Abstract

There is a need for device to aid someone with an upper limb loss in lifting objects of reasonable size and shape. This device must reduce barriers that prevent persons with disabilities from entering or advancing in the workplace. This device may assist a broad range of disabilities which include, but are not limited to, persons with upper limb loss, persons with bad backs, little people, the elderly, and people with injuries to their arms or shoulders.

This report details the design process for our team from start to finish. Our research, interviews, and observations are detailed throughout the first few sections, followed by all of the documentation surrounding our design work. The report addresses how we came up with our needs statement and how we narrowed our search. It also discusses the design decisions that helped us come up with and justify our initial prototype, and how that alpha prototype was changed into the beta prototype that is ready to be manufactured. Cost analysis, along with positive customer feedback, have fueled our recommendation to continue with this project and prepare it for mass production.
1.0 Introduction

1.0.1 Context

The official definition of a disability is “anything that disables or puts one at a disadvantage” (Dictionary.com, 2007). In 2002 there were 51,235,000 people with disabilities in America, which is 18.1% of the population. Of this, 25,597,000 are in the working age (21 to 64 years old) with only 14,313,000 or 55.9% maintaining stable employment. 18,289,000 of the 25,597,000 people with disabilities within the working ages have experienced employment problems related to their disability; 10,877,000 have been unable to work at a particular job due to their disability. This data demonstrates the large number of people who face severe adversities in the workforce due to a disability (Steinmetz, 2006).

1.0.2 Purpose

As defined by the NISH, the purpose of the design project is to facilitate disable persons in integrating into the workplace and/or helping them to achieve higher career goals. There are numerous disabilities with different limitations that pose problems when disabled individuals try to enter into a workplace. Our project will help those individuals to move into the workplace and allow them to explore areas of work which they might have been restricted from in the past.

NISH is a national nonprofit agency whose mission is to create employment opportunities for people with severe disabilities by securing Federal contracts through the AbilityOne Program, formerly Javits-Wagner-O’Day (JWOD), for its network of community-based, nonprofit agencies (NPAs).

The purpose of the NISH National Scholar Award for Workplace Innovation & Design is to encourage college students to design creative technological solutions to barriers that prevent people with disabilities from entering or advancing in the workplace. We will be participating in this competition.

1.0.3 Scope

Team ME Too will place our time, energy, and resources into creating a device to assist the disabled in the workplace. With the results of our background research, we will locate as many customers as needed to clearly identify our customer base and we will examine their problems to select a need area. After a need area and a customer are selected, that customer will work side by side with us throughout the year to continually improve our project. Our main goal is to produce a useable prototype that will be given to our customer(s). This working prototype should be ready to be mass produced if deemed necessary. Cost analysis and marketability of the concept should also be studied before the product is released for production.
1.0.4 Objectives

1) Identify a customer.
2) Identify customer needs.
3) Capture customer requirements.
4) Narrow to one need.
5) Narrow to one concept.
6) Develop the concept based on customer requirements.
7) Test concept.
8) Evaluate concept.
9) Manufacture concept.
10) Provide finished product to customer.

1.1 Initial Needs Statement

There is a need for assistive technology devices that reduce barriers that prevent persons with severe disabilities from entering or advancing in the workplace. Devices are needed to address environmental accommodation, functional assistance, and mobility issues for people with cognitive disabilities, developmental disabilities, and physical impairments (vision, hearing and mobility).

[NISH National Scholar Award for Workplace Innovation and Design]

2.0 Customer Needs Assessment

We decided on our initial customer needs through research, interviews, and observations. These items are described in this section through tables, outlines, and customer surveys. The customer surveys and interviewing outlines will appear first, followed by our conclusions of required needs.

2.0.1 Interview Data

Team ME Too interviewed numerous potential customers with various disabilities and asked them to describe the individual problems they encountered in the workplace on a daily basis. The interviewees included the following people:

a) Daniel Bohner – has been without his left arm his entire life
b) Gary Wycal – farmer who lost both legs
c) Eric Mailloux – little person
d) patients from a rehabilitation clinic at the University of Illinois

Appendix A shows the customer needs outline and the list of questions we used for our survey.

The following outlines and survey show the results of our background research and illustrate the wide variety of disabilities that we looked into.
Upper Limb Loss:

**General Statistics:**
1) "Every Week 2,996 People Lose a Limb." (Limbs for Life, 2007.)
2) 50,000 new amputations every year in USA based on information from National Center for Health Statistics (aboutonehandedtyping.com, 2007)
3) Existence of 350,000 persons with amputations in USA, 30% have upper limb loss (aboutonehandedtyping.com, 2007)
4) 30-50% of handicapped persons do not use prosthetic hand regularly (aboutonehandedtyping.com, 2007)
5) About one in every 2000 new born babies will have some form of a limb deficiency (aboutonehandedtyping.com, 2007)

**Specific Need Statements:**
1) There is a need for a device to aid someone in lifting an object of reasonable size and shape.

**Reasons for the Need:**
1) Person with one arm has difficulty grasping and lifting large objects that require two hands to hold.
2) Interviewee: “lifting large boxes is difficult because I don’t have another arm to support or pin the box (on opposite sides) to lift it” – Dan Bohner

**Specific Statistics:**
1) 7.7 million people between the ages of 15-64 have difficulty lifting 10 lbs (Steinmetz, 2006)

**Requirements:**
1) Must lift up to 40 lbs
2) Must lift to chest height
3) Must be comfortable
4) Lightweight
5) Must lift an object with a volume of about 8’ cubed
6) Durable – long fatigue life
7) Inexpensive < $50-75

**Customer Ideas/Concepts:**
1) Strap lift built into vest
2) Dolly aid
3) Mechanical Load Lift assist

2) There is a need for a device to aid people with only one hand to type as fast as someone with two hands.

**Reasons for the Need:**
1) In order to keep up the pace of work to compete with people who type with two hands.
2) Interviewee: “Yes, I would be interested in a keyboard that caters to people with one hand.”

Requirements:
1) Must enable typist to type 50-70 words per minute
2) Inexpensive < $100
3) Durable
4) Ergonomic
5) Should not be much bigger than a normal “qwerty” keyboard

Customer Ideas/Concepts:
1) One handed keyboard
2) Keyless keyboard

Lower Limb Loss:
Interview with local farmer Gary Wycal, October 20th, 2007, by Darin Cook

Specific Need Statements:
1) There is a need for a lift to raise the operator up and into farm equipment.
2) There is a need for a device to work the foot controls of equipment.
3) There is a need for mobility in the field (off-road).

Reasons for the Need:
1) Cannot easily access any of his equipment, uses a 2X6 to slide up and in.
2) Has lost both legs and uses a board to depress the clutch of his tractor.
3) His wheel chair sinks into the ground when he is out doing work in the field or at home.

Requirements:
1) Has to raise a max of 8 ft and over approximately 4 ft.
2) For all of his equipment the pedals must be depressed 1-12 inches.
3) Weighs 230lbs, must not sink in soft mud, gravel, etc...

Customer Ideas/Concepts:
1) A lift that is universal for all equipment, a lift that attaches to equipment.
2) A lever system, air actuated system, electrical system that can be calibrated depress the pedal as much as it is told to.
3) A wheel chair having larger diameter tires that have an off-road type tread.
Short Stature:

General Statistics:
1) Achondroplasia is the most common type of dwarfism and occurs in 1 in about 25,000 births (Weinberg, 1968).

Specific Need Statement:
1) **There is a need for little people to access ATM’s, Bank Counters, Hotel Counters, and Elevator Buttons.**

Reasons for the Need:
1) Short stature and that ATM’s, Bank Counters, and Hotel Counters are designed for average height people.

Requirements:
1) A device to elevate little people such as a step stool
2) Height needs range on a personal basis from about one foot to much larger with 2-3 feet being sufficient to help most.

Customer Ideas/Concepts:
1) A light weight easily maneuverable step stool with wheels.

2) **There is a need for an assistive device to help little people button and unbutton buttons.**

Reasons for the Need:
1) Short fingers, arthritis, missing fingers, or missing hand.

Requirements:
1) Must be able to button any size button with a hand the size of a child’s.

Customer Ideas/Concepts:
1) No specific improvement ideas in this area currently.

3) **There is a need for little people to access lawn equipment such as a push mower or a riding lawn mower.**

Reasons for the Need:
1) The handle bar for a push mower is too high about (4ft.) needs to be made shorter on an individual basis.
2) The pedals for the riding lawn mower cannot be reached.

Requirements:
1) To modify the handle for push mower lower but still keeping feet away from mower deck and blades. (Different for every person)
2) Develop pedal extensions for a riding mower similar to auto versions.

Customer Ideas/Concepts:
1) Developing solutions for various types of lawn mowers, push, riding, etc. to make them more usable for little people.
4) There is a need for an improved gripper / retriever device.

**Reasons for the Need:**
1) Lack of gripping power and size limitations of gripping pads when opened.
2) Trouble reaching and retrieving items from far away.
3) Inability to lift heavier objects.

**Requirements:**
1) Make gripper open wider or adjustable span, currently only 4”, 6-8” would be better.
2) Make gripper grip strong enough to pick up a large coffee cup which is about 2 lbs, and other items requiring a larger clamping force.

**Customer Ideas/Concepts:**
1) Modify a gripper with a clamping force adjustment like a vice grip, that can be retracted easily when larger / heavier objects are being picked up.
2) A gripper with more than two pads, an integral hook and foldable / retractable design. See pictures of existing product.

5) There is a need for more affordable, customizable automobile pedal lifts.

**Reasons for the Need:**
1) These items are very expensive and only have specific height ranges, especially for foreign vehicles and customizable on a personal basis.

**Requirements:**
1) A Rugged, sturdy design for daily use that does not affect drivability.
2) Similar size to stock pedals.
3) Corrosion resistant and provide a comfortable driving position.
4) Be able to be removed easily so other drivers can use the vehicle.

**Customer Ideas/Concepts:**
1) A cheaper version of what is currently available with modifications on a case to case basis for comfort and feel.
Figure 2.0 Summary of survey results from rehabilitation specialist at the University of Illinois.

<table>
<thead>
<tr>
<th>Disability / Time Disabled</th>
<th>Age</th>
<th>Employed</th>
<th>Tough Tasks at Work</th>
<th>Everyday Tough Tasks</th>
<th>Ever Been Discouraged From Job</th>
<th>Any Possible Ideas</th>
</tr>
</thead>
<tbody>
<tr>
<td>transverse myelitis, spinal cord injury, paraplegia -21 years</td>
<td>34</td>
<td>Grad Student</td>
<td>No</td>
<td>Difficulty cooking in apartment because of the apartment size, and the fact that can’t reach the higher shelves</td>
<td>Yes, could not be hired at library because couldn’t reach top shelves.</td>
<td>Environment to be more accessible</td>
</tr>
<tr>
<td>T4 Spinal cord injury - 21 years</td>
<td>older</td>
<td>Head coach of men's and women's volleyball teams at U of I</td>
<td>Has trouble lifting things and things just generally take longer.</td>
<td>Bathing child and reach objects higher up.</td>
<td>Only navel officer training, obviously couldn’t complete the tasks.</td>
<td>None</td>
</tr>
<tr>
<td>T11/T12 complete paraplegic - 16 years</td>
<td>23</td>
<td>Office of Campus Life at U of I as grad assistant</td>
<td>carrying/moving heavy boxes or equipment, cannot pick up heavy objects from ground</td>
<td>Lifting heavy objects, especially from the ground.</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>T7 paraplegic -7 1/2 years</td>
<td>24</td>
<td>Not employed</td>
<td>Worked at GAP and couldn’t reach the clothes on top shelf and couldn’t navigate the cramped stock room.</td>
<td>Not really</td>
<td>No</td>
<td>Market to change views on the disabled.</td>
</tr>
<tr>
<td>Spina bifida - lifetime</td>
<td>40</td>
<td>Alumni relations and development at U of I</td>
<td>None</td>
<td>None</td>
<td>No</td>
<td>Better aircraft lifts for the disabled.</td>
</tr>
<tr>
<td>Spinal Tumor - 19 years</td>
<td>20</td>
<td>Will be a personal trainer</td>
<td>None</td>
<td>Can’t reach high things.</td>
<td>No</td>
<td>Improve claw thing.</td>
</tr>
</tbody>
</table>

2.0.2 Customer Evaluated Needs

Figure 2.1: Customer Needs Based Off Interviews, Observations, and Research

There is a need for a device to aid someone in lifting an object of reasonable size and shape.
There is a need for a device to aid people with only one hand to type as fast as people with two.
There is a need for a lift to raise the operator up and into farm equipment.
There is a need for a device to work the foot controls of equipment.
There is a need for mobility in the field (off-road).
There is a need for little people to access ATM’s, bank and hotel counters, and elevator buttons.
There is a need for an assistive device to help little people button and unbutton buttons.
There is a need for little people to access lawn equipment.
There is a need for an improved gripper/retriever device sized for little people’s bodies.
There is a need for more affordable, customizable automobile petal lifts.

Figure 2.1 shows a list of different needs that are expressed as so by the disabled community. These suggestions were found by issuing surveys, watching videos, and by one on one interviews.
2.1 Weighting of Customer Needs

**Figure 2.2: Customer Needs Weighting Table**

<table>
<thead>
<tr>
<th>Weighting</th>
<th>Reaching High/Heavy Things</th>
<th>Lawn Mower Assesibility</th>
<th>Lifting Larger Objects</th>
<th>Getting into Small Equipment</th>
<th>Pedal Operation</th>
<th>Farm Mobility</th>
<th>Reaching Low Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>2</td>
<td>1.6</td>
<td>2.2</td>
<td>1.1</td>
<td>2.7</td>
<td>1.4</td>
<td>2.4</td>
</tr>
<tr>
<td>Knowledge</td>
<td>2</td>
<td>1.4</td>
<td>1.3</td>
<td>1.2</td>
<td>1.7</td>
<td>1.3</td>
<td>1.6</td>
</tr>
<tr>
<td>Need</td>
<td>3</td>
<td>1.4</td>
<td>2.3</td>
<td>1.2</td>
<td>1.7</td>
<td>1.9</td>
<td>1.9</td>
</tr>
<tr>
<td>Mfg.</td>
<td>1</td>
<td>1.6</td>
<td>2</td>
<td>1.3</td>
<td>2.4</td>
<td>1.6</td>
<td>2.3</td>
</tr>
<tr>
<td>Interest</td>
<td>2</td>
<td>1.9</td>
<td>2</td>
<td>1.3</td>
<td>2.3</td>
<td>2.2</td>
<td>2.3</td>
</tr>
<tr>
<td>Totals</td>
<td>16</td>
<td>20</td>
<td>12</td>
<td>19</td>
<td>17</td>
<td>20</td>
<td>18</td>
</tr>
</tbody>
</table>

**Figure 2.3: Customer Concepts Weighting Table**

<table>
<thead>
<tr>
<th>Weighting</th>
<th>Lawn Mower Assist</th>
<th>Tractor Lift</th>
<th>Offroad Wheelchair</th>
<th>One-Hand Keyboard</th>
<th>Keyless Keyboard</th>
<th>Gripper Assist</th>
<th>Strap Lift</th>
<th>Little People Pull Cart</th>
<th>Cabinet Access</th>
<th>Standing Wheelchair</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>2</td>
<td>2.6</td>
<td>2.9</td>
<td>2.6</td>
<td>1.7</td>
<td>1.9</td>
<td>1.3</td>
<td>1</td>
<td>1.9</td>
<td>1.8</td>
</tr>
<tr>
<td>Scope</td>
<td>2</td>
<td>1.3</td>
<td>1.4</td>
<td>2.1</td>
<td>1.8</td>
<td>1.9</td>
<td>1.8</td>
<td>2.4</td>
<td>1.6</td>
<td>2.1</td>
</tr>
<tr>
<td>Knowledge</td>
<td>2</td>
<td>1.3</td>
<td>1.6</td>
<td>1.8</td>
<td>2.7</td>
<td>3</td>
<td>1.6</td>
<td>1.1</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Need</td>
<td>3</td>
<td>1.4</td>
<td>1.4</td>
<td>2.6</td>
<td>1.7</td>
<td>2.1</td>
<td>1.8</td>
<td>1.8</td>
<td>1.6</td>
<td>2.1</td>
</tr>
<tr>
<td>Mfg.</td>
<td>1</td>
<td>1.8</td>
<td>1.9</td>
<td>1.9</td>
<td>2.6</td>
<td>2.7</td>
<td>1.6</td>
<td>1.1</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Interest</td>
<td>1</td>
<td>1.4</td>
<td>1.3</td>
<td>2</td>
<td>2.3</td>
<td>2.7</td>
<td>2.3</td>
<td>2.4</td>
<td>2.3</td>
<td>2.3</td>
</tr>
<tr>
<td>Totals</td>
<td>18</td>
<td>19</td>
<td>24</td>
<td>22</td>
<td>25</td>
<td>19</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>21</td>
</tr>
</tbody>
</table>
2.1.1 Analysis of Weighting Tables

We narrowed our search to one need area based on our analysis of weighting tables of customer needs and concepts. Figure 2.2 shows the results of our analysis of customer needs. The rating system is based off of low numbers (1) being a good rating, and higher numbers (3) mean the subject in question received a poor rating. The weighting factors on the left (1-3) are present to make the aspect stand out in accordance to its level of importance in our project. These numbers were chosen by the entire group. After each group member completed the decision matrix, the results were averaged and collected to give the present figure. As shown, the need which scored the best/lowest is the need for lifting larger objects.

When we evaluated the customer generated concepts the same way in Figure 2.3, the results were much closer together. The lawn mower assist, which would help a disabled person in and out of a riding lawn mower, little people pull cart, and standing wheelchair all scored very well. The problem with each of these arises when the customer base is considered. Each concept has plenty of customers, but not nearly as much as the strap lift assist would have. The strap lift assist could be a universal tool meant for the disabled with one arm, but it could also be used by people with two arms to help carry the load. The strap lift did not score as low in the interest area as the others, but every person in the group had good ideas on how to design it. Not to mention, it would be relatively cheap to manufacture, and it definitely goes along with the NISH needs statement. This gave us plenty of room to work and an area to let our minds soar to produce a product not like anything else on the market for people with upper limb loss.

Based on our analysis and discussion, we decided to move forward with the general need area of lifting large objects. This need area may pertain to people with upper limb loss, people with bad backs, little people, or the elderly.

3.0 Revised Needs Statement and Target Specifications

There is a need for device to aid someone in lifting and carrying an object of reasonable size and shape. This device must reduce barriers that prevent persons with disabilities from entering or advancing in the workplace. This device may assist a broad range of disabilities which include, but are not limited to, persons with upper limb loss, persons with bad backs, little people, and the elderly.

3.0.1 Target Specifications

The following customer requirements and target specifications were developed by discussion and recommendations from Daniel Bohner, who has been missing his left arm since birth. The requirements and specifications were also developed via testing in the lab and simulated lifting of heavy and large objects. Testing was completed with one arm held behind the back to simulate an upper limb loss. Customer needs appear first in Table 3.1, followed by the metrics linked to our needs in Table 3.2, and finally our target specifications are presented in Table 3.3.
Table 3.1: Customer Needs

<table>
<thead>
<tr>
<th>#</th>
<th>Need</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The device provides a means for ergonomic lifting</td>
</tr>
<tr>
<td>2</td>
<td>The device is lightweight</td>
</tr>
<tr>
<td>3</td>
<td>The device is inexpensive</td>
</tr>
<tr>
<td>4</td>
<td>The device accommodates various body sizes</td>
</tr>
<tr>
<td>5</td>
<td>The device supports heavy objects</td>
</tr>
<tr>
<td>6</td>
<td>The device is comfortable for prolonged use</td>
</tr>
<tr>
<td>7</td>
<td>The device accommodates various object sizes</td>
</tr>
<tr>
<td>8</td>
<td>The device transports objects long distances</td>
</tr>
<tr>
<td>9</td>
<td>The device is easy to get in and out of</td>
</tr>
<tr>
<td>10</td>
<td>The device is durable</td>
</tr>
</tbody>
</table>

Table 3.1 is a list of needs specified by potential customers that we will try to accommodate with our final design.

Table 3.2: Metrics Linked to Needs

<table>
<thead>
<tr>
<th>Need</th>
<th>Metric</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>provides a mean for ergonomic lifting</td>
<td>OSHA requirements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>is lightweight</td>
<td>Total weight</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>is inexpensive</td>
<td>Material and manufacturing cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>accommodates various body sizes</td>
<td>Use age</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>supports heavy objects</td>
<td>Payload capacity</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>is comfortable for prolonged use</td>
<td>Minimum continuous use</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>accommodates various object sizes</td>
<td>Payload size</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>transports objects long distances</td>
<td>Payload carrying distance</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>is easy to get in and out of</td>
<td>Time to get into device</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>is durable</td>
<td>Minimum lifetime</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3.2 shows visually which customer need each metric is linked to.
Table 3.3: Target Specifications

<table>
<thead>
<tr>
<th>Metric #</th>
<th>Need #’s</th>
<th>Metric</th>
<th>Units</th>
<th>Value</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,5</td>
<td>OSHA requirements</td>
<td>Y/N</td>
<td>Y</td>
<td>Spec</td>
</tr>
<tr>
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<td>2,6</td>
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<td>&lt;70</td>
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<td>Spec</td>
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<tr>
<td>7</td>
<td>7</td>
<td>Payload size</td>
<td>cubic ft</td>
<td>&gt;8</td>
<td>Spec</td>
</tr>
<tr>
<td>8</td>
<td>6,8</td>
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<td>ft</td>
<td>&gt;50</td>
<td>Criteria</td>
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<tr>
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<td>9</td>
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<td>sec</td>
<td>&lt;60</td>
<td>Criteria</td>
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<tr>
<td>10</td>
<td>10</td>
<td>Lifetime</td>
<td>years</td>
<td>&gt;5</td>
<td>Spec</td>
</tr>
</tbody>
</table>

Table 3.3 is a list of metrics linked to the specific customer needs. Each metric is given a unit of measurement, its correlating limit value, and type (specification or criteria). A specification is a must have value and a criteria is something that would be desirable to have, but not absolutely necessary. The specification values were determined through feasibility tests, research on the topic, and customer input.

These requirements and specifications were deemed sufficient but were subject to change as team ME Too progressed forward with our project.

4.0 External Search

Organized below is a summary of our external search. This section includes information gathered from numerous sources about the design problem and process. Sources include library, internet, patents, and observations of actual products. An extensive patent search was conducted to help determine what technology similar products have used in the past or are currently using.

4.1 Benchmarking

Benchmarking was done both before and after we narrowed our search to one need area. Findings from before and after are shown below.

4.1.1 Initial Needs Statement Benchmarking

In our external research we came across some currently manufactured products that access the needs of some of our initial needs and design ideas. The products address farming/agricultural lifts, one handed keyboards, keyless keyboards, lawn mower assistance, strap lifts, standing wheelchairs, and a pull cart/step stool. Some of the initial findings are shown below. Descriptions are kept to a minimum because they are no longer applicable to our revised needs statement.
The devices that appear below are keyboards that give ideas for opportunity in helping persons with hand/arm loss or very limited hand function gain the ability to type on a computer in an office setting. Figure 4.1 shows the layout of a one handed keyboard for left or right handed persons. The keyboard is ergonomically designed for comfort and the keys are specially situated to promote fast typing. Figure 4.2 is a noticeably different design geared toward persons with limited hand/finger mobility, and it uses spinner controls to assist with the typing.

Figure 4.1 – Single Handed Keyboards
http://www.enablemart.com/Catalog/One-Handed-Keyboards/Maltron-One-Handed-Keyboard

Figure 4.2 – Touch Spin Keyboard
http://www.enablemart.com/Catalog/Alternative-Keyboards/orbiTouch-Keyless-Keyboard

Figure 4.3 – Coach Tractor Lift
http://www.coachlift.com/farm-equipment-lifts.htm
Figure 4.3 shows two images of a platform lift device that helps disabled or elderly persons get into farm machinery. The devices can be specifically manufactured for each application or piece of machinery, and because of this they are very expensive.

4.1.2 Revised Needs Statement Benchmarking

In the area of assisted lift devices we will focus on building a system for a person with one arm or only one working arm/hand to lift objects by themselves. This system, as defined at the time of this report, will be composed of a vest with a strap. Included within this section are various products currently available in the area of assisted lift devices which gave us ideas that we used to develop our current design.

The first four figures below depict pneumatic and vacuum assisted lifting devices. These devices provide ideas of what is currently available within industry but are not very feasible for our project in terms of portability and personal use. While the vacuum lifts can handle up to 4000lbs (per manufacturers specs), this is outside the scope of our project.

[Image]

**Figure 4.4 – Pneumatic Lift #1**
http://shannahanergotech.com/lift_assists.htm

[Image]

**Figure 4.5 – Vacuum Lift #1- JumboSprint**
http://shannahanergotech.com/lift_assists.htm
Figure 4.6 – Vacuum Lift #2 – JumboErgo
http://shannahanergotech.com/lift_assists.htm

Figure 4.7 – Pneumatic Lift #2
http://shannahanergotech.com/lift_assists.htm

Figure 4.8 below depicts a wheeled hand cart with modifications that may make it easier for a person with only one working arm to operate. This item does not allow the object to be lifted off the ground easily, or provide adequate ways of placing items onto the cart.

Figure 4.8 – Modified Hand Truck
Globalindustrial.com
Figure 4.9 depicts a person wearing a construction harness. This manufacturer also produces lanyards, hooks, straps and other devices that can be sourced to build our vest/strap apparatus. We also may be interested in modifying existing construction harnesses to aid in lifting of objects.

Figure 4.9 – Construction Harness
http://www.snugharness.com/French-Creek-Production/

Figure 4.10 shows lifting straps where hooks are used to grasp around an object for lifting weights. This is one adaptation for the usable arm of the individual to be able to grip around an object or hook it in on one side and have additional lifting devices on the other side of the body. This type of hook allows great amounts of weight to be hung from the hand with little grip effort and is inexpensive at about $15.

Figure 4.10 – RD Millennium Hooker II Lifting Straps

Figures 4.11 and 4.12 show the Handi-Straps ergonomic lifting harness and the grip attachments that can be used along with the harness. This device is used by police, fire fighting and rescue personnel to carry stretchers and items in the field. Additionally, this device can be used to make the lifting of heavy object much easier. This is currently the closest product
available to our desired concepts; it costs $75 for the harness and the grip attachments and seems very adjustable, comfortable and versatile, as we desire our product to be.

Figure 4.11 – Handi-Straps Harness
www.handi-straps.com

Figure 4.12 – Handi-Straps Grip Attachment
www.handi-straps.com
4.2 Applicable Patents

Summarized below are a few applicable patents members of our group found when researching the revised needs statement. A description of each patent is provided as well as an evaluation.

4.2.1 Harness for Lifting Heavy Objects

With the need area being lifting devices, U.S. Patent #4280645 “Harness for lifting heavy objects” was chosen because of its similarity to one of the general product types that have emerged as possible solutions within this need area (Goodden, 1981). This particular device allows the lifting of much larger, heavier objects than otherwise possible. Pictures of the design of this device show that the weight is distributed across the shoulders allowing the individual using it to lift the item under power of their legs in the vertical direction. Stabilizing the object may be difficult with this apparatus and some major modifications would be necessary to allow a person with only one arm or limited use thereof to lift large objects. Some ideas for development of this apparatus include, additional straps, strap attachments higher up on the arm so the forearm down can be used easier, metal plates and conforming strap/rods to wrap around and tighten down upon the object to be lifted. The patent drawing appears below:
4.2.2 Lanyard operated sternum breakaway buckle with vertical position adjustment

This patent is applicable to our Senior Design Product because the sternum buckle could be used in some way to attach a strap type lifting device to the upper body (Howell, 2006). This system would allow for ample adjustments between body size and figure. It would also act as a breakaway buckle for safety purpose (i.e. the load becomes unstable, unsafe, or the strap system must be released in an emergency situation).

This would also be applicable to a strap lift system in ways other than strapping across the sternum. It could be used as a breakaway strap on the lifting strap to release the loads in an emergency situation. Besides an emergency situation it could be used to attach and detach when the load is either being picked up or set down. This buckle could prove to be useful in many ways for a strap lift system.
4.2.3 Backpack With Lumbar Support

This patent shows a good example of a lumbar support mechanism that could possibly be implemented in an assistive lifting apparatus to help prevent lower back strain or injury (Collier, 2006). The lumbar support plate in this patent is adjustable, giving more or less support when needed. The adjustable mechanism can be operated with the use of one hand. The lumbar support also provides an anchor point for any shoulder straps or harnesses.
4.2.4 Device and Method for Wireless Lifting Assist Devices

This patented device assists a person when vertically lifting objects of unspecified weight (Kazerooni, 2003). It is essentially a winch attached to the ceiling. A glove worn by the operator controls the motor by sensing the force applied by hand to the object that is to be lifted. The desired result is that the object feels lighter and the operator retains manual control of the objects position (limited in the horizontal plane).

The concept of this patent can be adapted for use by disabled persons whose lifting demands are not necessarily significant. It could be made to be portable and have a pulley that is easily positioned in space. A more simple strategy to control the assist would likely be employed. The method for which the cable is attached to the object would need to accommodate a wide array of sizes, shapes, and weights.
4.2.5 Ergonomic Lift and Transport Harness

Background

This invention is designed to ergonomically help a person lift heavy objects (Katz, 2001). It is specifically designed to force the load onto the chest, shoulder, and arm muscles of the user, as opposed to the knees and lower back. The arched shoulder pieces are padded to add comfort for the user, and the entire device is made of a hard plastic or light metal so that it is not too heavy for the user. The lifting device can be folded up at various hinged joints to allow it to be transported easily or stored in a smaller space.

To allow the load to be lifted with the person’s upper body, moveable handles are attached to the front of the harness. The user pushes down on the handles to pivot the harness on their shoulders and allow the load to be picked up. The handles can be adjusted once the load is lifted to make it as comfortable for the user as possible. In the figure, the device is shown with a hook (38) for lifting, but other accessories, such as a mechanical grip, may be attached instead of (38) to aid in other lifting applications.

Evaluation

This invention applies to our need area in the fact that it facilitates the lifting of heavy objects with the upper body, but with minimal use of the hands/arms. There are several key things about this invention that should be applied to the design of our device:

1.) The device is **ergonomically designed** to prevent lower back and lower limb injuries. The design of our team’s lifting device definitely needs to take ergonomics very seriously to prevent user discomfort and/or injuries; ergonomics will become even more important for our group because our customers will have some kind of disability. The above invention also has padding where the heaviest parts of the load will push against the body.

2.) The device is **lightweight**. Whether our lift device is a solid material, such as the plastic or light metal suggested in this patent, or some kind of harness, it must be lightweight to accommodate to the user and allow them to lift the maximum loads possible.

3.) The device is **collapsible** and can be easily stored or carried. Reducing bulkiness and facilitating easy transport, while still maintaining the functional requirements of a product, is an important key to consider during our conceptual design process.

While the invention is rather simple and handy, there are some areas of concern and areas of possible improvement:

1.) The invention is **made entirely of rigid materials** to aid in the lifting process, but a rigid base material will not be as comfortable as a more flexible material. Accessories that are actually attached to the load (like the hook in the figure) could be made of something that
could be formed to the individual object being lifted. This could be advantageous when trying to lift or move odd shaped loads.

2.) *It is unknown what the recommended load limits are for this lifting device* and how comfortable lifting such heavy loads is for the user.

3.) It is unknown exactly why the device picks things up from the user’s backside, but it is probably *not the most convenient or easiest way to lift objects*, especially when many things need to be moved. If our group could design a front loading device it would save the user time and make our product more convenient to use.
4.3 Applicable Standards

All of the information for this section was retrieved from the osha.org website under occupational lifting guidelines. Summary of proper lifting was originally for teens in the workplace but the same guidelines can be applied for every worker lifting objects.

Do:
- Keep your head up and back straight and bend at your hips.
- Bring the load as close to you as possible before lifting.
- Lift with your legs, not your back.
- Shift your feet to turn.
- Keep the load directly in front of your body.
- Try to perform lifts at waist height with your elbows in close to your body.
- Limit lifting by hand. Use mechanical lifts or get help.
- Stay fit to avoid injury.

Don’t:
- Lift heavy loads (35 lbs or more) get help.
- Reach across something to lift a load.
- Lift bulky or uneven loads.
- Reach to the side or lift while twisting.

Research that has been done by OSHA suggests that some of the reasons for the onset of back pain and injury arise from the following.

- Reaching while lifting.
- Poor posture--how one sits or stands.
- Stressful living and working activities--staying in one position for too long.
- Bad body mechanics--how one lifts, pushes, pulls, or carries objects.
- Poor physical condition-losing the strength and endurance to perform physical tasks without strain.
- Poor design of job or work station.
- Repetitive lifting of awkward items, equipment, or (in health-care facilities) patients.
- Twisting while lifting.
- Bending while lifting.
- Maintaining bent postures.
- Heavy lifting.
- Fatigue.
- Poor footing such as slippery floors or constrained posture.
- Lifting with forceful movement.
- Vibration, such as with lift truck drivers, delivery drivers, etc.

Our goal throughout the design process is to try to comply to as many of these regulations as we can. In particular, we want to keep the load as close to the user as possible and try to transfer
the load to the person’s upper body rather than their arms and hands. We especially want to make our device comfortable for the user so that they can maintain good posture as described by OSHA, which should result in a lower chance for injury.

4.4 Applicable Constraints

There are very few internal constraints on this need area. Space and budget are not an issue due to the small size and minimal material used in the proposed concepts. A small conflict of limited expertise could arise in the area of sewing; all proposed concepts use fabric and will most likely involve sewing. Also, health and safety become a concern when external constraints are looked at. OSHA has a lot of data in regards to the strain upon and injuries to the lower back.

Our need area involves lifting objects, so strain to the lower back is a big issue. Our designs will have to follow OSHA regulations in regards to the lower back. This could limit our concept ideas and call for drastic changes in designs. Also, the safety of a user must be considered in regards to the load falling. Our designs must take into account how secure the load will be when lifted. These constraints will most likely call for design changes and additions to the concepts. This could take more time and cost more than expected.

4.5 Business Opportunity

Our primary objective is to provide persons with one working arm/hand with a device composed of a vest with a strap that will aid in lifting objects. This device will allow these persons to lift objects in the workplace which they previously were unable to do. As discussed in section 4.1.2, there are no known products in existence that fit this exact need. While products exist in construction, safety harnesses, and rescue lifting harnesses, none of these are tailored to persons with one working arm, and some do not even address the idea of lifting objects with the vest. We believe that we will be providing a niche market with a low cost (less than $100) lifting aid that will benefit as many persons as possible as defined in our current customer requirements and specifications.

As stated above, the primary customers for this device are individuals with one working arm/hand who desire to lift objects such as boxes with less effort and greater personal/physical safety. Secondary customers include companies where persons with arm deformities are currently working that seek to help their employees be able to perform simple lifting tasks that were previously not possible given their condition. Some secondary customer ideas include shipping and receiving companies where lifting and moving objects is necessary such as UPS, FedEx, DHL, or other companies’ warehouses. Additionally, the construction industry could benefit with future adaptations or design changes which could be more tailored for lifting items in the construction industry. Other possible customers include persons with back problems and any company, industry, or person desiring to increase personal lifting power, stability, safety and time efficiency.
5.0 Concept Generation

This section will deal with the generation of concepts as well as initial evaluation of feasibility of the product. Input from the customer will be crucial at this point in the design because it will help to determine if the concept is feasible.

Figures 5.1 and 5.2 show a general vest with hooks (left) and a vest with adjustable straps as well as quick release straps for ease of use with one limb (right).

Figure 5.1

Figure 5.2

Figures 5.1 and 5.2 show a general vest with hooks (left) and a vest with adjustable straps as well as quick release straps for ease of use with one limb (right).

Figure 5.3
The concept drawing directly above shows the idea of using 90° metal platforms for supporting the load(s).

![Diagram](image)

**Figure 5.4**

Figure 5.4 shows the 90° platforms, quick release straps, and the addition of a back-support belt to help with user comfort.

Figure 5.5 has rigid shoulder and back pieces to support the user’s upper body as well as a back-support belt for the lower torso. It has 90° platforms and a metal plate to go under the object being lifted. Like some of the earlier drawings, this one also incorporates an extendable lifting strap to accommodate different sized loads and people of different heights.
5.1 Problem Clarification

The final design of the device must be able to be operated by the physical ability of the person using it. Our needs statement states that our targeted customer is a person with only one functional arm/hand, so the energy used to operate the device will have to be provided by the functional hand or by means of the shoulder or some other form of motion.

Another aspect to the lifting problem is the problem of carrying and controlling the object once it is lifted. Very rarely is the object being lifted in the general proximity of the end destination. To cope with this, the device must also allow the user, with the defined limitations, to carry the object to its final destination, without causing the user physical pain or the possibility of damage to the body after prolonged periods of use. Our target specifications for these user comfort areas are 50 feet for carrying one single object and one 8 hour shift for length of use (section 3.0.1).

5.2 Concept Generation

A variety of concept generating techniques were summarized and presented to the group for consideration. In the end, the use of sketches and brainstorming were used to generate almost all of our concepts. The earlier concepts, such as those shown in section 5.0, are from an initial brainstorming session that we did once we had narrowed our ideas down to the one need area of a lifting device. The later concepts, such as those shown later in section 5.3, were developed using a variation of 6-3-5 brainstorming. 6-3-5 brainstorming is a process where 6 group members take approximately 5 minutes to generate 3 concepts, and then the concepts are
passed around the circle and the process repeated with modifications or upgrades to the originals. The group used this philosophy with somewhat of a modification; we had 7 members start drawing just one concept for about 5 minutes and then passed them on to the next person. The concepts could be sketches, words, or a combination of both. There was no talking allowed during the brainstorming session, which led to greater diversity since every one interpreted the previous ideas a little bit differently. After the papers were passed around for four iterations, there were 7 solid concepts which had multiple modifications and extras which improved upon the original concept.

The final drawings were all put together and with each concept, the original illustrators describe the idea and function of his concept. After the original illustrator was finished describing the concept, each person who added or changed something on the concept described the purpose of the change they added and what new additions it brought to the concept.

As the discussion progressed, certain repeated ideas were made note of. Some of the ideas were voted out for lack of feasibility and/or benefit to the customer. The best ideas within the remaining concepts were then combined into the final concept.

5.3 Initial Screening for Feasibility and Effectiveness

Using the drawings from the 6-3-5 method, the following table was used to help us pick the most favorable design. The drawings which were applicable to our final concept are shown after the table, and the other drawings, which did not pertain to our final product, may be found in the appendix following the report.

**Table 5.1 – Concept Decision Table**

Rating system 1- good 2- average 3- poor

<table>
<thead>
<tr>
<th>Drawings</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<td>3</td>
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<tr>
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<td>1</td>
<td>3</td>
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<td>5</td>
<td>3</td>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>
**Drawing 2**

- **Vest**: Metal rings attached to strap, supports for metal rings go around the body to distribute weight.
- **Strap**: Green so ring sits in, and line so it's vertical.
- **Attach hooks to rings**: Different straps, adjustable length.
- **Note**: Use eyelet type attachments as well.
Drawing 6

- Make changeable for use on other side (same with hook attachment)
- Why not make one piece? Easier to get on?
- Zipper
- Adjustable strap?
- Small shelves to rest objects on
- Shelves retractable, able to move up and down
- Buckle: shelves to...
- Attach loop strap to loop around object and attach here
- Operating button to raise/lower shelves
Harness system

- Buckles for attachments

- Attachments that will tighten on their own

- Attachment w/ single loop

Length should be adjustable

Have buckles cross for better leverage on side w/ no limb.

Back brace support
1. Put an opposite side where it can be used as a second hook.

2. Metal bracing to distribute load throughout vest.

3. Retractable leash (similar to dog leash) attached with locking auto-retract mechanism. Attach harness to box, then lower clip to box. Bend over harness. Bend over retracted leash, hook leash around stand up, vola.

4. Pull down to tighten.

5. Adjustable to keep tight around operator.

6. Fits around one end or corner of box.

7. Could make this a fully system so that things can be lifted with steps.

8. Make straps adjustable or have multiple straps w/different lengths (5)
6.0 Concept Selection

6.1 Data and Calculations for Feasibility and Effectiveness Analysis

In order to research feasibility and effectiveness several steps were taken. “Lifting guidelines provided by the Occupational Safety and Health Administration suggest that a weight over fifty pounds should require a second person” (OSHA, 2007). Objects should be carried between mid-thigh and mid-chest, which is sometimes referred as the “Power Zone” (OSHA, 2007). The guidelines are based off of techniques for able bodied persons. Here is a list of Manual Handling Tasks provided by OSHA.

- Material handling tasks should be designed to minimize the weight, range of motion, and frequency of the activity.
- Work methods and stations should be designed to minimize the distance between the person and the object being handled.
- Platforms and conveyors should be built at about waist height to minimize awkward postures. Conveyors or carts should be used for horizontal motion whenever possible. Reduce the size or weight of the object(s) lifted whenever possible.
- High-strength push-pull requirements are undesirable, but pushing is preferred pulling. Material handling equipment should be easy to move, with handles that can be easily grasped in an upright posture.
- Workbench or workstation configurations can force people to bend over. Corrections should emphasize adjustments necessary for the employee to remain in a relaxed upright stance or fully supported seated posture. Bending the upper body and spine to reach into a bin or container is highly undesirable. The bins should be elevated, tilted or equipped with collapsible sides to improve access.
- Repetitive or sustained twisting, stretching, or leaning to one side are undesirable. Corrections could include repositioning bins and moving employees closer to parts and conveyors.
- Store heavy objects at waist level.
- Provide lift-assist devices, and lift tables.

The following equation was provided by the National Institute for Occupational Safety and Health (Waters, 1994). The NIOSH came up with an equation to evaluate the recommended weight limit (RWL) for a given lifting task. The NIOSH equation for RWL is the following:

\[
RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM
\]

(6.1)

The multipliers for equation (6.1) are shown below in Table 6.1. The frequency and coupling multipliers can be determined by using the tables provided in the Appendix A.3 of this report.
Table 6.1: Equations and Constants for Recommended Weight Limit Equation

<table>
<thead>
<tr>
<th>Variables</th>
<th>Metric</th>
<th>English</th>
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</thead>
<tbody>
<tr>
<td>Load Constant</td>
<td>LC</td>
<td>23 kg</td>
</tr>
<tr>
<td>Horizontal Multiplier</td>
<td>HM</td>
<td>(25/H)</td>
</tr>
<tr>
<td>Vertical Multiplier</td>
<td>VM</td>
<td>1-(.003</td>
</tr>
<tr>
<td>Distance Multiplier</td>
<td>DM</td>
<td>.82 + (4.5/D)</td>
</tr>
<tr>
<td>Asymmetric Multiplier</td>
<td>AM</td>
<td>1 - (.0032A)</td>
</tr>
<tr>
<td>Frequency Multiplier</td>
<td>FM</td>
<td>Appendix</td>
</tr>
<tr>
<td>Coupling Multiplier</td>
<td>CM</td>
<td>Appendix</td>
</tr>
</tbody>
</table>

The NIOSH lifting model assumes the following conditions, which were provided by OSHA:

- Lifting task is two-handed, smooth, in front of the body, hands are at the same height or level, moderate-width loads (i.e., they do not substantially exceed the body width of the lifter), and the load is evenly distributed between both hands.
- Manual handling activities other than lifting are minimal and do not require significant energy expenditure, especially when repetitive lifting tasks are performed (i.e., holding, pushing, pulling, carrying, walking or climbing).
- Temperatures (66-79°F) or humidity (35-50%) outside of the ranges may increase the risk of injury.
- One-handed lifts, lifting while seated or kneeling, lifting in a constrained or restricted work space, lifting unstable loads, wheelbarrows and shovels are not tasks designed to be covered by the lifting equation.
- The shoe sole to floor surface coupling should provide for firm footing.
- Lifting and lowering assumes the same level of risk for low back injuries.
- Using the Guidelines in situations that do not conform to these ideal assumptions will typically underestimate the hazard of the lifting task under investigation.
- This calculation will become important to further research when refining the product in later stages. For now, simple assumptions are made in defining a specific task: To enable a person of average height and strength the ability to lift an 8 ft³ (2 ft x 2ft x 2ft), 50 lb object from the floor with one arm. From there, the person should be able to place the object at a position that is at least waist high.

Unfortunately, the one drawback to the RWL equation is that it is only feasible when analyzing two-handed lifting, not one-handed lifting. Therefore, the RWL equation is not applicable to our project. After further research on the subject of one-handed lifting, there is no standard equation that describes the recommended weight limit. However, many of the guidelines provided by NIOSH and OSHA can help to define the effectiveness of the design and one-handed. The following are aspects of the final design that follow proper lifting techniques described by OSHA and in ergonomic text (Salvendy, 2001):

- The location of the hand when supporting the box should be as close to the body as possible. This criterion is met because the hand location on the box is the corner closest to the hip.
- The ergonomically preferred lifting power done is near when the arm is hanging straight down at the side.

- OSHA defines a proper lift by keeping the back straight up and down, bending at the knees, and lifting with the legs. This criterion is met because the lifting strap requires the operator to lean back, keeping the back straight and tension in the lifting strap, causing the operator to lift with his/her legs.

- Keeping the back straight up and down and tension in the lifting strap will reduce the spinal shearing force which is caused by leaning far forward over the object.

These assumptions can be used to explore the feasibility of a vest with a strap as a lifting assist. It is not necessary to define “waist height” due to the relative position of the vest to the waist. The strength of the fabrics used and the force applied to the person using the vest are discussed in the proceeding paragraphs below.

The assumption has been made that the material of the vest or strap will never be subjected to loads greater than the weight of the object to be lifted. The apparatus is to be designed in order to limit the movement (impact force) of the object being carried while being held through adjustability which is discussed in the final design below. It is impossible based on the laws of physics to support a load at any point and have the reactionary force greater than that of the load. The 1” tubular webbing is rated to safely support 4,200 lbs before failure and is very inexpensive ($0.35/ft). This reveals that our assumed weight of 50 lbs is well within the strength limits of straps and cloths which should translate to a reasonable final prototype cost near the target spec of $100.

Assuming that the object’s weight is evenly distributed and its force is directed vertically, the maximum moment, \( M = r \times F \), would equal half of the maximum radius multiplied by the maximum weight. Taking a box of 2ft x 2ft x 2ft, it longest horizontal radius would be from corner to corner of a horizontal surface of 2ft by 2ft. The values for the radius are shown below in equations 6.2 and 6.3. A free body diagram is also shown below in Figure 6.1.

![Figure 6.1 - Free Body Diagram](image-url)
\[ r_{\text{max}} = \sqrt{2^2 + 2^2} = 2.828 \text{ ft} \]  \hspace{1cm} (6.2)

\[ \frac{1}{2} r_{\text{max}} = 1.414 \text{ ft} \]  \hspace{1cm} (6.3)

Multiplying the maximum load of 50lbs and the assumed radius 1.414ft gives a moment of 70.7 ft·lbs. This is of course considering that all vertical resistance is applied through the strap from the shoulder. Actual simulations using the finished prototype were performed comparing the carrying ability of two able bodied persons. These simulations are outlined in section 7.4 of this report including comments on wearer fatigue. Carrying the same size and weight boxes, two individuals walked side by side, taking the same rest periods, pace and distance covered. One individual utilized the finished prototype vest as described in section seven of this report to carry his box, while the other carried his identical box by hand (two hands).

### 6.2 Concept Screening

Concepts were generated using the 6-3-5 method with prior discussion. Concepts were generated and improved by everyone in the group. Each concept was screened based on feasibility and effectiveness. Our final concept is a combination of many sub-system level concepts. Each sub-system level concept was evaluated and combined into a final system level concept set for development.

Team ME Too understands that goal of this process is not to select the best concept but to develop the best concept. Below are several factors that helped us to develop the best system level and sub-system level concepts with respect to the customer.

**Feasibility and Effectiveness of Final Concept:**

The most promising sub-system level concepts generated during final concept generation were as follows:

**1. Vest Concept**
- Easy to make, can also be purchased for less than $20-$30 from our research
- Vest will most likely be side-entry.
  - This will enable the user to place the vest over his head from the side and enable a one clip fasten after initial adjustment on the 1st wear. Fasteners are still under investigation but most likely and plastic clip in fastener will be used with more Nylon webbing at $0.38/ft.
- Vest will enable user to move comfortably as if he was not wearing a vest at all.
- Vest may require sewing training if we decide to make it. Otherwise very little training will be required to manufacture/purchase/operate.
- Vest will not be time consuming to put on.
- One size fits all adjustable vest can be worn by old/young/large/small people.
- Vest will fit over any regular or work clothing.
2. Strap Lift Concept

- 1" Nylon strap or webbing may be purchased for $0.38/ft
  - We would need about 4 ft or $1.52 per strap
- Strap must have metal ring at the end.
- Very little training will be required to operate.
  - Can be purchased at a hardware store for less than $1.
- Nylon will be easily operated and slid under box based on our testing.
- Strap will not be time consuming to place under the object based on testing.
- Strap may help user lift boxes on to a dolly for mass transport.
  - This would provide compatibility with existing solutions.

Combined, these two main sub-system level concepts will provide an effective solution to the problem. Our final concept should sufficiently fulfill all of our customer requirements and target specifications. If implemented well, this product will enable persons with upper limb loss to lift heavy or large objects in the workplace just as a non-disabled person would.

6.3 Concept Development, Scoring and Selection

The biggest obstacle for a one armed individual to overcome is to pick up and carry larger objects. The obvious problem is not having a second limb to assist in lifting an object like an able-bodied person would. To compensate for this, a strap can be used to lift and support an object opposite the good arm. The strap could have a number of different attachments that could hook directly to the vest including a metal loop or swivel hook. The individual would use their arm to place the strap around one corner or side of an object. Once the strap is in place, the individual would then latch the strap to the vest and grab the other side of the object and simply stand up. The strap actually supports most of the weight making the strain on the arm significantly less. However, lifting an object that is out in front of the person puts strain on the shoulders and lower back, therefore adjustability will be built in so that the object is lifted from close proximity.

Initial concept development conclusions:

The strap would be attached to a vest that the individual would be wearing. The vest could be a full vest of solid material, or could simply be straps such as a climbing harness. The lifting strap would be attached to the vest in a position that puts the least amount of strain on the individuals back when lifting. Also, the back of the vest could have a rigid back support for additional support. This support could be in the form of a thick belt around the waist similar to a weight lifting belt or a plastic piece that takes the shape of the lumbar. The vest must be easy for the individual to change into and out of. This would most likely be determined by where the strap attachment point would be and how the strap would be attached to the vest. For example, if the vest is zippered, the placement of the zipper would have a big impact on the ease of use.

Further concept scoring and design selection information was included in detail in section five above for the 6-3-5 generation method, including concept drawings and weighted decision matrices. Final concept development is outlined and described extensively in section 7 below.
through the use of design tools such as FMEA, DFMA, sourcing, compatibility, design materials and testing as well as cost analysis.

7.0 Final Design

The original design of the vest incorporated the use of two shoulder straps so that persons missing either arm would be able to wear the vest. The original vest design worked well, but it was noticed that the spare shoulder strap was unnecessary and made it harder to put the vest on. This gave rise to a new design that uses only one shoulder strap that crosses over the back and over the chest. Both vest designs were presented to the customer and a decision was made based off of the customers input, as well as group members input, to go with the newly designed vest with one shoulder strap. Our customer said, that “both vest were comfortable and easy to put on, but the new vest with one shoulder strap was better, less cumbersome, and more comfortable”.

Hardware Sourcing

FMEA

FMEA was completed on a few aspects that had to do with the hardware. The first was the spring failure within the bolt-snap. The occurrence of this was reduced by buying from Strap Works. They sell for continuous and rigorous use applications so the spring fatigue failure is very unlikely. The concern that debris could jam the bolt-snap is always possible, however, Strap Works is known for selling their products for many dirty/outdoor applications and the bolt-snaps are meant for this abuse.

Economics/Value

Price was a very important consideration. Extensive price comparisons were done in various markets (Lowes, industrial suppliers such as McMaster, and online companies). Strap Works had one of the lowest prices even with shipping. Also, they deal with both small orders and bulk orders; and the offer a quantity discount for future manufacturing purposes. Strap Works is a certified secure site by Volusion SSL which removes the concerns from buying online. Also, they sell to numerous major organizations such as N.A.S.A., Nike, the U.S. Armed Forces, Target, and the F.B.I. This showed that Strap Works was a secure reputable place to source parts in the lot sizes we needed, as well as the prices we could afford while still staying at or below our planned budget.

DFMA

Assembly was a big concern in this area. The hardware had to work with the straps that we were using. Strap Works carries all the types of straps that we wanted to use and all of their hardware is meant to be used with the selected straps. This ensured that the hardware was compatible with our straps and assembly proved to be problem free.

Testing

Numerous tensile tests were completed to determine if the strength of the hardware was adequate. All tests showed that the stitching and hardware had similar ultimate strengths and that these breaking strengths were much higher (greater than 1000 lbs) than the operating load of
50 lbs. These tests showed that the material and products used by the supplier were acceptable. Table 7.1 shows the results of our tensile testing. The straight stitch, X-pattern, bolt snap and D-ring are worthy of noting for this section.

**Loop Attachments**

**FMEA & Testing**

The lifting strap component of the assembly provides the means for lifting the objects. Initial FMEA analysis has been done for a number of the conceptual designs and a few have been constructed and tested. The basic design for the lifting strap is a simple loop attached at the shoulder which is placed around the object being lifted. The second version of the lift strap that was constructed was a simple loop with a stainless steel piece connected to the bottom. The steel was shaped like the corner of a box so that it would provide a flat rigid surface for square objects to sit on.

<table>
<thead>
<tr>
<th>Test</th>
<th>Max Load (lbf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight Stitch</td>
<td>3429</td>
</tr>
<tr>
<td>X-Pattern</td>
<td>5191</td>
</tr>
<tr>
<td>0.25 inch cut</td>
<td>&gt;1000</td>
</tr>
<tr>
<td>0.5 inch cut</td>
<td>&gt;1000</td>
</tr>
<tr>
<td>0.75 inch cut</td>
<td>900</td>
</tr>
<tr>
<td>3 - 0.5 inch cuts</td>
<td>890</td>
</tr>
<tr>
<td>Bolt Snap</td>
<td>&gt;1000</td>
</tr>
<tr>
<td>D-Ring</td>
<td>865</td>
</tr>
</tbody>
</table>

Regardless of which loop design is used, the lifted object will induce substantial stresses within the strap and for that reason it was important to determine the possible failure modes the strap would encounter and the effect of those failures on the user. The main failure mode examined was the strap fracturing due to a heavy load. Through tensile testing of the strap material it was found that the strap only fails at loads unachievable under normal loading conditions. Once it was determined that a defect free strap could hold the load, we analyzed the effect of defects on the strap. We determined that the most likely defects that could be imposed upon the strap which would have the greatest impact would be a laceration of the strap or the failure of the strap due to continual wearing.

We were able to justify the performance of our tensile tests because the cost of 1 inch nylon tubular webbing was only around $0.30/ft. This is the strap we will be using for the lifting strap. 2 inch nylon tubular webbing will be used for the vest at around $0.60/ft. All tests were
performed on the 1” strap, as long as the 1” strap withstood the testing, because the 1” strap is the weaker of the two straps.

Once again, the results of the tensile tests are listed in Table 7.1. The first two stitch patterns were tested to failure, while the remaining tests were performed up to 1000 lbf, where the test was stopped if the specimen had not failed. Below the stitching results in Table 7.1, are the strap strength results with varying cuts in the strap. We tested a .25” cut, a .5” cut, a .75” cut, and 3 x .5” cuts on various straps. We also tested the strength of our current bolt snap and D-Ring. As seen from our testing results, the lowest tensile strength of any of our tested materials was the D-Ring, with a tensile strength of 865 lbf, 16 times more than our recommended lifting weight. Because of this, we have determined all our components will be strong enough to withstand numerous lifting operations.

Testing revealed that even with 3 alternating half inch cuts in the strap, the strap still withstood 890 lbs. Also with a .75” cut in the strap, 75% of the way through, the strap still held 900 lb. These two results allow us to conclude that wear on the strap is not a significant factor as long as we continue to use at least 1” tubular nylon webbing. The user would be able to easily identify if 75% of the strap was cut and would be able to have it replaced or repaired. Figure 7.1 shows how the lifting strap will be used. It can be observed how the strap could potentially wear over time with multiple lifts.

![Figure 7.1: Lifting Strap In Use](image)

When the user is lifting an object with the strap, it has been observed that there is a tendency for the strap to slip off of the object and pose a threat to the user. Not only would the strap pose danger to the user but the falling object could harm the user or the object itself. For these reasons, the main focus of the strap design has been ensuring the strap stays on the lifted object and to prevent any possibility of it slipping off. To cope with the slippage problem, a rubberizing agent was used on the original strap design where the strap comes in contact with the
object. This rubberizing agent also helps with the wear-ability of the strap over time (this will be explained in more detail in the lift-strap coating section). As discussed earlier, the stainless steel metal piece was incorporated into the second strap design to provide a sturdy seat for the load (see Figure 7.12 below).

**Economics/Value**

Considering the wide range of objects that a user would have to lift in the workplace, a single lifting strap system that could be used for all possible cases would be impossible to design. The simple loop strap has shown to be effective with a wide array of objects but specialized lifting attachments would have to be constructed for specific applications. For this reason it is important to keep the price of the lifting straps low to allow for the users to easily purchase the lifting strap they would need without having to spend much money. The loop strap and the strap with the angle attachment both have shown to be extremely inexpensive to manufacture both in material costs and in construction time.

**DFMA**

To keep the cost down on the lifting attachments, the manufacturing cost had to be kept at a minimum. The two lifting systems currently developed both are very easy to construct. The loop only system has just one stitching operation to the bolt snap and a rubber coating operation and if all materials are readily available can be assembled in less than 5 minutes. The loop-metal system has two stitching operations, a rubber coating operation, and a metal fabrication operation so it will obviously take substantially longer to build. Even with these extra steps, the strap could be ready in less than 20 minutes. Both attachments also utilize similar hardware so purchasing in bulk becomes an option. The cutting and sewing points are easily plotted out and are kept to a minimum to allow quick assembly.

**Stitching Aid**

It was noticed soon after our concept was developed that stitching would be an intricate part in our design. Because of this, we thought there was a need for a stitching aid which would provide consistent dimensions and spacing for stitching throughout the vest. This would provide a quality product with an aesthetic advantage.

The advantage of this device would be to increase production rate and concepts were sketched on the basis of functionality and ease of use. Once concept had a jig that held two straps together while some type of marking tool (marker, spray-paint, etc.) would mark out a 1’’ x 1.25’’ “X” pattern stitch.

Since this jig was not designed to hold the straps in place during the stitching process, something else was needed to hold the two straps in place after the pattern was marked. This is where a fatal problem arose. There was not a feasible way to do this, which is why this concept was not taken to production or ever used for our prototypes, and is also why detailed assembly instructions and drawings are needed (see section 7.2 for more detailed information).
**Thread Selection**

Thread is a critical component linking together all the vest materials and was a major design decision. The selection of tubular nylon strap components, lifting support belt, nylon shoulder pads and various size metal hardware components were also major considerations in terms of vest design. The use of tubular nylon straps and the selection of them based on their strength properties proved as a starting point in researching the proper thread to bring the whole vest together. The first trials were with T-69 density thread which is typically used in heavy use applications. Heavier threading such as T-90 was considered but not as readily available at Ohio University Upholstery as the T-69 material was. This T-69 nylon thread is very strong with a tensile strength of 11 lbs. per fiber and had an elastic elongation of nearly 25%; these were the first two selection criteria for which the thread was chosen. This material was dense enough to provide a strong connection of the tubular nylon webbing to itself. Some other threading was considered, mainly polyester and Kevlar threading. These material fibers can be compared in Figure 7.2 copied from the book *On Rope* (Padgett, 1996).
The book *On Rope* is a widely referenced source of information regarding mountain climbing equipment selection and use. The chart above shows that overall, the abrasion resistance, tensile strength, possible elongation, flexing endurance, and resistance to sunlight and water are all key considerations when choosing threads. Extreme environments are tolerable for this material and the possibility of acids during normal use is slim. The cost of the nylon threading is about $15 per pound while threads such as Kevlar and spectra are much more expensive at around $120 per pound, as advertized. Therefore, the lowest cost alternative was chosen in that the nylon threading would be utilized and the stitching pattern would be chosen and optimized accordingly. Additionally, the thread chosen is compatible with rubberized coatings which will be used to combat wear and/or increase friction.

It was also shown in the lab via tensile testing that the threading was able to elongate well and return after large amounts of force were applied. Two different stitching patterns were tested based on commonly used methods in industry and the results were shown in Table 7.1. The first
was the bar tack pattern. This pattern achieved a maximum of 3500lb in tension in a tensile test of a 6” section of stitched tubular nylon strap and appears in Figure 7.3 below. Also the box with an X pattern was tested with an identical 6” section and achieved a maximum of 5100lb in tensile testing and appears in Figure 7.4 below.

Continued testing will be performed on the vest components and their stitching. These connections will be further optimized so that the minimum number of stitched passes can be used while still ensuring adequate factors of safety for the loads being lifted, shock force (impact) and flexing endurance in use.

**Stitching Pattern Decisions**

Per the tensile testing results, both X-pattern and straight stitching will be used on the strap and vest depending on where the stitch is located and where the forces act on it. Cross stitching will be used in the back of the vest where the most force will be pulling on the stitching, and it could be coming from multiple angles depending on the angle of the strap. Straight stitching will be used everywhere else to reduce assembly time and cost.

**Value Engineering**

Value engineering was applied to the stitching patterns used on the vest and focused on the function of the stitching. Excess or redundant stitching was removed from the vest because it was shown that the stitching was extremely strong relative to the loads that will be applied. Value engineering was also applied to the different stitching patterns. The bar stitching was used in areas where loads were not extremely high and in areas with limited space. This eliminated a lot of excess stitching throughout the entire vest. The cross pattern was used only in areas of high stress, because of their resistance to wear and excellent strength. The downside of the cross pattern is the amount of thread used and the increased time it takes to perform the stitch. Finally, value engineering was used to determine how many passes were used. At least two passes had to be used in order to prevent unraveling or fraying, but more passes could be used for increased strength. One of the areas where increased passes could be used is where the lifting strap is connected to the shoulder strap. Minimal passes were used for the cross pattern due to strength advantages already discussed.
DFMA

DFMA was applied to the stitching pattern to help decide what pattern should be used in different locations throughout the vest. Areas under high stress, or any area with twisting or bending, required cross pattern stitching. This pattern had to be used in these situations because it is much stronger than the bar pattern, however, the cross pattern was avoided as much as possible because it was more difficult to stitch and required more skill to assemble. The bar pattern is a stitch that was used frequently because it was easy to stitch, required little stitching time, and is adequate for the design.

Lift-Strap Coatings

The initial design of the lift-strap called for a single loop that would wrap around one corner of a box or one end of a load and assist the user in lifting the box or load. Through the use of our first mock up and prototype, we found early on that the coefficient of friction between the nylon strap and a smooth surface such as cardboard was not high enough to always keep the strap secured to the load, and strap slippage was observed. The slipping resulted in one of three things: the user was unable to use our vest for its intended purpose of lifting loads, the load slipped out of the strap when being carried, or the load slipped out of the strap due to a minor collision or external disturbance. The first result obviously was undesirable and the latter two results were determined to be detrimental to user safety and load security; improving the coefficient of friction of the nylon strap became a high priority.

One of the solutions we found was to coat the strap (mainly the portion that came in contact with the load) with some kind of rubber coating. After contacting several companies who deal with rubber coatings for floors, stairs, boat products, etc., it was discovered that many of the rubber or plastic coatings were not compatible with the nylon strap and they would weaken or damage it. Most of these companies also dealt with large applications such as floors, and it was hard to get a small enough quantity for our group’s purposes. These problems were eliminated when we found Rubberize-It Grip Dip from a company called Homax. The dip comes in smaller canisters (15 fl. oz.) which allowed us to apply it to our vest without wasting a lot of unused product. The dip also has not been found to cause damage to nylon or other rope materials. A picture of the product is shown in Figure 7.5.

Figure 7.5: Homax Rubberize-It Grip Dip
www.homaxproducts.com
From a functional standpoint, the grip dip serves our original purpose of increasing the friction between the strap and the load, but it also adds another valuable aspect. According to the product description, the grip dip “provides water, salt, and acid resistance” (Homax, 2008). Due to the added layer of protection, the coating should definitely increase the life of the strap.

The Homax coating also suits the project for a few other reasons; it is cheap, readily available through Homax or other distributors, and easy to apply. The approximate cost of a 15 oz container is $10/can. It is estimated that with that size can, approximately 10-20 of the original designed straps could be coated, resulting in a cost of less than $1/strap. With the new loop-metal strap design, much less is needed (approximately 1Tbs/strap), and that would allow us to coat around 31 straps, for a total of $0.33/strap. This extra cost would not be a significant increase in our manufacturing costs for either strap, and should hardly affect our overall vest price. The application of the coating is a simple process of either dipping or brushing on. Dipping the straps will be the easiest and most efficient way for our straps to be coated.

There are some concerns with the manufacturability of the coating. One concern is the drying time needed once the strap has been dipped. According to Homax, the product should be allowed to dry (at 70°F) approximately 4 hours for handling and a full 24 hours for normal use (Homax, 2008). Another manufacturability concern is the repeatability of the dipping process and coating thickness. If the coating is applied too thin, some of the “grip” may be lost, or the strap may show through allowing unnecessary wear. If the coating is too thick, we will be wasting the coating, increasing the overall cost of our vest. A coating that is too thick will also reduce the flexibility of the strap resulting in some lost functionality.

In conclusion, the Homax grip dip has shown that it has a high potential to increase the overall value of our vest. It should accomplish this by increasing user and load safety and by increasing the strap-life by providing a protective coating against unwanted damage. The grip dip has also shown to be an economical solution that is easy to apply and readily available.

Vest Layout

Ergonomics/Value

When dealing with the human body, ergonomics are important to ensure the user is safe and the operation causes as little impact on the user as possible. For this specific project, value is also highly important since this system would either be purchased by a disabled person or an employer, both of which are looking to spend the least amount of money on acquiring the vest. The vest will only be successful if it can be offered at a low enough cost and provide a significant advantage over the current way of lifting. To deal with both ergonomics and value many design specifications have been taken into account.

Initially, the layout of the vest consisted of a weight belt with two shoulder straps attached. The shoulder straps provided the lifting anchors and the straps were mounted to the weight belt where the most lift force was applied. Through prototype testing, it was found that one of the straps could be removed without causing any detriment to the functionality of the system. The shoulder strap was also altered from being directly sewed to the vest in the back to being
attached via a D-ring. The presence of the D-ring attachment allowed for one vest to be worn by a person with either right-side or left-side upper limb loss.

Also when dealing with the human body, there are a wide range of sizes and shapes to take into account. To deal with this wide range, numerous points of adjustability were incorporated to allow the user to customize the vest to the maximum comfort level (this will be addressed more in the adjustability section). There was concern about the wear-ability of the vest with female users, but feedback from two very differently shaped female classmates showed that the vest allowed for all sizes and gender of people. Additionally, padding was placed about the shoulder strap in order to distribute the forces imposed on the strap by the lifted object. The collar bone and shoulder plate were two areas of concern and points where the stresses of a lifted load would be concentrated. The addition of the padding removes and distributes the loads more evenly across the entire area of the shoulder as opposed to a select few spots.

FMEA

Many of the failure modes for the vest were common across the entire assembly. The main concern for failure was the stitching points and it was discussed earlier in the thread selection and stitching pattern decisions sections. There was also a chance that the shoulder strap would slide off of the user during use. To prevent this from happening, the strap starts in the middle of the users back and is crossed over the useable shoulder and then down across the chest to the opposite side, where it attaches to the back-support belt. This ensured the strap would remain where the user needed it to be.

During initial tests, it was observed that users had trouble with attaching the lifting straps to the vest anchor points. The D-rings would lie flat against the shoulder straps and it was difficult to clip the straps onto them. To deal with this, a strap wider that the D-ring was threaded through the D-ring and the folding of the wider strap would cause the D-ring to stand up perpendicular to the shoulder strap. This allowed the lifting attachments to be easily attached to the vest.

DFMA

To keep the cost of the system down, special care was taken when considering manufacturing. All aspects of the construction allow for uniform and inexpensive parts and simple sewing. The geometry of the vest is simple and the only cuts that have to be made to the straps are simple and straight forward allowing for less confusion and quicker assembly.

Adjustability

Adjustability refers to all mechanisms on the vest that makes it adjustable for different size customers. The vest design includes one shoulder strap that could be adjusted by using two 3-bar slides shown in Figure 7.6, one in the front and one in the back. There was no FMEA taken into consideration for the 3-bar slide because they are not load bearing. The 3-bar slides are designed to keep the shoulder straps from loosening as well as shortening and extending the length of the strap. The cost analysis for the 3-bar ring shows that it would be cheaper to outsource the hardware instead of manufacturing them. Having two 3-bar slides on the shoulder
strap allows the user to adjust the vest to their size making the vest adjustable to fit the majority of the population. A third 3-bar slide is used on the lifting strap to make it adjustable for different size boxes.

**Figure 7.6 - 3-Bar metal slide. Image provided by MSC Industrial Supply Company.**

Another design feature on the lifting vest that makes it adjustable are the guide straps located on the support belt that hold the shoulder strap in place. The guide straps are 7 inches in length which gives room for the shoulder strap to move. The guide straps are shown in Figure 7.7. The purpose of the guide straps is to give the customer room to move the shoulder strap from side to side until they are comfortable with the fit.

**Figure 7.7: Guide strap on support belt. Located on inside and outside of belt.**

The last design feature that makes the lifting vest adjustable is the support belt. The support belt comes in four different sizes ranging from small to extra large. Each belt size can be adjusted to fit a certain range of waists shown in Table 7.2.

**Table 7.2: Support belt sizes.**

<table>
<thead>
<tr>
<th>Sizes</th>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
<th>X-Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waist Sizes (in)</td>
<td>22-29</td>
<td>30-36</td>
<td>37-43</td>
<td>44-51</td>
</tr>
</tbody>
</table>
7.1 How does it Work?

Before using the lifting vest the customer must first be aware of the hazards when lifting objects. Failure to comply with these regulations could result in serious injury to the back, spine, or other muscles.

- Support belts do not prevent injury when lifting objects heavier than the recommended weight limit.
- Do not attempt to use the lifting vest if you already have back problems as this could cause further injury.
- Lifting objects heavier than the customer’s ability could result in back injuries.
- The customer must also perform correct lighting techniques recommended by OSHA.

To use the lifting vest the shoulder strap (indicated by the letter A in Figure 7.1.0) must first be placed on the correct side of the support belt. The shoulder strap should be placed on the same side of the support belt as the customer’s disabled arm indicated in Figure 7.1.0. For example, if the left arm is disabled than the shoulder strap should be placed on the left side of the support belt.

![Shoulder Strap](image)

**Figure 7.8: Orientation of Shoulder Strap**

To secure the shoulder strap to the support belt there are two guide straps shown in Figure 7.9, D on the inside and outside of the support belt. The guide straps are located on both the left and right side of the support belt and are held in place by Velcro shown in Figure 7.9, H and I.
Once the shoulder strap is in the correct position the user can now put on the vest. First undo the support belt strap if not already done so shown if Figure 7.10. Then pick up the vest and place the shoulder strap on the same arm that you picked it up with by lifting the shoulder strap over the head. For example, the correct wearing position of the lifting vest for users with left arm disabilities is shown in Figure 7.8.

After the lifting vest is placed on the shoulder the support belt strap can be secured by feeding the strap through the plastic ring on the support belt and pulling back on the strap to tighten the belt. The support belt strap is held in place by Velcro. The tightness of the support belt can be determined by user comfort. It is suggest that the support belt not be too loose causing the belt to ride up the back of the user when lifting.

At this point, the lifting vest should be adjusted to fit the user comfortably. There are two slide adjustors on the front and back of the shoulder strap that can be lengthened and shortened to fit the user’s size shown in Figure 7.9, L. This step may need to be repeated until the user is satisfied with the comfort level keeping in mind that the D-ring on the shoulder strap needs to be positioned at the top of the shoulder shown in Figure 7.11, K.
After all the adjustments have been made to the lifting vest the user can now prepare the lifting strap. The lifting strap shown in Figure 7.12, E, can be adjusted using the slide adjustor shown in Figure 7.12, M, to lift various sizes boxes.

**Figure 7.11: Shoulder strap D-ring position.**

**Figure 7.12: Lifting strap and components.**
To lift a box, the user first attaches the lifting strap to the lifting vest using the bolt snap shown in Figure 7.11, N, and the D-ring shown in Figure 7.11, K. The metal attachment on the lifting strap shown in Figure 7.12, O, is placed under the opposite corner of the box farthest away from the lifting arm shown in Figure 7.13. The user’s hand is then placed under the corner of the box closest to the body shown in Figure 7.13. Finally, the user can lift the box remembering to keep the back strap and lifting with the legs.

Figure 7.13: Lifting strap and hand location.
7.2 How is manufactured and assembled, and what does it cost?

The manufacturing run for the lifting vest will be for 1000 units. For the production run the cost for materials per vest was $28.61. The cost breakdown for the components is listed below in Table 7.3 – “Materials” along with the estimated labor costs are shown in Table 7.5 “Labor and Overhead” for the manufacturing procedures. Most parts used for the construction of the vest are parts sourced from supply companies. The two major manufacturing procedures are the cutting of the straps and the machining of the angle piece. The dimensions and tolerances needed for each of the manufactured parts are shown on the drawings. All tolerances for sourced parts are taken from their prospective manufacturers. The vendor sources are located in Table 7.4.

<table>
<thead>
<tr>
<th>#</th>
<th>Part</th>
<th>Material Description</th>
<th>Cost (per Vest)</th>
<th>Qty</th>
<th>Total</th>
<th>Vendor #</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lifting Strap</td>
<td>1” Tubular Webbing</td>
<td>$0.23 /ft</td>
<td>10 ft</td>
<td>$2.30</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Shoulder Strap</td>
<td>2” Tubular Webbing</td>
<td>$0.78 /ft</td>
<td>7 ft</td>
<td>$5.46</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Velcro Anchor</td>
<td>1” Velcro</td>
<td>$0.50 /ft</td>
<td>1 ft</td>
<td>$0.50</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Lifting Strap Clip</td>
<td>1” Metal D-Ring w/ Square Corners</td>
<td>$0.32</td>
<td>1</td>
<td>$0.32</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Lifting Strap Anchor</td>
<td>2” Metal D-Ring</td>
<td>$0.31</td>
<td>1</td>
<td>$0.31</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Shoulder Strap Adjustment</td>
<td>2” Metal Slide</td>
<td>$0.27</td>
<td>2</td>
<td>$0.54</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>Lifting Strap Slide</td>
<td>1” Stainless Steel Slide</td>
<td>$0.81</td>
<td>1</td>
<td>$0.81</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Lifting Strap Clip</td>
<td>1” Metal Bolt Snap</td>
<td>$1.03</td>
<td>1</td>
<td>$1.03</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>Shoulder Pad</td>
<td>220&quot;x220&quot;x1/4&quot; Shoulder Pad Foam</td>
<td>$0.15</td>
<td>1</td>
<td>$0.15</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>Shoulder Pad</td>
<td>60&quot;x45&quot; Shoulder Pad Fabric</td>
<td>$0.21</td>
<td>1</td>
<td>$0.21</td>
<td>3</td>
</tr>
<tr>
<td>11</td>
<td>Belt</td>
<td>4” Weight Lifting Belt</td>
<td>$13.80</td>
<td>1</td>
<td>$13.80</td>
<td>4</td>
</tr>
<tr>
<td>12</td>
<td>Lifting Strap Angle</td>
<td>6&quot;x6&quot;x1/8” Stainless Sheet Metal</td>
<td>$3.18</td>
<td>1</td>
<td>$3.18</td>
<td>5</td>
</tr>
</tbody>
</table>

**Total Material Cost (1000):** $28.61

<table>
<thead>
<tr>
<th>Vendor #</th>
<th>Vendor</th>
<th>Website</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Strapworks</td>
<td><a href="http://www.strapworks.com">www.strapworks.com</a></td>
</tr>
<tr>
<td>2</td>
<td>Efoam store</td>
<td><a href="http://www.efoamstore.com">www.efoamstore.com</a></td>
</tr>
<tr>
<td>3</td>
<td>JoAnn Fabrics</td>
<td><a href="http://www.joann.com">www.joann.com</a></td>
</tr>
<tr>
<td>4</td>
<td>Ultra Home Store</td>
<td><a href="http://www.ultrahomestore.com">www.ultrahomestore.com</a></td>
</tr>
<tr>
<td>5</td>
<td>McMaster Carr</td>
<td><a href="http://www.mcmaster.com">www.mcmaster.com</a></td>
</tr>
</tbody>
</table>
Table 7.5 Labor and Overhead

Cost Details for Vest Subassembly (1000)

<table>
<thead>
<tr>
<th>Operation 1: Cut 12&quot; sheet metal in half. Stamp out 1&quot; slots at ends. Bend corners up. Grind and deburr edges. Rubberize slots to further reduce sharp edges. Inspect and cleanup.</th>
<th>Operation 2: Cut all webbing to respective lengths. Feed 2&quot; webbing through Metal Slides, D-rings, and Shoulder Pad. Pin together first, then stitch. Feed 1&quot; webbing through Metal Slide, Bolt Snap, and Metal Corner Piece from Operation 1. Pin and stitch 1&quot; strap. Inspect and cleanup.</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Total time to complete operation(s) in hours</td>
<td>0.25 hour per vest</td>
</tr>
<tr>
<td>b. Labor rate for the operation</td>
<td>$15/hr</td>
</tr>
<tr>
<td>c. Labor cost = a x b</td>
<td>$3.75</td>
</tr>
<tr>
<td>d. Basic overhead factor</td>
<td>1</td>
</tr>
<tr>
<td>e. Equipment factor</td>
<td>0.5</td>
</tr>
<tr>
<td>f. Special operation/tolerance factor</td>
<td>0</td>
</tr>
<tr>
<td>g. Labor/overhead/equipment cost = c x (1+d+e+f)</td>
<td>$9.38</td>
</tr>
<tr>
<td>h. Purchased materials/components cost</td>
<td>$3.18</td>
</tr>
</tbody>
</table>

Total Vest Cost = **$90.77**

This cost method was used because the duration of the operations is very short and without initial time studies when multiple vests are manufactured, the exact time breakdown could not be determined with certainty any further than shown in the above table.

Vest Assembly Protocol:

Reference All “Part ID” Letters stated here in Table 7.7 – “Master Parts List” below

1. Both the 1” and 2” straps are cut to the specified lengths shown in Table 7.6. Each cut must be made with a hot strap cutting blade with the cut perpendicular to the length of the strap.

Table 7.6: Strap length and Quantity

<table>
<thead>
<tr>
<th>Material Length (in)</th>
<th>2 inch strap</th>
<th>1 inch strap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>75</td>
<td>6.5</td>
</tr>
<tr>
<td>Part ID</td>
<td>A</td>
<td>B</td>
</tr>
</tbody>
</table>

2. Align the support belt “F” on a table with the inside facing down. The belt should be parallel to the edge of the table. The Velcro strap on the belt should be pointing to the right.
3. Pass “B” through “J”. The Strap should then be folded around the flat side of the D-ring back onto itself.
4. Assembly “B” and “J” should be pinned in the center of the belt measured from one end of the belt. The looped section of the strap should be oriented perpendicular to the length of the support belt and with “J” fully protruding from the edge of the support belt.

5. Take “A” measure 37.5” to the midway point and mark with chalk pencil.

6. Pass “C” through “K” bending the strap so that when “C” is placed flat on the table the D-ring stands vertically.

7. Pin assembly “C” and “K” to “A” at the marked midway point with the D-ring oriented such that it is perpendicular to the length of “A”.

8. Pass one end of “A” through one of the 2” slides “L”. Position the slide so that is approximately 12” from the end of the edge of the 75” strap. Pass the end of the 75” strap with the slide on it through “J” on the support belt. Fold the end of the 75” strap that was passed through the D-ring back onto itself. Thread the doubled over portion of the strap back through the 2” slide and leaving only 1” end hanging out of the slide. Fold the 1” end back onto itself and pin.

9. Pass the free end of the 75” strap through the loops on the shoulder pad “G” and position the pad so that “K” is in the middle. Complete the same procedure as in 8 with the other end of the 75” strap but do not pass the strap through a D-ring. After completion, there should only be one end of the strap attached to the support belt and the free end with a loop in it.

10. Take two of the 7” sections “D” and place them at either end of the padded portion of the support belt each with their edges 1” from the edge of the support belt and their lengths parallel and centered to the length of the support belt.

11. Pin the edges of “D” closest to the end of the support belt.

12. Pin a male section of the Velcro “H” to the underside of the unpinned end of “D” and pin the matching female section of the Velcro “I” to the support belt where the male section lies. Repeat this procedure for the other 7” section.

13. Turn the support belt over and mirror steps 10-12 for the remaining two “D” sections on the other side of the support belt.

14. Pass “E” through “N”.

15. Pass one end of “E” through “M”.

16. Manufacture the Stainless Steel piece “O” to the specifications detailed on the part drawings.

17. Use the rubber coating to coat either end of the steel piece. Let dry completely.

18. Pass both ends of the 1” strap through either end of the angled stainless steel plate. One end should be pinned back onto itself with 1” of the end used for sewing (Box/X pattern) and the other end needs to be passed back through “M” and pinned back onto itself.
### Table 7.7 Master Parts List:

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Dimensions</th>
<th>Quantity</th>
<th>Part ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>2&quot; Strap</td>
<td>Shoulder Strap Section</td>
<td>75&quot;</td>
<td>1</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>Section to hold D-ring to support belt</td>
<td>6.5&quot;</td>
<td>1</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>Section to hold D-ring to shoulder strap</td>
<td>2&quot;</td>
<td>1</td>
<td>C</td>
</tr>
<tr>
<td>1&quot; Strap</td>
<td>Section for Velcro adjustment straps</td>
<td>7&quot;</td>
<td>4</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Section for main lifting strap loop</td>
<td>92&quot;</td>
<td>1</td>
<td>E</td>
</tr>
<tr>
<td>Back Support Belt</td>
<td>Medium (30-36&quot;)</td>
<td></td>
<td>1</td>
<td>F</td>
</tr>
<tr>
<td>Shoulder Pad</td>
<td></td>
<td></td>
<td>1</td>
<td>G</td>
</tr>
<tr>
<td>2&quot; Velcro - male</td>
<td>Connecting Pieces for adjustment straps</td>
<td>2&quot;x2&quot;</td>
<td>2</td>
<td>H</td>
</tr>
<tr>
<td>2&quot; Velcro - female</td>
<td>Connecting Pieces for adjustment straps</td>
<td>2&quot;x2&quot;</td>
<td>2</td>
<td>I</td>
</tr>
<tr>
<td>D-rings</td>
<td>Ring shoulder strap connects to</td>
<td>2&quot;</td>
<td>1</td>
<td>J</td>
</tr>
<tr>
<td></td>
<td>Ring lifting strap connects to</td>
<td>1&quot;</td>
<td>1</td>
<td>K</td>
</tr>
<tr>
<td>Metal Slides</td>
<td>Adjustment for shoulder strap</td>
<td>2&quot;</td>
<td>2</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>Adjustment for lifting strap</td>
<td>1&quot;</td>
<td>1</td>
<td>M</td>
</tr>
<tr>
<td>Bolt Snap</td>
<td>Connects lift strap to vest</td>
<td>1&quot; square end</td>
<td>1</td>
<td>N</td>
</tr>
<tr>
<td>Corner Attachment</td>
<td>Connects to the main lifting loop strap</td>
<td>9&quot;x2&quot; flat</td>
<td>1</td>
<td>O</td>
</tr>
</tbody>
</table>
Assembly drawings shown below were created using Solid edge screen shots in order to show in color, part contrasts in greater detail. While created in Solid Edge they are not traditional Solid Edge Part Drawings with borders but shown in this manner in order to achieve the views desired by the designer / manufacturer. During the drawing selection process, the contrast in effectiveness of design conveyance was readily apparent and supported our decision.

**Assembly Drawing #1: Belt Outline: (Back View)**

Belt Outline Notes:
1- Datum of reference is lower left corner.
2- All drawing tolerances +/- 0.1 inches.
3- Coloring: Belt is white and attachments are all yellow in contrast.
4- All part IDs are showing and referenced in the “Master Parts List” above.
Assembly Drawing #2: Shoulder Strap Assembly: (Top View)

Shoulder Strap Assembly Notes:
1- Datum of reference is lower left corner.
2- All drawing tolerances +/- 0.1 inches.
3- Coloring: Belt is white and attachments are all yellow in contrast.
4- All part IDs are showing and referenced in the “Master Parts List” above.
For complete assembly details of corner attachment piece, please reference both Assembly Drawings #3 and #4.

**Assembly Drawing #3: Flat, Stamped Corner Attachment: (Top view)**

Flat Stamped Corner Attachment Notes:
1. Datum of reference is lower left corner.
2. All drawing tolerances +/- 0.1 inches.
3. Coloring: Belt is white and attachments are all yellow in contrast.
4. All part IDs are showing and referenced in the “Master Parts List” above.
5. Slot widths are 0.25 in.
Assembly Drawing #4: Bent, Stamped Corner attachment: (ISO view)

Bent, Stamped Corner Attachment Notes:
1. Datum of reference is lower left corner.
2. All drawing tolerances +/- 0.1 inches.
3. Coloring: Belt is white and attachments are all yellow in contrast.
4. All part IDs are showing and referenced in the “Master Parts List” above.
5. Bends are to be 90 degrees.
6. Slot widths are 0.25 in.
7.4 Design validation through test results and operating experience

Once the prototype vest was manufactured, testing needed to be done to determine how effective the design actually was. As discussed earlier, strength tests were done on all of the materials to insure safety when lifting. These results showed that all materials were strong enough to sustain the lifting loads; an unsafe situation due to material failure was no longer a concern. Preliminary tests were done to determine the functionality of the vest.

Multiple group members tried the vest on using only one arm and proceeded to pick up multiple boxes. All users found that putting the vest on and adjusting it using only one hand was not a difficult task, taking less than a minute. Also, each user was able to pick up all the boxes present with no problem. Picking the boxes up took approximately 50% longer than it would take to pick them up using both hands. In the group members’ opinions, the vest was more effective than expected in picking up boxes and was also very comfortable.

That test, however, was just preliminary and more controlled testing had to be done. The first was to get our customer, Dan, to use the vest. Three different size boxes were prepared for Dan to lift; a large 15 pound, a medium 30 pound, and a small 45 pound box. Dan was observed picking up these boxes as he usually would without the assist of us or any devices; that is, by pinning the boxes against his leg, and shimmying them up to carrying height. This process takes about 30 sec. He was able to pick the large box only half way up to carrying height and was unable to walk with it. The medium box was lifted to carrying height and he could walk with it, and he was unable to lift the small box. It was noted that this process puts a lot of strain on Dan’s back due to the shimmying and twisting he must do to hold onto the box. Also, Dan stated that walking with the box was very uncomfortable because of the lack of support, as it put a lot of pressure on his hips and leg.

After the team observed Dan lifting how he normally would, he was given the vest to use. With little instruction, Dan was able to easily put the vest on and adjust it to fit him comfortably in less than 2 minutes. He stated that he had no problem putting on the vest and that it felt very comfortable to him. Once he proceeded to lift the boxes, he had no problem putting the strap around the far corner of the box and was then able to lift with minimal strain on his back. The time taken to lift the box was reduced by 75%. He was also able to pick up the large box and 45 pound box with the same minimal effort. Dan also noted that carrying the box was much more comfortable than before due to the fact that the load was transferred to his shoulders and back. This test with Dan gave us direct positive customer feedback that the vest was effective and functional. It also showed that the vest was comfortable to wear and use, and more desirable than Dan’s old lifting methods.

The last test performed was an extended use test. Two group members carried, at a walking pace, identical size and weight boxes for 30 min. The box was 1 foot x 1 foot x 1.5 foot and weighed approximately 15 pounds. Every 5 min, they set the box down and immediately picked it back up. One member was using the vest and only one hand while the other just used both hands. After 30 min, they switched so the user that had the vest now used both hands and the user that was using both hands now had the vest. They continued the test for another 30 min and then reported on their findings.
Both group members experienced the same results. They felt that carrying the box was much easier with the vest. It made picking the box up multiple times much easier and dramatically reduced the strain on their back. When carrying for the extended time, using the vest reduced the fatigue experienced by their arms and made walking with the box much more comfortable. The vest did however make the shoulder with the strap on it a little sore. Both members stated that this soreness was offset by the great benefit the vest provided in carrying the box. It was concluded that the vest was effective for use in extended use and did not become overbearingly uncomfortable.

Based on our specifications, we expected the user to be able to comfortably wear the vest for an 8 hour shift during a normal workday. During a typical workday the user would have multiple breaks, lunch, and other down time, such as when they have moved one box and were walking back to retrieve another. There would be very limited cases where a worker would actually be using the vest for 8 hours straight. Because of that fact, we deemed this 30 minute test with continual use as a good indicator of the long-term comfort of our vest.

8.0 Conclusions

In section 3, we defined our needs statement as “a need for device to aid someone in lifting and carrying an object of reasonable size and shape. This device must reduce barriers that prevent persons with disabilities from entering or advancing in the workplace. This device may assist a broad range of disabilities which include, but are not limited to, persons with upper limb loss, persons with bad backs, little people, and the elderly.” As this report has shown, we have found that our design successfully accomplishes all aspects of our initial statement.

As shown in Table 8.1, we have exceeded our target specifications without reducing the effectiveness of the system. The main purpose of the device is to aid in the lifting operation. The device needed to lift objects in the range of 8 cubic feet and above, and if need be, objects which exceeded 50 lbs. Both of the lifting requirements were met by our design with the tested vest lifting boxes up to 8 cubic feet and with weights of up to 60 pounds. The specifications which would specifically lend themselves to the marketability and success of the product would be the ergonomic and cost specifications. Although it appears we have not met our cost requirements, in reality we have. Our initial cost estimation was for materials only without the consideration of manufacturing cost. As shown in our actual specifications, the cost presented includes manufacturing which adds considerable cost. Table 7.5 showed a better estimate which included the price of the vest when it was mass produced, a much more reasonable cost to the consumer. In addition to meeting our cost requirements, the ergonomics were met as well. The vest is comfortable and extremely lightweight. Since the vest is both lightweight with little impact on the user and relatively cheap there is a strong potential for product success.
Table 8.1 – Specifications and Results

<table>
<thead>
<tr>
<th>Metric</th>
<th>Units</th>
<th>Value</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSHA requirements</td>
<td>Y/N</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Total weight</td>
<td>lbs</td>
<td>&lt;10</td>
<td>Y - 1.8</td>
</tr>
<tr>
<td>Material, manufacturing, and overhead cost (alpha)</td>
<td>US $</td>
<td>&lt;70</td>
<td>143.14</td>
</tr>
<tr>
<td>User age</td>
<td>years</td>
<td>&gt;15</td>
<td>Y</td>
</tr>
<tr>
<td>Payload capacity</td>
<td>lbs</td>
<td>&gt;50</td>
<td>Y - 60</td>
</tr>
<tr>
<td>Continuous use</td>
<td>hours</td>
<td>8</td>
<td>Y</td>
</tr>
<tr>
<td>Payload size</td>
<td>cubic ft</td>
<td>8</td>
<td>Y - 8</td>
</tr>
<tr>
<td>Payload carrying distance</td>
<td>ft</td>
<td>&gt;50</td>
<td>Y</td>
</tr>
<tr>
<td>Time to get into device</td>
<td>sec</td>
<td>&lt;60</td>
<td>Y</td>
</tr>
<tr>
<td>Lifetime</td>
<td>years</td>
<td>&gt;5</td>
<td>TBD</td>
</tr>
</tbody>
</table>

Since the product met all of the target specifications except life testing, we feel the product has a good chance at market success. The potential customer base covers a wide range which includes the targeted persons with upper limb loss, but also workers in jobs where lifting is common place such as postal workers, or warehouse workers. Since the vest is cheap, the appeal for a product which would help in their daily work environment with little cost could entice people to buy. Testing has shown that there is little impact on the user through use of the vest but to ensure there is no possibility for personal injury and potential lawsuits via use of the vest, a professional doctor would have to be consulted before actual production would begin. With the help of a trained marketing team we feel that the product could be successfully launched based on the fact that the product is functionally sound, affordable, and beneficial to a wide variety of customers. To cut costs it is also recommend that the product be produced in batches of at least 1000.
Appendix A: Interviewing Guidelines

A.1 Template for Customer Needs Assessment Based on Interviews

Lower Limb (example):

General Statistics:
- XX% of Americans have lower limb disabilities
  - Severe
  - Not Severe
- Number of lower limb disabled people that are employed
  - Etc. (Any statistics that cover your general area)

Specific Need Statements:
1) There is a need for people with a lower limb disability to climb into their farm equipment

   Reasons for the Need:
   - Because... (Comment and quotes from interviewee on personal experience)

   Specific Statistics:
   - XX% of Americans with lower limb disabilities have trouble climbing steps
   - XX% of American farmers have lower limb disabilities

   Requirements:
   - Has to go from seated position up 5 feet into the piece of equipment
   - Has to lift a minimum of 300 lbs
   - Etc. (Need Many More Requirements!)

   Customer Ideas/Concepts:
   - A type of lift for a tractor
   - A swivel seat in the tractor
   - Etc. (Any Ideas the Interviewee has)

2) There is a need for people in wheelchairs to reach elevated places (standing up)

   - Reasons for the Need:
   - Specific Statistics:
   - Requirements:
   - Customer Ideas/Concepts:

3) Etc.
A.2 Survey Sent to Rehabilitation Specialist Working at the University of Illinois*

1. What is your disability? How long have you been disabled?

2. How old are you?
3. Are you currently employed? If so, what do you do? If not, what would you like to do?

4. Are there any tasks at work that you have trouble completing because of your disability?

5. Have you ever been discouraged or excluded from a job because of an inability to complete the required task/s? Please explain.

6. Is there any way that some sort of device could help you be more employable or join the workforce? If so what would it be?

7. Is there any basic task that you have trouble doing in your day to day tasks (not work related)?

Thank you for your time

* All questions in survey developed internally by team members
### Appendix B: Relevant Tables

#### B.1

**Figure B.1 - Frequency Multiplier Figure**

<table>
<thead>
<tr>
<th>Lifts/min</th>
<th>&lt; 1 Hour</th>
<th>&gt; 1 but &lt; 2 Hours</th>
<th>&gt; 2 but &lt; 8 Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>(F) ‡</td>
<td>V &lt; 30 †</td>
<td>V &gt; 30</td>
<td>V &lt; 30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>V &lt; 30</td>
</tr>
<tr>
<td>&lt; 0.2</td>
<td>1</td>
<td>1</td>
<td>0.95</td>
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<td></td>
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<td>0.91</td>
<td>0.91</td>
<td>0.84</td>
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† Values of V are in inches.
‡ For lifting less frequently than once per 5 minutes, set F = 2 lifts/minute.
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<td>V &gt; or = to 30&quot; then CM = 1.00</td>
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1. For containers of optimal design, such as some boxes, crates, etc., a "Good" hand-to-object coupling would be defined as handles or hand-hold cut-outs of optimal design.

2. For loose parts or irregular objects, which are not usually containerized, such as castings, stock, supply materials, etc., a "Good" hand-to-object coupling would be defined as a comfortable grip in which the hand can be easily wrapped around the object.

1. For containers of optimal design, a "Fair" hand-to-object coupling would be defined as handles or hand-hold cut-outs of less than optimal design.

2. For containers of optimal design with no handles or hand-hold cut-outs or for loose parts or irregular objects, a "Fair" hand-to-object coupling is defined as a grip in which the hand can be flexed about 90 degrees.

1. Containers of less than optimal design or loose parts or irregular objects that are bulky or hard to handle.

2. Lifting non-rigid bags (i.e., bags that sag in the middle).
Appendix C: Extra Drawings and Sketches

**Drawing 8**

- Have front piece flip down w/ a foot switch so box can be picked up w/ one arm and then won’t have to move cart.

- Have it fold in half and handle fold down for storage.

- Steering Assist Needed For One N2M
Drawing 3

- **B**: Drawn item at bottom.
- **Sliding Clamping**: Green type.
- **Nail**: No nail here.
- **Scissors**:
  - Attach at waist and have hook/cover piece to assist on side w/ no limb.
- **Vest**:
  - Make attack up here.
- **Sticks**:
- **X-shape**:
  - Handle so that when you pick up and pull towards yourself, it comes into play.
- **Adjust length angle of tifters**.
- **Soft Rubber end pieces to aid in picking up fragile things**.
Drawing 7

Light weight Portable Hoist

Folds to size of loadbase

Folding legs

Need to develop

Why to need

Assisted winch always pulls in slack

(adjustable tension in cable)

Office chair wheels

(omnidirectional)

Host, retracts cable when button is pushed. Already exists in most machining plants or loading docks.
Appendix D: Relevant Sources


Capy, Gilbert; Allain, Jean-Luc; Benarrouch, Jacques. “Sandwich wrapper”, U.S. patent number RE35241, May 14, 1996.


"Limbs For Life Foundation." Limbs For Life Foundation. 26 Oct. 2007
<http://www.limbsforlife.org/about>.


