit of using the single transformer approach is that our team would only need to purchase a single component, and not have as large an impact on the budget allotted to us. One downside to using this design would be that the voltage level may be too far in one direction of the design, providing favorable conditions for one component over another. This could either be presented in a voltage level high enough to work with the book slot motor, and be too large for the microcontroller’s need, or it
could be too low for the motor to use, but at a good level to power the microcontroller. For accommodating the higher level voltage needed in the design, the amount of heat generated in the integrated circuits (or IC’s) such as the voltage regulator would be high for the voltage drop from 24V to 5V. When run at our book slot motor’s required current flow, and even higher for every subsequent component that needs to be added, this design would require that at least 10.1W to be dissipated. The second design approach for this power supply would be to use two separate power supplies within the design. Following through with this design would be the converse of the situation with the single transformer design in that we would need to purchase double the amount of parts compared to the single transformer power supply. This design would, however, be more accommodating to the voltage level required for both the book slot motor and the microcontrollers because the transformers will be able to have more degrees of freedom when it comes to the secondary transformer voltages as well as the maximum current flow each transformer can sustain. Within the context of our ‘return’ robot’s design, this would be a better design approach to pursue. With this design selection in mind, the amount of components that need to be selected for each stage of the power supply would double as mentioned before, but with an additional constraint. These circuit elements, such as the capacitors, the bridge rectifiers, and the voltage regulators, must be rated to handle the voltage differences as well as the current that will be driven through this supply to every connected component, which when the design progresses will include the intermediate motor between stages ‘A’ and ‘B’, the actual motors in stage B, and possibly the drones within stage ‘C’. So in addition to the two major components of stage ‘A’ which are the microcontrollers and the book slot motor, this power supply will have to be designed to accommodate the other designs implemented within the later stages, meaning we will need to include a great measure of foresight for our whole design in terms of power requirements.

For circuit elements within the power supplies, the most immediate stage after the transformer is the bridge rectifier stage. A bridge rectifier design will be used in both of the power supplies currently being considered for the design of our robot. One downside to using the bridge rectifier design for full wave rectification is that they incur twice the voltage drop of the dual diode with center-tapped transformer design. This doubled voltage drop means that the secondary voltage of the transformer will need to be higher to offset this loss, and will affect the later stages as well, such as the capacitor and the voltage regulator. The benefit of selecting the bridge rectifier over the other full-wave rectifier design is the amount of peak inverse voltage subjected to each diode in the bridge rectifier is
significantly less. The bridge rectifier is better at preventing voltage breakdowns, which fits into our team’s design for a robust system within our robot.

The selection of the capacitor to filter the full-wave output depends on the maximum current level that will be subjected in this power supply, the other factors. Knowing this, the capacitance for the filtering stage will be dictated by the output rectified voltage because capacitors need to be at an appropriate maximum voltage to be able to withstand the voltage difference across it without shorting out and breaking. Other variables in determining the capacitance are the ripple voltage and the frequency, the latter of which is fixed due to the standards of the voltage signal from the wall. The ripple voltage we will select in this case will have a very narrow margin, which will be selected to be at about two to three volts. This ensures that the resulting ripple will be well within the margins for the regulator IC to remain active and provide a smooth output voltage.

The voltage regulator IC that will be used in designing the power supply will be unique for both power supplies being designed. The two driving determinants in regulator selection are the voltage inputs needed to activate the IC, and the current load that it can handle. The voltage at the input must be within a certain range of voltages dictated by the regulator used; in this case, we will need to use a 24V and a 5V regulator as starting points for the circuit design. The voltage regulator design will be chosen over another design such as a zener diode because zener diodes do not have precise zener voltages at exactly 24V or 5V, while voltage regulators do.

With all these factors of power and component selection taken into consideration, below are the preliminary designs for the 5V and the 24V power supplies drafted in LTSpice. The 24V supply in particular will not use the resistor configuration seen at the voltage regulator. This was included in the design because the regulator was an adjustable regulator and these resistors were calculated in order to produce a 24V output. The design will instead use a regulator similar to the 5V configuration. The components selected for inclusion in these design are selected for sustaining the peak inverse voltages in the diode bridge as well as maximum current that will be accumulated through connection of multiple voltage-driven elements, particularly in the diodes and the voltage regulators.
Figure 14: Regulated 5VDC Power Supply designed in LTSpice

Figure 15: Regulated 24VDC Power Supply using Adjustable Regulator designed in LTSpice
7.4 Software Design

Library Integration

Data on the books will be stored in a custom database that we will implement. For shelving purposes, the dimensions of the books are measured by the system and kept in this database. The first time a book is processed, it will take some time to take the physical measurements and make a new database entry, but every time following, the dimensions can simply be read out of the database, saving the time of measuring the book. Database alternatives are discussed in the following section labeled Database.

We plan to integrate our software with the Evergreen library software for two purposes. The first is to copy all of the entries in a library’s database into our own so that a new entry does not have to be made when a book is seen for the first time. The other reason is so that we can automatically check a book back in to the library instead of a human having to do that. There are no existing APIs for this, but we talked with Hekman staff and Evergreen is accessible through terminal commands. We would use Evergreen because our customers, GRPL and Hekman library, both use it. Other alternatives we may look into later on are Koha, VuFind, and LibLime, which all have APIs we can work with.

Database

The first choice regarding the database is whether do store it locally or remotely on a server. We chose local because we do not want our system to have to rely on a network connection that could go down at any time. We currently have working Python code for a local database from before this project, but our main code will be written in Java, so we would have to communicate between the two languages using JPype or Jython. We chose Java as our main language because we all know it, so we would not have to spend time learning it, and it is faster to develop than C or C++. Pure Java options are JavaDB and HyperSQL. Table # 2 shows the decision matrix for these options.

<table>
<thead>
<tr>
<th>Custom Database Type</th>
<th>Simplicity</th>
<th>Ease of Use / Installing</th>
<th>Supports Local Databases</th>
<th>Supports Unix</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weights</td>
<td>30%</td>
<td>20%</td>
<td>40%</td>
<td>10%</td>
<td>58%</td>
</tr>
<tr>
<td>JPype</td>
<td>0</td>
<td>0.4</td>
<td>1</td>
<td>1</td>
<td>58%</td>
</tr>
<tr>
<td>Jython</td>
<td>0</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
<td>60%</td>
</tr>
<tr>
<td>Apache Derby (JavaDB)</td>
<td>1</td>
<td>0.9</td>
<td>1</td>
<td>1</td>
<td>98%</td>
</tr>
<tr>
<td>HyperSQL</td>
<td>1</td>
<td>0.7</td>
<td>0</td>
<td>0</td>
<td>44%</td>
</tr>
</tbody>
</table>

*Table 2: Database Decision Matrix*
Apache Derby is a clear winner here. The problem with JPype and Jython is that they aim to have most of the code written in Python and only what we really need in Java. This is the opposite of what we have where we want the bulk of the code to be in Java and just the database function in Python. HyperSQL is a bad alternative because it supports neither local databases nor the Unix operating system. To install Apache Derby, follow the instructions on this website: http://db.apache.org/derby/integrate/plugin_howto.html, but put the 3 files in /eclipse/features not in /eclipse as they claim.

**Book Measurement**

![Figure 16: Book Measurement Software Test](image)

Book dimensions can be measured either mechanically or visually using a camera. Because Chris is already very busy with other mechanical designs, we decided to pursue the visual option. This involves a camera taking a picture of the book and some of the surrounding area and then finding the bounds of the book using software. Figure # 16 shows the results of this software.

Once a book is measured, the dimensions can be found using geometry and the fixed distance the camera is away from the book. Because this does not need extremely clear images like the OCR did, we would not need a high quality camera. This works well for high-contrast book colors, but an all white book failed to be recognized. To solve this, we need a background that would not conflict with any potential book color. Another possible problem is that the distance between the camera and the book varies depending on the thickness of the book. The further away the camera is, the smaller this error will be. A physical system would be more accurate in measuring the dimensions, but we do not
know if we will need the book dimensions until next semester.

### 7.5 Possible Issues

**Multiple Book Detection**

One possible issue with our system is if someone returns a stack of books all at once. Ultra-sonic range finding is an alternative we are considering for detecting if there are multiple books coming in the slot. It emits high-frequency clicks and measures times how long it takes for the signal to return, creating a virtual map of how far away things are. This data is processed to determine if there is one book-like shape or multiple. It is not a perfect system because two books that are the same dimensions and are right on top of each other will appear to be on thicker book. We were thinking RFID could be used to identify multiple books, but our RFID scanner can only read one tag at a time. If multiple books are detected, a mechanical system would still need to separate them. A last-resort solution would be to require the user to insert one book at a time. Although this is a nuisance, places such as Rochester Public Library have systems with this requirement. Another alternative is to have the library place our system in their current sorting room and keep an employee to feed it books one at a time. Our research shows that any company attempting to do a system like this requires it to be fed one book at a time. Some systems allow library customers to use the standard drop off that dumps books into a big bin and then has an employee feed the machine. Because our research has not turned up a way to handle multiple books, we will require that our design be fed one book at a time.

---

8 Testing

8.1 Incremental Tests

Motor control Tests

*to be done for all motors we have

Preconditions: have micro-controller, motors, power supply, control systems designed.

Test Procedure1: hook up power supply to motors. Make sure they run.

Test Procedure2:

1. add the controls designed to manipulate the motor and amplify the micro-controllers PWM signal.
2. Send a variety of PWM signals and make sure the motor speeds up and slows down.

Test Procedure3:

connect the motor to a wheel with an alternating black-white tape on it. Use a sensor to determine the speed.

Test Pass Criteria:

the motor can be controlled at the speeds required to accurately manipulate the mechanical system. If this test fails for any of our motors, the results will need to be used to push back on the mechanical design.

8.2 Module Testing

Input to our system will be a book return chute at a 60 degree angle roughly a meter above the ground.

The following tests will be done on prototypes as they are built as well as on the final design.

Stage A: The Wheel

**Slot placement test**

Preconditions: Wheel is built and has a control system that takes an input (type of input TBD) from the micro-controller which will initiate a spin of the wheel to the next slot.

Test Procedure: Make the micro-controller send a single signal to rotate to the next slot. When it stops, send a book down the chute.

Test measurements:

1. Time to stop at new location.
2. Watch the wheel as the next slot approaches the chute. Measure how much overshoot if any
there is.

3. Measure how far off from exact alignment it is.

4. See if the book actually slides into the slot

Test passing criteria:

1. Time to stop should be less than 3 seconds.
2. Overshoot should be less than 3 cm.
3. Final stopping position should be at or up to 1 cm past exact alignment.
4. Any of our test books should be able to slide into the slot at the stopping position.

Test Justification:
The time to rotate to a new slot was calculated assuming a somewhat difficult to use book drop mechanism which prevents a user from inputting more than one book. The overshoot was estimated assuming we wouldn’t be able to stop it exactly in the time allotted. This is 30% of the width of a book. The final position of the slot is less than the clearance expected for a typical book.

Wheel Balance test

Preconditions: Wheel is built and has a control system that takes an input (type of input TBD) from the micro-controller which will initiate a spin of the wheel to the next slot.

Test Procedure: Place the three heaviest test books in consecutive slots. Send the rotate signal to the wheel 6 times to rotate it all the way around. Repeat with 1 and 2 books as well.

Test measurements: after each rotation, measure the offset of the receiving slot from the chute.

Test passing criteria: The offset should be less than one centimeter past the ideal location.

Test Justification:
This test is to determine if a counter-balance will be needed. In the worst case, the books will be all on one side which could offset the desired receiving location with respect to the chute.

Queuing test

Preconditions: have books, stage A is built and slot placement test passes

Test Procedure: fill the first queue with books. Close the flaps. Rotate past the drop for stage B. Rotate around again and deposit book into stage B.

Test Passing: can control flaps to keep books in the wheel. Book is successfully deposited into stage B.

Test Justification: The reason for stage A is to receive books and queue them until stage B is ready to process, this test will determine if there is sufficient control to successfully keep the books in Stage A.
Stage B

Preconditions: receiving a book on a 60 degree angle

**Book alignment**

Preconditions: Have books, a slanted surface, some motors, and some pistons/actuators. RFID testing was done to determine maximum distance a read can occur.

Test Procedure: re-test with at least 3 books: large, medium, and small each with at least 5 different starting positions. Initiate alignment software. Draw lines on the slanted surface to specify where the RFID tag is allowed to be based on RFID reading.

Test Passing Criteria: For each run, the RFID tag should end up in an allowed zone.

Test Justification:

If we are using the location of the RFID tag on the book to determine the spine location, we will have to align the book accurately enough before reading to know where the book is so we can calculate the spine location.

**RFID Distance read test**

Preconditions: Have RFID tags, and RFID reader

Test Procedure: take the RFID reader and take an RFID reading at increasing distances from the RFID tag.

Test Passing Criteria: None, this is to determine max distance we can read a tag.

Test Justification:

We need to know the max distance a tag can be read to determine what methods we can use for spine recognition.

**RFID Recognition**

Preconditions: Have RFID tags, RFID reader, and sample books

Test Procedure:

1. Affix (tape) RFID tag on the middle of the spine. Re-test with RFID tag on the front cover at the middle next to the spine.
2. Use the RFID reader to ‘look’ for the RFID tag at each edge.
3. Test with the smallest sized books in the sample books.

Test passing criteria: The RFID tag should only be read at the side at which it is affixed.

---

1 These tests have become obsolete after talking with GRPL which informed us that the standard placement for tags
1 is in the bottom left corner. Having the tag in the corner makes it impossible to determine which of the two sides is the spine from the tag.
Test Justification:
If we can read the tag at only one side, we won’t need to use a suction device to lift the cover to determine where the spine is. This will significantly reduce the complexity of stage B.

**Book Rotation test**
Preconditions: have books, motors, and stage B slanted surface
Test Procedure: put book on rotating surface, initiate the basic stamp rotating program, send signal to rotate book.
Test passing criteria: book should rotate 90 degrees, pause, then rotate 45 degrees. After each rotation, the book should be square to the sides and ready to be put into the second queue.
Test justification:
This test is used to determine if the mechanical system is controlled correctly and accurately.

**Book Flipping Test – depends on if we can determine if a book is upside down**
Preconditions: have books, motors, and stage B slanted surface
Test procedure: Put book on rotating surface, initiate the basic stamp flipping surface, send signal to flip book.
Test passing criteria: Book should be flipped upside down and square to the sides of the platform and ready to be put into the second queue.
Test justification:
This test is used to determine if the mechanical system is controlled accurately and correctly. We might not be able to determine if a book is upside down.

**Book passing Test**
Preconditions: have books, stage B materials, motors, piston?, Stage C queue built and in position
Test Procedure: send signal to push book out of stage B and into Stage C queue.
Test Passing Criteria: book is not damaged and is fully in the queue with no overlap with stage B.
Test Justification: This test is to make sure the passing into stage C does works correctly and does not damage the book.

**Information gathering test**
Preconditions: sensors, RFID tags and reader, books
Test Procedure: Use sensors and RFID reader to gather and pass information to main controlling computer.
Test Passing Criteria: all information gathered should be saved in memory in the controlling computer.
Test justification: This is to test the communication and storage capacity need to measure, recognize, and keep track of books through the system.

**Book placement in queue test**

Pre-condition: Have books, second queue, motors

Test Procedure: use micro-controller program to place a book in each slot, with pause in between to place new book on device.

Test Passing Criteria: Each book should be in a different slot. When placing a book, the device should be aligned with an empty slot before pushing the book into it.

Test Justification: This will test the physical system of filling the second queue. This needs to work in order for the books to pass on to the rest of the system.

**Book location storage test**

Preconditions: have books, stage C queue, RFID reader, information gathering test passes, book placement in queue test passes

Test Procedure: slot in second queue should be stored in the controlling computer.

Test Passing Criteria: the slot number should be stored in memory in the controlling computer.

Test Justification: This will test the communication needed to keep track of a book through the system.

**Stage C**

**Re-shelving cart finding test**

Preconditions: have a mobile drone, micro-controller, simulation of re-shelving carts

Test Procedure: send drone out to place book on cart

Test Passing Criteria: drone finds re-shelving cart

Test Justification: This test will determine if the cart finding algorithm works and if the drone moves correctly.

**Queue / book grabbing test**

Preconditions: Drone designed and built, Stage C is working

Test Procedure: load the drone with the micro-controller program that tells it to grab new books and initiate it.

Test Passing Criteria: Drone has control of one book or the full queue of books without dropping any or damaging anything.

Test Justification: This test will determine if the drone can get new books.
8.3 System Testing

Stage interaction testing
Preconditions: each stage involved in the interaction needs to pass all tests specific to it.
Test Procedure: Put the book into the beginning of the first stage. Initiate book processing programs.
Test Passing Criteria: Book should be at the appropriate location, undamaged at the end of the last working stage.
Test Justification: This test will determine whether the interactions between stages are working correctly.

Stationary Power Supply Filter Testing
Preconditions: Power Supply is designed and built
Test Procedure: Hook up oscilloscope to measure power supply output at motors and micro-controllers terminals with nothing connected. Turn on power supply.
Test Passing Criteria: Discrete voltage spikes on power up should not exceed half-way between micro-controller max input voltage and minimum input voltage at the micro-controller terminals. Discrete voltage spikes on start-up should not 0.5 V at motor terminals.
Test Justification: This test will determine whether it is safe to connect the power supply to the micro-controller and motors.

8.4 Tests Completed

RFID Test

Reasoning
This test was done to determine the functionality specifications of the RFID scanner in relation to the tags. The results of this test might affect the mechanical designs.

Reading RFID
Reading the RFID sensor using the Arduino is very simple. The RFID scanner board reads the radio frequencies and converts them into hexadecimal values. It then sends the hex values in serial to the Arduino board. The Arduino then sends the hex values to the computer over the USB blaster cord. The code to do this came with the RFID scanner [see http://www.calvin.edu/academic/engineering/2011-12-team1/documents.html for the code].

Testing Procedure
In this test:
Preconditions: Have Arduino, RFID scanner, wires, and software.

1. Set up the hardware as described on the Arduino website.
2. Upload the software to the board.
3. Test with multiple tags
4. move tags around scanner and measure distance it can be read and determine orientations it can
   not be read in.

**Testing Issues we overcame**
To make sure the code works, we wired the Arduino to the scanner on a breadboard according to the
hardware description on the Arduino's website. Next we connected the Arduino to the computer and
tried to program it. The first few times we tried to program the Arduino the RFID scanner was
connected and powered up, and the upload would always fail. We then tried other example code that
was working earlier that day and that failed to upload as well. Next we took the RFID scanner off the
breadboard and tried programming the Arduino again and it worked. The problem resides with the
Arduino. If it's sending power to the RFID scanner, it will not program. The solution we came up with
is to connect the RFID scanner board after the Arduino is programmed.

**Results**
Once the board was programmed, we used the serial monitor in the Arduino software to read the
values passed back. We tested each of our tags and recorded the results.

**RFID Scanner Characteristics:**

**Connections:**
The scanner has 4 pins: power (5V), GND, /Enable (active low), and SOUT. Enable is connected to a
pin of our choosing and SOUT is connected to the Arduino's RX pin (pin 0).

**Multiple tags**
We put multiple tags in front of the scanner and only one was read. This means that this scanner could
not be used to detect multiple tags. Other scanners can detect multiple tags: for example at our GRPL
visit we saw them turn on a long-range scanner and saw 20 some tags show up on their computer
screen.

**Tag placement:**
A tag can be read as long as it's not perpendicular to the center of the scanner. The two largest tags we
have (credit card size and a circular with diameter of 7 cm) can be read at a 12.5 cm distance if some
part of the tag is over the scanner antennae which gives us a RFID reading area on the range of 26
square cm for the rectangle tag which is most of a textbooks surface. The circular tag can be read over a
13 square cm area. A tag can also be read if it is off to the side by 3-4 cm no matter it's orientation.
Since libraries have a standard location, usually the bottom of the book right along the spine, where
they place identification, once the book is oriented we will be able to reliably predict where a tag will be which will allow us to keep the scanner stationary.

**RFID used for Spine Recognition**

This test shows that we can read the tag over a large distance which makes using it to recognize the spine difficult as for smaller books, it is possible to read it on all sides. When we are working with legacy systems where the RFID tags have already been placed, we will have no say as to where they go. If they are in the typical spot, the bottom left corner, they can be read equally well from either of the two sides that connect at the corner. One of them will be the spine, but there is no reliable way we can think of to determine which one it will be.

**Next**

The next step in using this software is twofold: 1. wrap the Arduino code into a function so our main method can call it and 2. write java code to listen to the serial results so we can integrate it with the database.

**8.5 Arduino PWM Test**

**Reasoning**

This test was done to determine the functionality of the Arduino's analogwrite() function which produces PWM signals. An LED was used because an LED can only be on or off and any dimming is done by varying the amount of time that it is on.

**Test Procedure**

1. Run the dimming LED examples.
2. Change values in code to get different frequencies

**Results**

After running the example code several times we determined that we could get any frequency we desired by using a combination of pauses and analogwrite() function calls. The analogwrite() function operates on a clock of 0 to 255 and is incremented every clock period unless a pause is added in the loop. For low frequency PWM's we will have to use a long pause and as such, it might be better to implement our own PWM function on any digital output pin by setting it high pause, low pause longer. For the motors like the wagon wheel drive motor, the analogwrite() function will work well as it gives a few orders of magnitude of speed change.
8.6 Optical Character Recognition Test

Reasoning
This test was done to determine the feasibility of Optical Character Recognition as a means of identifying library books. A digital camera was used to photograph the Dewey Decimal stickers and software was used to interpret the text.

Test Procedure
1. Take pictures of book spines
2. Pre-process them with custom image software
3. Use GOCR to interpret the images into text

Results
Two different cameras were used, a low-quality 0.7 megapixel iPod Touch camera and a 7.0 megapixel digital camera. Our software isolates the text into a raw black/white image which GOCR can more accurately read. Pictures were taken of multiple types of book labels including dark, faint, printed, and hand-written with both cameras. Faint and hand-written labels were not successfully parse-able by this system. Dark, printed labels were identifiable, but only about 50% of the characters were correctly recognized. The camera type was not a huge factor in output quality.

*This code was lost when Luke's computer crashed and he had to buy a new one.

8.7 Book Recognition Test

Reasoning
This test will determine how well books are identified in stage B of our system.

Test Procedure
1. Take picture of book and surrounding area
2. Use software to determine book's location
3. Use location to determine where the RFID scanner should scan

Results
Preliminary results show that the book location can be easily determined using software, as long as the book is a different color than the surrounding area. Testing of the RFID scanning shows that as long as the scanner can get within about 4 inches of the tag, it will be properly recognized. Combining these test will be deferred to spring semester once the physical system has been constructed.
9 Prototypes Built

9.1 Stage B Proof of Concept Build

Reasoning

The design is somewhat complicated so a model will help with the completing the design.

Test Procedure

Chris will use his Vex kits to prototype a concept for Stage B and work out any problems as he builds. He has basic sketches to work from.

Test Results

The prototype is built and is on display at our station. It currently can move in a limited two dimensional plane and has the capability of moving a shaft up and down. Right now there are no controls on the design.
Next

The next step with this design is to find a better location for some of the motors, to add a control system, and to determine the best (least obstructed) place to put a camera for book location detection.
10 Budget Management:

Our team is faced with a significantly sophisticated project possibly requiring a larger budget compared to other teams. At the moment, our current conservative estimate stands at around $1000 for the whole project.

10.1 Tools

For the purpose of budget management and cost estimation, our team has developed a dynamic cost estimating spreadsheet divided up according to the three separate stages of our machine.

<table>
<thead>
<tr>
<th>Item Cost List</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sheet Metal</strong></td>
</tr>
<tr>
<td>National Mfg. 12x24 16ga Steel Sheet N215756</td>
</tr>
<tr>
<td>12x18 22ga Steel Sheet</td>
</tr>
<tr>
<td>Plywood</td>
</tr>
<tr>
<td>Plytanium 3/8 x 4 x 8 Plywood Sheathing</td>
</tr>
<tr>
<td>Plytanium 11/32 x 4 x 8 BC Pine Plywood</td>
</tr>
<tr>
<td>Plytanium 1/4 x 4 x 8 BC Pine Plywood</td>
</tr>
<tr>
<td>1/4 x 2 x 2 Oak Plywood</td>
</tr>
<tr>
<td>5.2mm x 2 x 2 Lauan Plywood</td>
</tr>
<tr>
<td>General Plywood (estimated pricing) (4x8)</td>
</tr>
</tbody>
</table>

| Plexiglass | | |
|----------------|
| 12 in. x 24 in. Clear Polycarbonate Sheet | 12 in. x 24 in. Clear Polycarbonate Sheet | 13.98 |
| 18 in. x 24 in. x .093 Acrylic Sheet | 18 in. x 24 in. x .093 Acrylic Sheet | 19.98 |
| 24 in. x 18 in. Polycarbonate Sheet | 24 in. x 18 in. Polycarbonate Sheet | 13.98 |
| .093 in x 12 in. x 24 in. Polycarbonate Sheet | .093 in x 12 in. x 24 in. Polycarbonate Sheet | 18.48 |
| .220 in. x 18 in. x 24 in. Clear Acrylic Sheet | .220 in. x 18 in. x 24 in. Clear Acrylic Sheet | 13.00 |
| Servos | Servos | |
| Parallax (Futaba) Continuous Rotation Servo | Parallax (Futaba) Continuous Rotation Servo | 13.00 |
| Futaba - S3003 Servo Standard | Futaba - S3003 Servo Standard | 9.00 |
| Savox SC-1258TG Standard Digital | Savox SC-1258TG Standard Digital | 65.00 |

**Figure 20: Budget Item List**

First a table was created showing all the relevant items for our project and the cost cited on-line by the selling company. This included materials costs for items like particle board, wood, and sheet metal from vendors like Home Depot and Lowes.
Using the on-line cited costs for materials, motors, servos, micro-controllers, and all other relevant item cost for our project, a VLOOKUP column has been created to find the given cost for a component given the item name. The items can be selected from a drop-down list (Figure 21) populated with the item name column.

The drop-down list is updated dynamically as new item names are added into the spreadsheet allowing us to monitor our budget as new component and materials are suggested as design alternatives for each stage of the machine.

### 10.2 Cost Estimation

In general the costs for our project will be estimated using the cites materials and components costs from the Budet.ods spreadsheet mentioned above. However, some costs are more difficult to estimate especially specific component costs not often advertised on-line. Items such as gears, wires, miscellaneous electrical components, metal stock are either difficult to find on-line and/or will vary change considerably from source to source.

For these components, conservative estimates are used and counted as overhead until more reliable sources such as company catalogues or personal references are found. The estimates are, however included in the overall current budget estimation.

Fortunately, we also expect to receive donated components that will significantly relieve the budgeting constraint on our team. Team 2 has indicated that the two high-torque electric motors obtained from
Rapid-Line will not likely be used in their project and are willing to hand over both of them to our team saving us about $248 off of our current expected budget. Also Phil Jaspers has also confirmed that any metal stock in the shop is free for student use on any senior design project.

10.3 Key Numbers

It is important to note that our initial conservative estimate for the total budget may still be subject to a great degree of change. Our team will not accept any overall design that exceeds our $1000 design requirement. However, because of the dependent nature of each subsystem on the previous subsystem's design estimating costs for each of the subsystem will be a very iterative process. A change in the design of subsystem 'A', for example, may completely alter the nature of the subsequent portions of the machine.

1. Total Estimated Cost (assuming purchase of all equipment and materials): $930.59
2. Stage 'A' Cost (Book queuing subsystem) $208.59
3. Stage 'B' Cost (Book orienting subsystem) $294.98
4. Stage 'C' Cost (Book pre-drone storage subsystem) $20.00
5. Stage 'D' Cost (Book placing drone subsystem) $316.44
6. Miscellaneous Estimated Costs $90.00
7. Current expected materials donation value $308.23
8. Expected Budget of Project Post Donation $622.36
11 Marketing Study

11.1 Competition

There are two main areas of competition for our design: small scale and large scale.

Small Scale Competition

The small scale competition consists of other technologies that can’t replace our sorting system, but make checking items back into the library system and keeping track of their location a lot easier. They are in competition because they are competing for library funds which are limited and the small scale technologies might update the libraries systems enough that they wouldn’t be as willing to buy our sorting system. These solutions are largely based on RFID technology that is used to find books on the shelves with hand-held scanners, check in and out large quantities of books at a time, keep track of where a book is, and a handful of other convenience solutions. These solutions currently utilize hand held and stationary scanners and the largest cost associated with them is the cost of an RFID tag for each book in the library’s collection. These products are targeted at almost all libraries.

There are also small scale sorters that are in operation. How they work is that they receive one book at a time through a computerized conveyor belt book drop, identify the book (likely RFID), check it in, then they use a conveyor belt system to move the book to up to 15 bins. Our design is looking to be able to deliver a book to upwards of 30 locations so librarians have a better starting position to do the final perfect sort. By delivering to more locations, our design will reduce the total time still needed to finish sorting. Our design is also going to deliver a book to a re-shelving cart so librarians don't have to bend into bins (or buy the bins for that matter) which could put a repeated strain on their back.

Large Scale Competition

Seattle Public Library

Seattle Public Library has a fully automated sorter for returning books that uses RFID technology. The sorter begins at the check in where materials are moved through a conveyer belt to a separate complex dedicated to sorting materials. Depending on whether the items are going to the central or branch libraries, the materials are either sorted onto return carts, or placed into bins to be shipped to different locations. For materials being checked in to the central library, materials go through a module that uses a vacuum suction device to detect the books orientation so they are placed spine out on the re-shelving
carts. Then a robotic arm quickly places the books on a shelf in an orderly fashion. The problem with having this type of approach in a smaller library is that it requires 10 million dollars to implement, as well as adding additional building space to house the sorting device. This type of system for smaller branch libraries would not be well suited because they can’t afford the cost—they currently spend tens to hundreds of thousands of dollars to sort and re-shelve books—or the space additions as public libraries are often in cities or surrounded by private property.

**Mansueto Library (University of Chicago)**

Mansueto Library at the University of Chicago also uses an RFID system for cataloging and locating their materials. The system recognizes books by their attached RFID tags and uses that information to sort them into bins. The bins are placed on shelves by an automated lift. The main difference from Seattle Public is that the University of Chicago’s system is only automated for the bins that the books are placed in, and not for the books. The books inside the bins are handled manually by employees, and not by machines like Seattle Public. Similarly, this system also requires a lot of space (5 stories deep with space for 3.5 million books) for the machine to operate as well as for book storage.

**Companies**

Both large scale competition and small scale competition can come from the same company. For example, 3M has a wide range of library products and have even designed large-scale sorters which are multi-million dollar machines that require a whole building be built around them. Large-scale sorters can even lend to the library having closed shelves like the Mansueto Library. Closed shelves are not a feasible option for many libraries.

If a company like 3M decides to pursue expanding their small-scale sorters, they could conceivably overwhelm our company and snag most of our potential customers. They are at a disadvantage because they would have to totally re-think how they are sorting books as their current conveyor belt systems take up additional space (3 new bins and

---


additional conveyor belt length) when they are expanded.

Integrated Technology Group (ITG) has similar products to 3M (both utilize conveyor belts), but neither company advertises its prices for the sorting technology. 3M's products are seen in figures 22 and 23.

Figure 23: 3M 7-bin Intellisort System

11.2 Patents

US 6257816.10

The suction cup design we are using has a patent that's very similar to it. The main patent claims are summarized below and won't likely be a legal issue.

Main claims:
Claim 1: first positions the book, which our book opening device will not do. Then it applies suction to one cover, lifts and senses the tilt.
Claim 4: similar to claim one, but using a conveyor system instead of positioning the book.
Claim 10: which goes into details about the control systems.
Claim 20: deals with moving a book through the system, also refers to conveyors.

This patent shows how to implement a spine orientation device using suction, but it looks like if we went into business with our current design, the patent isn't robust enough to be a barrier to entry in the industry.

US 2009/0155029 A1 patent applications

This patent is about using a conveyor system to transport a book in a near vertical orientation. This patent was looked at because we will want to deliver a book in a near vertical position onto a re-shelving cart. Ultimately, it will not be a good design due to space considerations.

US 5213193

This patent is about taking to books laying one behind the other and separating them so they are laying side by side. This type of system could be used at a book drop to separate a stream of books into two different systems. It could potentially get rid of our Stage A and instead use multiple Stage B's working in parallel. This design is out of scope as it relates to scaling the project up, not enhancing it.

Figure XXX: 3M’s 15 bin sorting solution Source: 3M.com

11.3 Market Survey

We contacted about 40 libraries with a request to take a survey we created and we have received 5 responses that all say similar things: Libraries are currently spending $60,000 or more on sorting and re-shelving books, but are only willing or able to spend up to $5,000 on a sorting solution. We are assuming this $5,000 amount could be a yearly payment for several years. We are also talking extensively with GRPL to determine further design requirements and cost analysis for a typical library. We are using the GRPL as our initial ‘customer’ and assuming that their requirements are fairly typical of any library’s requirements as they have 8 branch locations of various sizes.

GRPL has told us that to be a feasible design, the sorting system would have to take the place of their initial 30 to 35 level sort where they manually empty the large receiving bins under the book drops onto about 8 re-shelving carts with 4 shelves each. They usually have to do this half an hour to an hour. Their throughput is between 5,000 books a month (around 1,250 books a week) and 76,000 books a month (19,000 books a week) depending on the branch. GRPL looks for a 3 year payback period for new systems. The money saved is calculated by the salaries of the people they can re-purpose or fire. With our system, they would be able to eliminate up to 2 monotonous, minimum wage jobs for a savings of $18,000 a year.

The libraries we contacted were interested in our project and would like a sorting solution that didn’t take up much room and that would be cost effective. 1 library that responded is already using RFID and

3 more were considering switching to RFID within the next 5 years.

12 Business Plan:

There are two main options for us in regards to making money on this design: 1. We sell the design to 3M or ITG, or 2. we create a business around the design. Selling the design would cost less on our part, but it might not produce the most profits. Creating a business around the product would cost more, but would produce more revenue in the long run. If we create a business around the product we would likely team up with team 2 to sell both our products and to improve them to work with barcodes and maybe OCR if we have enough revenue as well as develop new products.

After the prototype we will spend 2 months re-designing the system to make a production model. We will then manufacture 10 samples for in-depth testing. This will involve a mini library of 100 books of all acceptable sizes which we feed into our sorter through the book drop intake.

Below is our business plan for if we create a business solely on our sorter robot.

12.1 Executive Summary

Rozebotics will be a company that offers low-cost automation solutions for large volume markets like libraries and restaurants. In these markets, employees are paid to do menial, repetitive tasks that could be automated. Rozebotics initial product will be a sorting machine for libraries to do an initial 30 to 35 level sort of returned books. Rozebotics will also offer optional warranty coverage for an extra fee as well as a customer hotline and extensive debugging and operating guides.

We are targeting the subsection of the library market that has book returns between 1,000 and 40,000 items a week. These libraries are spending upwards of hundreds of thousands of dollars to sort and return books. The market isn't growing or changing much as libraries are not being built or decommissioned en masse. The market will support products up to 15 to 30 thousand dollars payable over a few years.

Rozebotics will employ strategies to speed up time to market, ensure quality, and offer excellent quality support. The company is outsourcing the manufacturing to manufacturing companies which will improve our time to market. To ensure quality, we will be offering warranties, inspecting all products, and including product documents detailing common issues and how to debug the machine.

Key people will be passionate, excellent at their jobs, and innovative thinkers that can stay on task. The sales people will be excellent at talking and some technical experience. Managers will have leadership experience and exhibit willingness to listen and work with their underlings while still keeping them on
task. Customer support personnel will know the system and be able to communicate effectively. Engineers will be detail oriented, personable, and have some experience in their fields. The goal is to have an upbeat and supportive work environment to improve efficiency and likelihood of excellent customer support.

Rozebotics will require funding of 5 million dollars after which it will survive of the sales revenue. Assuming an interest rate of 3.25% on the funding, Rozebotics will be able to pay off the principal of the funding after the first three years and will pay off the interest during the fourth.

12.2 Mission Statement

The goal of Rozebotics is to remarkably improve the cost efficiency for all of our customer's businesses and institutions by providing inexpensive automation solutions for a broad customer base.

12.3 Vision

Our company will begin by marketing the Robotic Entity That Uses RFID indexing or 'return;' product. Our focus throughout the company's evolution will be to provide automation solutions to small businesses and other institutions typically ignored by larger automation and materials handling companies such as Dematic and J&R Automation. Our company will develop automation solution that can be manufactured by third party contractors such as Rapid-Line. Future product markets could include automated systems for restaurants, super market, airports, hotels, and hospitals where the technical challenges increase with profit making potential.

12.4 Industry Profile and Overview

Industry Background and Overview

Automation has been an integral part of many industries, such as the automotive, storage, and manufacturing industries. The industry for automated materials handling has been implemented in certain library settings, but mostly on a large scale level, for libraries like Seattle Public Library. This industry in the small branch library setting is very similar to the large library counterpart, but it is more innovative in terms of needing to accommodate a smaller floor space for machines; that is, the functionality of a large library book sorter system has to be scaled down to accommodate small branch libraries.

Major Customer Groups

We are targeting our design and business at the branch library market in creating compact, automated
material handling solutions. We are working to establish a solid foundation with this current market so that in the future, we would be able to expand our products and services to other areas, like grocery stores, restaurants, and hospital settings. Good public relations and a reputation for quality are key to future expansion.

**Regulatory Restrictions**

This industry is both small and specialized to the point where few regulations have been established. One set of regulations from the US Department of Labor that could potentially be set in place would be in the realm of automated processes should Rozebotics decide to implement a manufacturing in its structure.

**Significant Trends**

Significant trends for the library industry have typically been providing solutions for large central libraries, and creating solutions that are just as sizable, to the point where expansion of facilities is necessary. Not a lot of innovations in terms of the smaller libraries have been established, such as a small scale sorting system that can accommodate a well-matched space. Other library products are in the market are targeted at personal use to make searching a library more convenient. Small-scale sorters are reduced in functionality to the point where they don't provide the librarians with much help.

**Growth Rate**

In the short run, this market would exhibit slow growth because there are not a lot of automated products that exist for the branch library market. In the long run, there could be a fair amount of growth to this market sector, which could expand to branch libraries that are part of a cooperative, like the Lakeland Library Cooperative in West Michigan. We would expect the start-up for our company to be a venture at first, but should the customers of our target market realize the need that we can cost-effectively meet, we would expect the growth rate to increase.

**Barriers to Entry and Exit**

The only known barrier to entry and exit is the amount of interest that companies express in this market. If there is a company that is established in the library automation industry, then the biggest barrier to entry would be the potential competition with the established company to establish market dominance. That scenario would likely not be the case since not a lot of companies have shown explicit interest in this market. Exiting the market may not be as difficult, but in the event that this market starts generating revenue, the barrier to exiting the market may be presented through customer interest in our

---

product as well as our obligation to address their maintenance and warranty needs.

**Key Success Factors in the Industry**

The key to success in industries such as the library industry includes setting high standards in terms of both the product components as well as the people who create them. This would show customers that it is possible for them to benefit from automated solutions, and upon demonstrating said automation, be assured that it was created by the hands of specialists who have considered their needs.

**Outlook to the Future**

There is a lot of potential for markets like library branches to find a lot of use for automation in their environment. That being said, automation could also pique the interest of other markets that could benefit from having a process automated, like packing groceries, making fast-food, or transporting patients via wheelchair in hospitals.

### 12.5 Business Strategy

**Goals**

**Operational Goals**

The production of our automated book drop-off sorter should meet a minimum requirement of about 1200 units per year. This would allow us to meet the estimated selling point of 1000 units per year for our customers, all without producing too high of a surplus. Initially, we would not plan to fabricate our automaton in-house at Rozebotics, but rather outsource it to a manufacturing company. This would allow us to save additional funding because we would not have to factor in the costs for factory space, workers, or fabrication machines. Initial estimates for manufacturing show that it will cost Rozebotics around $1140 to manufacture return. This figure was determined from sending design sketches seen in appendix D to Claire Phillippi, an intern at Rapid-Line. She consulted with her co-workers and estimated that the first three stages would cost $400. She included material, but not electrical components in the cost estimate. The last stage will likely include more welding which is more expensive, and more labor as it is more complicated, but less material than the first three stages. Using these guidelines, we are estimating it will cost $400 to manufacture stage D. Additionally, Rapid-Line adds on 50% of the manufacturing cost as well as a $150 fee for the project. Assuming electronic components will cost around $40 per machine (buying them in bulk for all our machines) This brings our estimated manufacturing cost to $1,200. Through research and development, we can possibly find other markets for automated solutions, such as grocery store checkouts and hospitals; renting factory
space may be more feasible than outsourcing within the company’s future.

**Financial Goals**

Since the market of space-efficient automated book returning is a relatively new and unique market, our financial goals would have to be set in a way that would attract investors to our company, as well as set precautionary measures in place to address potential risks. This being said, a reasonable minimum accepted rate of return (or MARR) we should set would be about 16%. This level allows for more security given the circumstances of the market. For future years at Rozebotics, the MARR would be adjusted based on factors like the decision to expand to other markets and the company’s financial stability.

**SWOT (Strengths, Weaknesses, Opportunities, and Threats) Analysis**

**Strengths**

One of Rozebotics' largest strengths in venturing into this market is that there is very little competition in this market. Another benefit that we have is that there exists an interest in a product that sorts dropped off library books. The combination of these two strengths would provide a great opportunity for our company to set a high standard of quality and innovation for a promising market. Should other opportunities come along as well, our company would be able to expand to other markets as well.

**Weaknesses**

One of Rozebotics' greatest strengths could also prove to be a great weakness as well. Because the market of automated drop-off sorter machines is as small as it is, this could also be an indication of the market’s volatility. Specifically, if there is not as much expressed interest from the branch library markets for our products, then there is a reason why this market has been untouched. If this is not the case, then there exists a possibility for other companies larger than Rozebotics may enter the scene and dominate the market before we could do so. On the same concept of size, another prominent weakness is that Rozebotics could struggle to grow in the long run because we are not doing in-house production.

**Opportunities**

Opportunities that currently present themselves to Rozebotics are in the form of expressed interest in market of branch libraries. This opportunity, as time goes by, could prove to be invaluable to Rozebotics because it would allow us to expand our horizons in terms of other potential markets that have room for growth if only products were created to suit them. An example of such a market would be the fast-food industry. Specifically, the cooking could all be automated. Customers are already used to quick, crappy food so an automated cooking system could flip burgers and such. Since all kitchens
of a chain are designed to be very similar, the system wouldn't have to be adapted for each location. Other potential markets could be supermarkets or airports.

**Threats**

One of the previously mentioned threats to a company of our stature would be the larger, more experienced companies who have a lot of personnel and funding to work with. This could prove to be a threat to a start-up company such as ours. Another threat to Rozebotics can emerge through unions. Unions such as the American Federation of State, County and Municipal Employees (AFSCME) union could object to purchasing our automated book sorter if it compromises too many employees’ jobs at libraries.

**Competitive Strategy**

**Cost Leadership**

Our cost leadership would involve outsourcing manufacturing to a company with moderate throughput capabilities for feasibility’s sake. Yet where we lack in stature, we make up with in efficiency. Our small organization allows for interpersonal relationship internally with our workers, as well as externally with the customers who use our product because of our large sales team.

**Differentiation**

Our company would be able to differentiate ourselves from competitors in several facets. Provided our product thrives in a large portion of the automated book-sorter market, we would set high standards for other companies who would try to make similar products. What also makes Rozebotics different from other companies is organization. While our size would not necessarily be overwhelming, we most certainly excel in being more personal with our customers as well as specialized in automation solutions that we develop.

**Focus**

The focus for our company would be to provide the branch and main libraries the highest of quality in drop-off automation as well as searching for new opportunities to expand to other markets. The qualities of our machines include robust designs in hardware, high-precision software, and low machine maintenance. Our focus would also be to provide the best service to our customers through the machines we create.
12.6 Products and Services

Description
The return automation solution for libraries will be the sole product for our company during its first three years of life. Our system is capable of receiving books directly through a modified drop-off window or from library staff. It will then organize the books according to the sorting strategy desired. The system can be composed of any number of individual units. The actual implementation of our product will vary from institution to institution. Smaller branch libraries, with expected book return volumes less than 100,000 books/year, will likely require only one to five units to meet their needs. Larger central libraries will be more likely to require five or more units to meet their patron's needs. The beauty of the return solution lies in its flexibility and scalability. Each unit is designed to handle a worst-case book volume load of eight books/min or:

\[
\frac{8 \text{ books}}{\text{min}} \times 60 \frac{\text{min}}{\text{hour}} \times 8 \frac{\text{hour}}{\text{day}} \times 355 \frac{\text{day}}{\text{year}} = 13,630,000 \frac{\text{books}}{\text{year}}
\]

At this volume a single unit can be expected to provide a sort as fine as twelve (i.e. the machine can sort books into twelve separate locations). Institutions would then purchase multiple machines to fit either their book volume or sorting requirements.

Our launch product will allow libraries to either reduce their staff and/or labor costs or relocate existing labor to more meaningful and productive tasks such as organization, library programs, or research assistantships.

Guarantee
Our guarantee to all our customers is that they will never pay for a non-working machine. If at any point our machine stops working for any reason short of sabotage, payment for the machine will cease until the machine is fixed. For this purpose we will also guarantee complete reliability (i.e. no machine breakdowns for the first three years of the machines life).

Patent Protection
Because our machine is complicated in nature and patent protection law considers slightly different designs to be patentable in their own right, Rozebotics will not be pursuing any patent protection. Doing so would only make the return automation solution product more susceptible to replication by another company. In our sales agreement, the library will be required to keep the design away from
people who would reverse-engineer it.

12.7 Marketing Strategy:

Our target market is public libraries with circulation between 1,000 and 40,000 books a week for any of their locations. These libraries are currently spending $60,000 to $150,000 on sorting and re-shelving books. Initially we will target public libraries because they are most likely to have multiple branches that would fit our estimated circulation capacity, we would be able to sell multiple machines to one customer, and our money saving machine will have a greater impact.

We have been asked many times how long printed materials and the libraries that house them will survive with the digital age. To answer this, we talked with the Grand Rapids Public Library (GRPL) which has 8 branch locations. They estimate that by the end of the century, electronic books will start to threaten their survival. They shared with us the circulation numbers for the past two years and they have seen an increase in total circulation of 12,000 books per month. This data was taken by comparing June in 2010 and 2011. Some books like historical documents take too long to digitize and there is not a high enough demand yet to warrant taking the time to digitize them which is one of the many reasons why they do not anticipate eBooks taking over the book loaning industry. GRPL is interested in our project and if it reaches a production quality, they would likely buy at least one to test it out.

Libraries will be motivated to purchase our sorting machine because it will save them money and speed up the return process. For example, GRPL currently employs nine people at minimum wage to sort and re-shelf books. This comes to around $90,000 that they currently spend and assuming about half of that is spent on sorting, the market could afford around $5,000 a year for a machine.

12.8 The library market is not shrinking or growing much as libraries tend to be financially stable and an increase in demand for renting books can be accommodated by current libraries.

Pricing

We plan to price our machine at $15,000 so a library could easily pay it off in three years (manufacturing it is around $2,000 with safety factor of 2 for possible scrap and re-work). Our competitors are currently not showing their prices, but according to GRPL, the price of a custom sorting machine design, not implementation, is on the order of $90,000. By producing a versatile sorter that can fit in most libraries, we can spread the cost of design among many customers instead of just one, which reduces the cost per machine.

We will also modify sections of the design to work independently for different use cases. For example, a library like GRPL would like a machine for their main location that sits in their basement, restricted access sorting room and is fed books by an employee. A small library, perhaps one of their branches, would rather modify their book return to only accept one book at a time and have our machine at the other side to sort it
directly.

**Advertising**

Our advertising message will focus on the cost savings and reliability our machine will provide. We will be able to save a library $35,000 (what they would pay an employee – our system's price) over the course of our products estimated ten year life span.

To reach libraries with information about our product, we have a budget of $100,000 a year for conferences, events, advertising with the American Library Association (ALA), and other outlets our sales and marketing teams come up with.

Our company will work with the ALA and shipping companies to provide reliable distribution of our system to our customer libraries.

### 12.9 Location and Layout

Because we have decided to outsource our manufacturing for as a start-up, our location requirements are minimal. We will not require our own plant to produce our product or our own inventory storage. 'return;' automation solutions will be manufactured on a per-order basis by our planned third party manufacturer Rapid-Line.

Therefore, our company can now accept a significantly smaller start up location both in terms of size and cost. We will need to provide offices for our twenty-two full time employees including our accountants, engineers, financial analysts and managers. For this purpose we have

---

already located a suitable location for start-up. Image Office Suits has a location at 2828 Kraft Ave SE right here in Grand Rapids. Our company will require four of the five suits they have available giving ample working space for our twenty-two employees at an affordable total lease rate of $ 29,790/year. Additional layout details for workspace? Our total workspace will also have to include 25 computers and 25 office desks, lamps, meeting tables, phones, a copy machine and scanners. All of which will be added into the total fixed cost figures during our financial analysis.

12.10 Competitors

The existing competitors are the library employees who are sorting the books by hand. The sorting job is an entry-level position that is typically paid minimum wage. The strength is that they are in the market already and they are human (some employers have moral qualms about replacing people with machines) while their weakness is that they are not willing to cut their pay to compete financially.

Another existing competitor is companies like 3M that have sorters for smaller libraries as well as huge custom systems for very large libraries. They have experience in the field and they have market contacts, however their systems are likely much more expensive, and their systems can only do up to a 15 level sort with the same space limitations, and that sort is just dumping books into bins that an employee then has to sort. Our solution is doing the initial 30-35 level sort directly onto re-shelving carts that libraries like GRPL currently do.

An indirect competitor is other RFID solutions geared towards improving the efficiency of various tasks around a library. These gadgets are also attractive to libraries and they are often a lot cheaper than our sorting machine would cost. However, they do not handle books so they could only compete with us if the library’s budget is tight. Our product could easily co-exist with these library solutions.

Potential competitors that could enter our market are automation companies like Innotec or Dematic that have experience in some form of automation but do not do anything with libraries yet. If they enter the market, they would likely need to spend at least a year to develop a product during which time we will be making contacts and entrenching ourselves as the first company while maintaining good quality and customer service. If they enter the market with a good marketing and sales teams, they could compete with us. We estimate that we would get around 60% of the market from being the first and having a good reputation. There’s a small chance that they could under-cut our prices but they would need an excellent, easy to manufacture design. If customers show that price is their main concern and they would choose a competitor because it was cheaper, we could reduce our total price somewhat and still make a profit. We don’t see this being a major concern as our product is likely cheaper than competing products.
Management Team

Figure 26 shows the company management structure. Below, specific management positions are defined.

**Business Management**

**Operations manager**

The Operational Manager will be the operating head of the company and management team. This person will be responsible for the daily operation and financial stability of the business. He will be the main relation to lenders, vendors, and community officials. In addition he will be responsible for relations with the out-sourced manufacturing firm, making sure to that expectations for precision manufacturing are met. The Operations Manager is also to be the Marketing Manager, making decisions about what the target market is and how the sales/marketing team will reach it.

**Quality control, safety, environmental manager**

This person will operate alongside the manufacturing company to ensure that the final products meet the design specifications. He is responsible for the quality of the product. He will also be responsible for ensuring that any current and future designs meet OSHA requirements and any other applicable safety compliance’s.

---

Accountant, bookkeeper, controller, CPA
The Accountant (CPA) will be responsible for the company’s finances. This includes tracking accounts payable and receivable and generating monthly financial reports for review by the Operations Manager and other applicable managers. The Accountant will also manage the payroll and the company’s cash.

Office manager/Purchasing manager (Engineer)
The Office Manager will also act as the Purchasing Manager. As Office Manager, he will be responsible for organizing the company’s human resources as well as the marketing/sales team. He will be the main contact for sales people in their respective areas around the country. As Purchasing Manager, he will serve as an extension of the Operations Manager overseeing and authorizing all purchases made by the company and reporting directly to the Operations Manager.

Receptionist
The Receptionist will be responsible for answering phones, receiving and sending mail, and billing. In addition, the Receptionist will act under the Office Manager, carrying out tasks required by him.

Foreperson, supervisor, lead person

Shipping and receiving person or manager
The Foreperson is the second in command under the Operations Manager. As such he is responsible for knowing the day to day operations of the company so that he can act as head in the absence of the Operations Manager. The Foreperson is responsible for handling new employees and setting up training and schedules. As Shipping and Receiving Manager, he will oversee the shipment of product and be responsible for ensuring that the product reaches the customer in time. This also means working with the manufacturing company to ensure that products are ready in time for quality control checks and on-time shipment.

Professional staff

Lawyer
A Lawyer (or legal firm) will be outsourced to provide legal counsel on such things as patent application, patent defense, and claims against the company for such things as warranties or personal injury.

CPA
If the Company Accountant is not a CPA or is not a full time employee, there will be a CPA hired to take on the responsibility of generating monthly financial statements for review by the company managers.
Engineering Management

Engineering Manager
The Engineering Manager will be responsible for overseeing the two engineering departments: the Research and Development department and the Redesign and Project Support Department. The Engineering Manager will operate under the Foreperson and will represent the connection between the engineering side and the business side of the company. As a manager, the Engineering Manager is responsible for ensuring that the companies engineering resources are allocated in areas that are deemed viable economically by the company at large.

Engineering R&D Manager
The Engineering R&D Manager will oversee the Research and Development department of the company. The Engineering R&D Manager is responsible for directing the resource of his department and assigning the R&D Engineers to specific projects. He will also collect research reports and, after determining their quality and feasibility, relay them to his superiors. In this way, the research and development projects conducted by the department can become products for the company to produce.

Engineering Redesign and Project Support Manager
The Engineering Research and Project Support Manager will oversee the maintenance and redesign of the company’s current engineered products. He will oversee a team of engineers and delegate them to tasks as he and the rest of management sees fit. The Engineering Redesign and Project Support Manager will compile reports on how the company’s current products can be improved and made less costly.

12.11 Plan of Operation

Legal Form Operation
Rozebotics has decided to form under a modified worker cooperative structure of company leadership. In our cooperative structure, investors will recommend management personnel for hire, but the ability to elect management personnel will reside with the employees they will be managing. Employees will also be given options for investment in the company.

The intention is to balance the control and sense of investment between both the investors and employees; giving employees a clear connection between their success and the success of the company success as a whole and letting investors have some say in the company decisions. For a small businesses just starting up, it is very important to have every employee invested in the business' success. An employee who is invested in their own success will provide better quality of work, be more
attentive to possibilities for innovation, and be more proactive in shaping the company's direction. During startup especially, our company will not be able to afford employees who simply show up to collect a pay check.

**Decision Making Authority**

Rozebotics will utilize a board of four manager headed up by the company president. The five members of the board would be the ones responsible for all the company decisions. The president will, by default, be the company founder unless decided otherwise by the first board. The four managerial heads will be nominated by the company investors and elected by the employee.

### 12.12 Financial Forecasts

There are a number of key assumptions regarding the financial analysis of Rozebotics. First of all, our staff and their salaries. Table 1 shows this data.

*Table 3: Employees and Salaries*

<table>
<thead>
<tr>
<th>Employee</th>
<th>Quantity</th>
<th>Annual Salary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales Person</td>
<td>10</td>
<td>$45,000.00</td>
</tr>
<tr>
<td>Marketing Person</td>
<td>4</td>
<td>$45,000.00</td>
</tr>
<tr>
<td>Business Manager</td>
<td>2</td>
<td>$71,000.00</td>
</tr>
<tr>
<td>Accountant</td>
<td>1</td>
<td>$50,000.00</td>
</tr>
<tr>
<td>Engineering Manager</td>
<td>2</td>
<td>$90,000.00</td>
</tr>
<tr>
<td>Engineer</td>
<td>8</td>
<td>$70,000.00</td>
</tr>
<tr>
<td>Janitor</td>
<td>1</td>
<td>$15,000.00</td>
</tr>
<tr>
<td>Engineering Intern</td>
<td>2</td>
<td>$10,000.00</td>
</tr>
<tr>
<td>Other Intern</td>
<td>3</td>
<td>$5,000.00</td>
</tr>
<tr>
<td>Sales Budget</td>
<td>1</td>
<td>$60,000.00</td>
</tr>
</tbody>
</table>

The salaries are average amounts for those professions with about 2-5 years of experience\(^\text{16}\). Another assumption was that we could borrow money at 3.25% interest\(^\text{17}\). One of our biggest assumptions is that we would be able to sell 1,000 units per year at 3 annual payments of $5,000.

Our income statement can be found in Appendix A. In the first year, our income is -$818,356, in year two $2,303,444, and in year three $5,353,172. Our balance sheet in Appendix B shows that we will be making a significant profit. Our quarterly cash flow statement can be found in

---


Appendix C. It shows that we will not run out of money at any point in the first three years. Due to our 3-year payment plan, break-even analysis is not as straightforward as if payments were a lump sum. However, 2,129 units would need to be sold in year 1 to break even. Following that, year 2 and 3 would actually not need to sell any units to break even due to the recurring payments from year one.

In year 1, the contribution margin will be 22%. Due to our payment plan, this rises to 61% the second year and 74% the third because of the recurring payments that do not incur any expenses.

12.13 Loan or Investment Proposal

In order to get Rozebotics started, we would require a loan of $5,000,000 in cash with an annual interest rate of 3.25%. Our annual operating costs would be $6,202,630 for the first year, so $5 million would cover us for most of the year, and then our estimated sales revenue of $5 million will cover us thereafter. Our payment plan would be to pay back $2,500,000 each year for years 2 and 3. Any interest on this loan will be incurred as an expense for that year.

The goal of the timeline for getting started is to get to the market quickly. Since our manufacturing will be outsourced to another company, the business would be started immediately upon hiring all of the employees. The hiring process will start in December 2011 and the company will get started with production on June 1, 2012. One of the reasons we will outsource our production is to improve our time to market.
13 Feasibility
To see our current Work Breakdown Schedule (WBS), see

13.1 WBS summary:

**Accomplished:**
So far the mechanical designs for Stage A are near done, only the slot controls need to be finalized.
Mechanical design for Stage B is nearing completion as well. Currently we have a prototype we have
used to visualize how it will work. This still needs to be optimized.
The power supply is designed but still needs to be tested and optimized.
The RFID reader is functioning and passing data correctly.
We have preliminary software for recognizing the location of a book in Stage B given a picture of it.
We have done market research and component research to determine what the market wants and how to
best go about delivering that.
We chose to use the Arduino micro-controller.

**To go:**
Stage C mechanical design has not been started, but it should be simple as it is only a shelf. Stage D
mechanical design is fairly complicated and no design calculations have been started.
All control systems.
Camera system for Stage B.
Software integration with Evergreen.
Most testing.

13.2 Feasibility Statement
While we do have a lot of work to do, we believe that as a team we can definitely finish our project.
The main reason for this is that both Theo and Luke have interim off to work on Senior design. Theo
and Luke also have more free time to dedicate to design work spring semester. Luke is on the swim
team and currently dedicates 20 hours a week to swimming. The swim season ends in February so he
will have up to 20 more hours for senior design. Theo has a lighter class load next semester (12 credit
hours, 1 100 level lab) a third of which is Senior design. This is down from 15 credit hours and 2 300
level labs. Josh is also taking only 12 credit hours. Chris has slightly more credit hours, but a lot of his
tasks for senior design are already designed and just need to be built.
## Appendix A: Income Statement

### Pro-Forma Statement of Income

<table>
<thead>
<tr>
<th></th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Units Sold</td>
<td>1,000</td>
<td>1,000</td>
<td>1,000</td>
</tr>
<tr>
<td>Sales revenue</td>
<td>5,000,000</td>
<td>10,000,000</td>
<td>15,000,000</td>
</tr>
<tr>
<td>Variable Cost of Goods Sold</td>
<td>2,640,000</td>
<td>2,640,000</td>
<td>2,640,000</td>
</tr>
<tr>
<td>Fixed Cost of Goods Sold</td>
<td>261,000</td>
<td>15,000</td>
<td>15,000</td>
</tr>
<tr>
<td>Depreciation</td>
<td>3,327</td>
<td>5,701</td>
<td>4,072</td>
</tr>
<tr>
<td>Gross Margin</td>
<td>2,095,673</td>
<td>7,339,299</td>
<td>12,340,928</td>
</tr>
<tr>
<td>Variable Operating Costs</td>
<td>1,240,000</td>
<td>1,240,000</td>
<td>1,240,000</td>
</tr>
<tr>
<td>Fixed Operating Costs</td>
<td>2,038,350</td>
<td>2,038,350</td>
<td>2,038,350</td>
</tr>
<tr>
<td>Operating Income</td>
<td>(1,182,677)</td>
<td>4,060,949</td>
<td>9,062,578</td>
</tr>
<tr>
<td>Interest Expense</td>
<td>81,250</td>
<td>121,875</td>
<td>40,625</td>
</tr>
<tr>
<td>Income Before Tax</td>
<td>(1,263,927)</td>
<td>3,939,074</td>
<td>9,021,953</td>
</tr>
<tr>
<td>Income tax (40%)</td>
<td>(505,571)</td>
<td>1,575,629</td>
<td>3,608,781</td>
</tr>
<tr>
<td>Net Income After Tax</td>
<td>(758,356)</td>
<td>2,363,444</td>
<td>5,413,172</td>
</tr>
</tbody>
</table>
### Appendix B: Balance Sheet

#### Rozebotics Pro-Forma Balance Sheet Year 1

<table>
<thead>
<tr>
<th>ASSETS</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Non-Current Assets</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Furniture</td>
<td>$4,480.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technology</td>
<td>$18,800.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Current Assets</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Receivables</td>
<td>$10,000,000.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cash</td>
<td>$4,161,690.68</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL ASSETS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$14,184,970.68</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EQUITY AND LIABILITIES</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Owner's Equity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital</td>
<td>$9,103,720.68</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Non-Current Liabilities</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.25% Loan</td>
<td>$81,250.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Current Liabilities</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Payables</td>
<td>$5,000,000.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL EQUITY AND LIABILITIES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$14,184,970.68</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Rozebotics Pro-Forma Balance Sheet Year 2

<table>
<thead>
<tr>
<th>ASSETS</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Non-Current Assets</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Furniture</td>
<td>$4,480.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technology</td>
<td>$18,800.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Current Assets</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Receivables</td>
<td>$10,000,000.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cash</td>
<td>$3,970,836.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL ASSETS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$13,994,116.19</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EQUITY AND LIABILITIES</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Owner's Equity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital</td>
<td>$11,372,241.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Non-Current Liabilities</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.25% Loan</td>
<td>$121,875.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Current Liabilities</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Payables</td>
<td>$2,500,000.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL EQUITY AND LIABILITIES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$13,994,116.19</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Appendix B: Balance Sheet (cont.)

**Rozebotics**  
**Pro-Forma Balance Sheet Year 3**

<table>
<thead>
<tr>
<th>ASSETS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Non-Current Assets</strong></td>
<td>$23,280.00</td>
</tr>
<tr>
<td>Furniture</td>
<td>$4,480.00</td>
</tr>
<tr>
<td>Technology</td>
<td>$18,800.00</td>
</tr>
<tr>
<td><strong>Current Assets</strong></td>
<td>$16,828,079.86</td>
</tr>
<tr>
<td>Receivables</td>
<td>$10,000,000.00</td>
</tr>
<tr>
<td>Cash</td>
<td>$6,828,079.86</td>
</tr>
<tr>
<td><strong>TOTAL ASSETS</strong></td>
<td>$16,851,359.86</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EQUITY AND LIABILITIES</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Owner's Equity</strong></td>
<td>$16,810,734.86</td>
</tr>
<tr>
<td>Capital</td>
<td>$16,810,734.86</td>
</tr>
<tr>
<td><strong>Non-Current Liabilities</strong></td>
<td>$40,625.00</td>
</tr>
<tr>
<td>3.25% Loan</td>
<td>$40,625.00</td>
</tr>
<tr>
<td><strong>Current Liabilities</strong></td>
<td>$0.00</td>
</tr>
<tr>
<td>Payables</td>
<td>$0.00</td>
</tr>
<tr>
<td><strong>TOTAL EQUITY AND LIABILITIES</strong></td>
<td>$16,851,359.86</td>
</tr>
</tbody>
</table>
## Appendix C: Cash Flow Statement

**Rozebotics**

**Pro-Forma Statement of Cash Flows**

<table>
<thead>
<tr>
<th>Year 1 Q1</th>
<th>Year 1 Q2</th>
<th>Year 1 Q3</th>
<th>Year 1 Q4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginning Cash Balance</td>
<td>$0</td>
<td>$4,772,963</td>
<td>$4,569,205</td>
</tr>
<tr>
<td>Net Income After Tax</td>
<td>-$204,589</td>
<td>-$204,589</td>
<td>-$204,589</td>
</tr>
<tr>
<td>Depreciation expense</td>
<td>$832</td>
<td>$832</td>
<td>$832</td>
</tr>
<tr>
<td>Invested Capital (Equity)</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Increase (decrease) in borrowed funds</td>
<td>$5,000,000</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Equipment Purchases</td>
<td>$-23,280</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Ending Cash Balance</td>
<td>$4,772,963</td>
<td>$4,569,205</td>
<td>$4,365,448</td>
</tr>
</tbody>
</table>

**Rozebotics**

**Pro-Forma Statement of Cash Flows**

<table>
<thead>
<tr>
<th>Year 2 Q1</th>
<th>Year 2 Q2</th>
<th>Year 2 Q3</th>
<th>Year 2 Q4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginning Cash Balance</td>
<td>$4,161,691</td>
<td>$2,238,977</td>
<td>$2,816,263</td>
</tr>
<tr>
<td>Net Income After Tax</td>
<td>$575,861</td>
<td>$575,861</td>
<td>$575,861</td>
</tr>
<tr>
<td>Depreciation expense</td>
<td>$1,425</td>
<td>$1,425</td>
<td>$1,425</td>
</tr>
<tr>
<td>Invested Capital (Equity)</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Increase (decrease) in borrowed funds</td>
<td>$-2,500,000</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Equipment Purchases</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Ending Cash Balance</td>
<td>$2,238,977</td>
<td>$2,816,263</td>
<td>$3,393,550</td>
</tr>
</tbody>
</table>

**Rozebotics**

**Pro-Forma Statement of Cash Flows**

<table>
<thead>
<tr>
<th>Year 3 Q1</th>
<th>Year 3 Q2</th>
<th>Year 3 Q3</th>
<th>Year 3 Q4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginning Cash Balance</td>
<td>$3,970,836</td>
<td>$2,810,147</td>
<td>$4,149,458</td>
</tr>
<tr>
<td>Net Income After Tax</td>
<td>$1,338,293</td>
<td>$1,338,293</td>
<td>$1,338,293</td>
</tr>
<tr>
<td>Depreciation expense</td>
<td>$1,018</td>
<td>$1,018</td>
<td>$1,018</td>
</tr>
<tr>
<td>Invested Capital (Equity)</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Increase (decrease) in borrowed funds</td>
<td>$-2,500,000</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Equipment Purchases</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Ending Cash Balance</td>
<td>$2,810,147</td>
<td>$4,149,458</td>
<td>$5,488,769</td>
</tr>
</tbody>
</table>
Stage B

Side View

Wheel Slot

45-50 cm

W

Edge on View

Stage C

Edge on View

Stage B

Rollers

Motor

Pulley

Pusher holes

Motor

Eject screws

Tilted sliding surfaces are medium density particle board.

Rollers are small beads in circular grooves.
Stage C

Side View
metal shelf: 3/product

W = 45-50 cm

x = 13 cm

Stage D
black box

- line following robot
- carries stage C
- can put hooks from stage C onto re-shelving carts

edge on View
W = 45-50 cm