Fall 12-15-2019

Group E: Improved Greens Harvester

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Improved Greens Harvester

The Improved Greens Harvester is a project designing an improved machine that will be used to harvest crops by our client, EarthDance Organic Farm School in Ferguson, MO. The goal of our design was to provide a simple, easy-to-use, and easy-to-fix machine that would cut and collect baby green leaves as the user walks along the plant bed. We first sought to address issue with the client’s current machine including low cutting accuracy, strain on the user’s body, frequent jamming, and low efficiency. Our initial design was a cart design that included: an oscillating blade for cutting, a rotating rope-shaft mechanism, conveyor belt, and basket for collecting, and a hand drill and tension cable and lever system for powering the machine. After further designing and prototyping, we eliminated the conveyor belt component and switched to a nylon bag to hold the collected greens. We also included a miter gear system to initiate motion about perpendicular axes for the ropes and blade. The most recent prototype functioned very well and met design goals; however, further development would make include making the machine food safe and improving stability in the car.

CURRAN, Ned
GRITTNER, Paige
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MATA, Jennifer
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1 Introduction

The Improved Greens Harvester is a project designing an improved machine that will be used to harvest crops. The client, EarthDance Farms, currently has a handheld machine that cuts the leaves of greens as you walk along a row of crops. Some outstanding issues with their current technology is that it forces the operator to bend at an awkward angle, there is not a high level of accuracy in cutting the greens at the right height, and there is a limited capacity for how much harvested greens the harvester can store. Our goal is to make an improved design based off their current technology that will both improve efficiency, accuracy, and user comfort while meeting the client specifications.

2 Problem Understanding

2.1 Existing Devices

Below is a list of three current devices that are used in the organic agriculture industry. A brief description of each device is given with a comparison of the benefits and drawbacks of each.

2.1.1 Existing Device #1: Johnny Seeds Harvester ($280)

![Figure 1: Johnny Seeds Harvester (Source: Johnny Seeds Harvester)](https://www.johnnyseeds.com/tools-supplies/harvesting-tools/greens-harvester/)

Description: Johnny Seeds Greens Harvester, is a completely manual harvester that comes in multiple lengths depending on the width of the farm bed. The device requires no electricity and is all manual conducted. The device cuts the the greens as you feed it back and forth in a sawing motion down the bed. This device is redimentary and requires the greens to be dense in order to self feed the greens into the collection basket. Since the device is not electrically assisted it would be tiring for the user to bend over and move the blade back and forth the entire length of the bed. According to the product page online, the harvester can manage to collect 100 lb.per hour. Overall, the system is essentially a knife that is attached to a basket, to gather cut greens more quickly.
2.1.2 Existing Device #2: Quick-Cut Greens Harvester ($560)

![Quick-Cut Greens Harvester](https://farmersfriendllc.com/products/harvest/quick-cut-greens-harvester)

**Figure 2: Quick-Cut Greens Harvester (Source: Farm Friends LLC )**

**Link:** [https://farmersfriendllc.com/products/harvest/quick-cut-greens-harvester](https://farmersfriendllc.com/products/harvest/quick-cut-greens-harvester)

**Description:** Farm Friends LLC’s Quick Cut Green harvester, is the current harvesting device that Earth Dance Farms uses. The device does a more effective job at harvesting compared to Johnny Seeds Harvester since it uses a electric power drill to drive a harvesting collection device. The device uses food safe materials to keep the organic produce contamination free. The quick-cut harvester leaves the bed undamaged, to allow for future harvests from the same bed. The devices uses a rope spindle to collect the greens, so that the greens don’t need to be densely planted in order to be collected, like Johnny Seeds Harvester.
2.1.3 Existing Device #3: Sutton Ag Harvest Star ($10,500)

[Image: Quick-Cut Greens Harvester (Source: Sutton Ag)]

Link: [http://www.suttonag.com/harvest_star.html](http://www.suttonag.com/harvest_star.html)

Description: The HarvestStar is a push style harvester that utilizes a band saw blade to cut the greens approximately an inch off of the ground. Instead of feeding the plants in by a rope spindle, the HarvestStar uses a conveyor belt system to collect the greens and drop them into a basket. It is of stainless steel construction and has a 28-inch wide motor powered blade. The harvester is able to collect 300 lbs. per hour. This device is by far the most expensive at over 10,000, when compared to the other two device, which cost roughly 500. The HarvestStar also compacts the bed after harvesting which, may not be ideal for allowing the same bed to have a subsequent harvest.
2.2 Patents

2.2.1 Baby Greens Harvester (Patent Number 5964081)

This patent employs similar components to the existing products above. The Baby Greens Harvester, shown in Fig. 4, rolls along a bed of baby greens and cuts the leaves with a horizontal blade. Two parallel conveyor belts transport the greens to a chute which deposits the leaves in a basin. The top conveyor belt has finger-like attachments that guide the cut greens on to the bottom flat conveyor belt.

![Figure 4: Patent Image for Baby Greens Harvester](image.png)

2.2.2 Method and Apparatus for Harvesting Lettuce (Patent Number US 8,722,200 B1)

This patent uses similar techniques to the patent above but applies them to harvesting lettuce. The Apparatus for Harvesting Lettuce, shown in Fig. 5, uses a type of claw technology to cut the stalk of a mature lettuce plant from opposite sides. Within the "claw", there are multiple arms or fingers that descend until they make contact with the lettuce head and then secure the head in place. Actuators power the claw and finger actions. From there the lettuce head can be enclosed and raised up to be deposited in a new location. In this figure, the new location is a conveyor belt on a tractor or similar machinery.

![Figure 5: Patent Image for Lettuce Harvester](image.png)


2.3 Codes & Standards

2.3.1 NSF International Standard - Food Equipment Materials
( NSF/ANSI 51-2017)

This international standard sets rules to prevent food from being contaminated either by affecting its color, taste or odor. It prohibits the use of certain materials that might affect the products. These include lead, arsenic cadmium or mercury. It also talks about different Aluminum Alloys that should be used if aluminum is used with direct contact with food. Some include Wrought alloys such as 1xx series alloys, 3xxx series alloys 4xxx series alloys, 5xxx series alloys and others. This standard is important in the design of the project because the machine will be used for harvesting organic greens, that is it will have a direct contact with food. It is important that the materials used to build the machine are food safe and will not contaminate the greens.

2.3.2 7 CFR Part 205- National Organic Program(NOP)

This is a list of codes that are used to make sure that when a food is organic nothing damages it. It ensures that when a product is labeled organic it will be 100 percent organic. Organic products can sometimes come into contact with certain chemicals that could damage them therefore this codes and standards ensure that it will not happen by labeling all the care that organic products must go through. For example in part § 205.105 it prohibits the use of certain synthetic materials and substances. This is important to the project as the Machine created for the Earth-Dance Organic Farm must be approved by the OMRI which follows these set of codes and standards. Otherwise the machine created will be useless for them and just a waste of money. It is important to know what counts as organic and what doesn’t that way when the machine makes direct contact with the greens they won’t be affected.
2.4 User Needs

Rae Liening is looking for an improved version of their Quick Cut harvesting machine. They need something that can cover a 30-36 inch wide bed. The machine needs to be able to move along the harvesting area without damaging the crops. She would prefer a harvester that can be rolled along the walking area. The height of the new machine’s opening needs to be adjustable by up to 6 inches to accommodate taller greens. Additionally, the height of the blade should be adjustable so that it can efficiently cut crops on uneven ground. The bucket that collects the crops needs to be able to hold at least 5-10 pounds. Any materials used for the machine must be food safe. For example, the ropes that push the green into the basket after each cut must be resistant to bacteria.

2.4.1 Customer Interview

Interviewee: Rae Liening and Cat Dunsford  
Location: EarthDance Farms, 233 S Dade Ave, Ferguson, MO 63135  
Date: September 6th, 2019  
Setting: Our interviewee showed us the crops that our new harvester will eventually be cutting and the old harvester that it will replace. She showed us how the current model works and showed us some of the things she would like to see improved with the new machine. This all took place outside on the farm, and we each took notes of her recommendations. The interview lasted around 30 minutes.

Interview Notes:

How big do you need the basin to be? How much product would you like to harvest in one trip?

- The current harvester weighs 15-20 pounds when full and can hold 5-10 pounds. More capacity would be nice, and being able to harvest an entire row would be amazing.

How do you feel about the machine rolling or going over plants?

- It should not touch the bed.

What are the biggest problems with the machine you have now?

- The belt-drive power system is unreliable. Having to bend over and constantly hold the drill is tiring. The harvester tends to “jam” when trying to cut larger greens. Some harvested crop falls out of the side and has to be picked up by hand later.

Would you prefer something manual? Electric? Gas-powered?

- The current power system is handy and efficient, as the batteries are easily available. Efficiency is key.

What are any specifications you cannot compromise on?

- The materials used must be food-safe and OMRI-certified. It must cut a 30-36 inch bed and must not roll over the soil of the bed.
2.4.2 Interpreted User Needs

They would like the harvester to be on wheels and to be able to cover the full width of a bed. They want it to be able to harvest more greens in one run, but their main need is ease of use. The current model is cumbersome and unreliable. They need it to be easy to use while standing up. The product will not need to leave the farm, but it will need to be stored indoors. It should be durable and reliable.

Table 1: Interpreted Customer Needs

<table>
<thead>
<tr>
<th>Need Number</th>
<th>Need</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The harvester is comfortable to use</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>The harvester is reliable</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>The harvester can cut the full width of a bed in one motion</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>The harvester is portable</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>The harvester must be food-safe</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>The harvester cannot roll over the ground of the bed</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>The harvester is efficient</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>The harvester’s height off the ground is adjustable</td>
<td>4</td>
</tr>
<tr>
<td>9</td>
<td>The harvester’s opening height is adjustable</td>
<td>4</td>
</tr>
</tbody>
</table>

Any improvement on their current harvester would be appreciated, but we must prioritize the key demands of ease-of-use, efficiency, food-safety, and crop yield.

2.5 Design Metrics

While many of the user’s needs for this product are qualities, they did provide us with some desired quantitative specifications to work towards.

Table 2: Target Specifications

<table>
<thead>
<tr>
<th>Metric Number</th>
<th>Associated Needs</th>
<th>Metric</th>
<th>Units</th>
<th>Acceptable</th>
<th>Ideal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>”Ease of use” rating from farm workers</td>
<td>score</td>
<td>&gt; 3/5</td>
<td>&gt; 4/5</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>Width of blade inches</td>
<td>inches</td>
<td>&gt; 30</td>
<td>&gt; 36</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>Reliable operating time</td>
<td>Hours</td>
<td>&gt; 200</td>
<td>&gt; 500</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>Food safety and OMRI certification</td>
<td>binary</td>
<td>Complies</td>
<td>Complies</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>Crop yield</td>
<td>pounds</td>
<td>5-10</td>
<td>35-40</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td>Efficiency</td>
<td>score</td>
<td>&gt; 3/5</td>
<td>&gt; 4/5</td>
</tr>
<tr>
<td>7</td>
<td>6,8</td>
<td>Does the harvester touch the bed?</td>
<td>binary</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
<td>Adjustability of opening</td>
<td>inches</td>
<td>&gt; 4</td>
<td>&gt; 6</td>
</tr>
</tbody>
</table>

2.6 Project Management

The Gantt chart in Figure 6 gives an overview of the project schedule.
<table>
<thead>
<tr>
<th></th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
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<td>18</td>
<td>25</td>
<td>2</td>
<td></td>
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<td></td>
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</table>

**Design Report**  

**Problem Understanding**  

**Concept Generation**  

**Concept Selection**  

**Concept Embodiment**  

**Design Refinement**  

**Peer Report Grading**  

**Prototypes**  

**Mockup**  

**Proofs of Concept**  

**Initial Prototype**  

**Initial Prototype Demo**  

**Final Prototype**  

**Final Prototype Demo**  

**Prototype Expo**  

**Presentations**  

**Critical Design Review**  

**Final Presentation**

Figure 6: Gantt chart for design project
3 Concept Generation

3.1 Mockup Prototype

The first Mockup we designed was a possible solution to modify the system used to transmit the rotation from the drill to other components of the greens harvester. The original machine used a complex pulley system. In our mockup, we substituted gears in for the pulleys. Figures 7, 8, and 9 show the mockup. The shaft, made from PVC pipe in the mockup and located in the bottom center of the side view (Fig. 7), rotates to spin a gear. That main gear, which is label as "Front" in the front view (Fig. 8), has an extension shaft which rotates the cutting mechanism. The pinions of the main gear interact with pinions of another gear oriented at a 90 degree angle. This gear would also have a shaft connected to it to rotate the harvesting mechanism. Both the cutting and harvesting mechanisms are still unknown, but the this gear set up is a possible solution to driving both mechanisms orthogonally with one motor.

Figure 7: Side View of Gear Mockup
Figure 8: Front View of Gear Mockup
3.2 Functional Decomposition

Below, Fig. 10 shows the Function Tree used to generate and organize the necessary functions of our improved greens harvester.

![Function Tree for Greens Harvester](Image)

Figure 10: Function tree for Greens Harvester, hand-drawn and scanned
3.3 Morphological Chart

Figure 5, below shows the Morphological Chart for the Green Harvester. The Morphological Chart presents solutions to the functions need for the machine from the function tree.

Figure 11: Morphological Chart for Greens Harvester
3.4 Alternative Design Concepts

3.4.1 Band Saw, Conveyor Greens Collector

Figure 12: Preliminary sketches of the Band Saw Conveyor concept
Figure 13: Final sketches of the Band Saw Conveyor concept

Solutions from morph chart:

1. Conveyor Belt
2. Band Saw Blade
3. Push Cart
4. Hole and Pin
5. Lawn Mower Lever Switch
6. Battery

Description: This concept utilizes a band saw blade and conveyor belt to cut and harvest the greens. The blade wraps around two large sprockets that are driven by the drill. The drill also drives the conveyor belt through a bevel gear system, which translates the drill’s rotation to another plane 90 degrees. The whole system is fixed on a push cart that has a set of wheels at the front and allows the user to lift or lower the blade by tilting the entire cart up or down, depending on the beds height. In addition, the cart is fixed with a basket that is used to collect the organic greens uninterrupted. By using a fixed cart the device does not need to be emptied halfway through a bed and can expedite the harvesting process.
3.4.2 Modified Lawn Mower Concept

Figure 14: Preliminary sketches of the lawn mower concept
Solutions from morph chart:

1. Power Drill
2. Lawn Mower Lever
3. Agitator Blade
4. Rope Slapper, Lawn Mower Bag, and Wide Mouth
5. Bicycle Side Car
6. Hole and Pin

Description: The Modified Lawn Mower concept uses solutions similar to those found on a lawn mower. The main lawn mower components include the power lever and catching bag. The bag is a good solution to collect and contain the baby greens. Their current design uses a bag of similar material, but it is open and greens fall out easily. The power lever also allows the user to power the blade and green collector without bending over. The "side car" capability would allow the user to walk along side the bed rather than pushing the cart while straddling the plant bed. The push motion would be similar to a lawn mower, but this device would hopefully be much lighter and able to be used from the side. The lawn mower concept also keeps the rope slapper device used to collect the greens. This device would be adjusted by a hole and pin that would be attached to a pulley with an elastic band. The pulley and blade would both be powered by a power drill and the gear system discussed in the mockup phase of design.
3.4.3 Modified Quick Cut

Figure 16: Modified Quick Cut Sketches

Solutions from morph chart:

1. Power Drill Battery
2. Power Drill Switch
3. Bandsaw Blade
4. Conveyor Belt and Rope Slapper
5. Push Cart
6. Adjustable lever

Description: This concept is similar to the quick cut used at EarthDance Farms, with some modifications to make it easier and faster to harvest greens. This concept is powered by a drill which is also what is used to turn the machine on and off. The drill is currently used for the quick cut and is kept in this concept so that the client doesn’t have to spend money in new motors or batteries. The blade used in this concept is a band saw blade that can make a quick and clean cut. The blade will stay in position and will be powered by the drill. Once the greens are cut they will be pushed inside the green’s collector by rope slapper system which will slap the green onto the conveyor belt that will take the greens down to the basket. The rope slapper will be adjustable to the desired height by the lever arm. The Harvester will have four wheels two big ones on the back and two smaller ones at the front. The small wheels at the front of the machine will make it simpler to move the harvester while still being close to the ground to cut and collect the greens.
3.4.4 Double Drill Harvester

Figure 17: Initial Sketches of Double Drill Harvester

Solutions from morph chart:
1. Two Power Drills
2. Switch on Handlebars Connected to Drills

3. Agitator Blade

4. Roper Slapper and Cloth Receptacle

5. Push Cart

6. Blade Pivots By Hand

Description: This design fixes many of the issues with EarthDance’s existing harvester but does not stray too far from their current machine. The workers at EarthDance like the rope slapping device, the agitator blade, and the drill-operated mechanism, so these features were kept for this design. To simplify the mechanical mechanism, which was prone to failure on the last harvester, this design has two drills to run the two mechanical operations of the harvester. The blade and rope slapper are powered separately. This should make the harvester more reliable and more efficient, as it will not suffer the same friction losses a gear or pulley design would. Additionally, two batteries having to perform the same tasks as one will result in increased battery life. A switch on the handlebars controls both drills. This switch will be wired into either modified drills or a mechanism that pushes the triggers on both drills in. This cart is wider enough to cover a full bed. The increased width, longer green carrying space, and wheeled design will make longer runs of the bed possible before needing to unload the harvester. The height of the rope slapper is adjustable so that taller greens will not jam the mechanism. The rope slapper having its own drill makes this possible, at it does not need to connect to the blade mechanism. The two-wheeled design allows the user to adjust the height of the blade by simply pivoting the whole device up or down on its wheels.
4 Concept Selection

4.1 Selection Criteria

In order to determine the weighted scoring of each criteria, criteria needed to be chosen. The criteria chosen were all based on the vendors desires for the greens harvester (safety, ease of use, accuracy, portability, energy efficiency, reliability).

![Analytic Hierarchy Process (AHP) to determine scoring matrix weights](image)

<table>
<thead>
<tr>
<th>Safety</th>
<th>Ease of Use</th>
<th>Accuracy</th>
<th>Portability</th>
<th>Energy Efficiency</th>
<th>Reliability</th>
<th>Row Total</th>
<th>Weight Value</th>
<th>Weight (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>3.00</td>
<td>2.00</td>
<td>5.00</td>
<td>7.00</td>
<td>1.00</td>
<td>19.00</td>
<td>0.33</td>
<td>32.76%</td>
</tr>
<tr>
<td>Ease of Use</td>
<td>0.33</td>
<td>1.00</td>
<td>1.00</td>
<td>3.00</td>
<td>3.00</td>
<td>0.50</td>
<td>8.83</td>
<td>0.15</td>
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<tr>
<td>Accuracy</td>
<td>0.50</td>
<td>1.00</td>
<td>1.00</td>
<td>5.00</td>
<td>5.00</td>
<td>1.00</td>
<td>13.50</td>
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<tr>
<td>Portability</td>
<td>0.20</td>
<td>0.33</td>
<td>0.20</td>
<td>1.00</td>
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<td>0.25</td>
<td>2.98</td>
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<tr>
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<td>0.33</td>
<td>0.20</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>3.68</td>
<td>0.06</td>
</tr>
<tr>
<td>Reliability</td>
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<td>2.00</td>
<td>1.00</td>
<td>4.00</td>
<td>1.00</td>
<td>1.00</td>
<td>10.00</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Column Total: 57.99  1.00  100%

Figure 18: Analytic Hierarchy Process (AHP) to determine scoring matrix weights

4.2 Concept Evaluation

From the analytic hierarchy process the weighted scoring matrix for each design concept was used to determine the best base concept to build from.

![Weighted Scoring Matrix (WSM) for choosing between alternative concepts](image)

<table>
<thead>
<tr>
<th>Alternative Design Concepts</th>
<th>Safety</th>
<th>Ease of Use</th>
<th>Accuracy</th>
<th>Portability</th>
<th>Energy Efficiency</th>
<th>Reliability</th>
<th>Total score</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (%)</td>
<td>Rating</td>
<td>Weighted</td>
<td>Rating</td>
<td>Weighted</td>
<td>Rating</td>
<td>Weighted</td>
<td>3.364</td>
<td>3</td>
</tr>
<tr>
<td>Safety</td>
<td>32.76</td>
<td>3</td>
<td>0.98</td>
<td>4</td>
<td>1.31</td>
<td>3</td>
<td>0.98</td>
<td>4</td>
</tr>
<tr>
<td>Ease of Use</td>
<td>15.23</td>
<td>2</td>
<td>0.30</td>
<td>4</td>
<td>0.61</td>
<td>4</td>
<td>0.61</td>
<td>4</td>
</tr>
<tr>
<td>accuracy</td>
<td>23.28</td>
<td>5</td>
<td>1.16</td>
<td>3</td>
<td>0.70</td>
<td>2</td>
<td>0.47</td>
<td>4</td>
</tr>
<tr>
<td>Portability</td>
<td>5.14</td>
<td>4</td>
<td>0.21</td>
<td>4</td>
<td>0.21</td>
<td>4</td>
<td>0.21</td>
<td>4</td>
</tr>
<tr>
<td>Energy Efficiency</td>
<td>6.34</td>
<td>3</td>
<td>0.19</td>
<td>3</td>
<td>0.19</td>
<td>3</td>
<td>0.19</td>
<td>3</td>
</tr>
<tr>
<td>Reliability</td>
<td>17.24</td>
<td>3</td>
<td>0.52</td>
<td>3</td>
<td>0.52</td>
<td>4</td>
<td>0.69</td>
<td>3</td>
</tr>
<tr>
<td>Total score</td>
<td>3.364</td>
<td>3.531</td>
<td>3.143</td>
<td>3.764</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rank</td>
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<td>2</td>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 19: Weighted Scoring Matrix (WSM) for choosing between alternative concepts
4.3 Evaluation Results

From the analytical hierarchy process, the importance of each criteria was able to be determined. Based on group decisions of hierarchy, safety, accuracy, and reliability were ranked as the three most critical aspects of the organic greens harvester. Based on the ranking of the alternative design concepts the overall consensus was very close between the four different designs. The Double Drill Harvester was the overall highest ranking design concept, although many of its mechanisms were similar to the other 3 devices. With this in mind, when designing our final concept we will be pulling different designs variations from each of our concepts in order to satisfy what we believe is the most important aspects of the greens harvester. Some of the design changes that will come from other devices include the addition of a conveyor belt system to collect the greens and drop them into a basket at the back of the cart. As well as the simplification of the driving mechanism by removing one of the drills, to create a more reliable device that utilizes mechanical advantages rather than electrical power.

4.4 Engineering Models/Relationships

The following are possible models to be used to make informed design decisions for different components the greens harvester concept.

1) Blade Height
   a) Figure 20 shows the model for determining the changing blade height
b) This model allows us to relate how changing the height of your hands would change the height of the blade based off a design with only one wheel axle. From this model, we can set parameters for range of blade height, how much movement we would want the user to do to, and the angle of the frame to determine dimensions for the frame.

Figure 20: Model for determining the changing blade height that results from the changing height of handle bars
2) Gear Ratios for RPM’s
   a) Model for gear ratios is shown below in fig. 21.

   b) This is an important model that can help the team to make important decision regarding the type of gears to be used, the power and velocity of the gears. One of the first decisions that needs to be made is what type of gears will be more appropriate for the design. It is important to know some of the different gears that can be used such as spur, bevel, helical or worm gears. Then a more important aspect is the rotation of the gear, this will depend on how fast the new green harvester needs to operate and how big the gears are which can be expressed as equation 1, above. It is also important to make sure that the rotational speed will be supported by the 18 volts power drill that will be used to power the machine.
3) RPM to side-to-side movement of Agitator Blade
a) Figure 22 shows a model for agitator blade velocity and drill RPM.

\[
L^2 = x^2 + r^2 - 2rx \cos \theta \\
x^2 - (2r \cos \theta)x + (r^2 - L^2) = 0 \\
x = r \cos \theta + \sqrt{L^2 - r^2 \sin^2 \theta} \\
V = \frac{dx}{d\theta} = \frac{r^2 \sin \theta \cos \theta}{\sqrt{L^2 - r^2 \sin^2 \theta}} \\
V = -r \sin \theta - \frac{r^2 \sin \theta \cos \theta}{\sqrt{L^2 - r^2 \sin^2 \theta}}
\]

Figure 22: Model for determining velocity of blade at given drill RPM

b) This model will help us set up the mechanism connecting the drill to the agitator blade. The drill's maximum speed is a set value, and we need the blade to move at some speed in order to cut greens effectively. These equations will help us set the radius of the disk we will attach to the drill and the length of the arm that attaches it to the blade.
5 Concept Embodiment

5.1 Initial Embodiment

Figure 23: Exploded view with callout to BOM
<table>
<thead>
<tr>
<th>Part</th>
<th>QTY.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4' T Slot AL Frame</td>
<td>2</td>
</tr>
<tr>
<td>3' T Slot AL Frame</td>
<td>3</td>
</tr>
<tr>
<td>2' T Slot AL Frame</td>
<td>2</td>
</tr>
<tr>
<td>Tent Nylon Fabric (72&quot;)</td>
<td>1</td>
</tr>
<tr>
<td>36&quot; Saw Blade</td>
<td>1</td>
</tr>
<tr>
<td>Dewalt Cordless Drill</td>
<td>2</td>
</tr>
<tr>
<td>Spindle</td>
<td>1</td>
</tr>
<tr>
<td>10-32 Rod Ends</td>
<td>2</td>
</tr>
<tr>
<td>10-32 Socket Head Bolts</td>
<td>4</td>
</tr>
<tr>
<td>10-32 Lock-Nuts</td>
<td>4</td>
</tr>
<tr>
<td>1/2&quot; Broom Stick</td>
<td>1</td>
</tr>
<tr>
<td>75' Nylon Rope (Cut into 18&quot; sections)</td>
<td>50</td>
</tr>
<tr>
<td>1&quot;x1&quot; T Slot Gussets</td>
<td>10</td>
</tr>
<tr>
<td>1&quot; T Slot Fasteners</td>
<td>24</td>
</tr>
<tr>
<td>Sliding Rails</td>
<td>2</td>
</tr>
<tr>
<td>MISC Washers</td>
<td>7</td>
</tr>
</tbody>
</table>

Figure 24: List of initial prototype components
Figure 25: Exploded view with callout to BOM
5.2 Model-Based Design Components

Blade Height

The purpose of this model was to help determine the changing handle height. We needed to know what movement the user must do to achieve a goal 6 inches in blade height variance. Based off material selection, the total length of the cart is set at 4 feet. However, there is room for variance in where to locate the wheel axle. The current lengths of 2.5 feet from axle to back frame and 1.5 from front frame to axle allow the user to move the handles a total of 10 inches to obtain a 6 inch variance. One of the biggest advantages to this operating height is that the user’s movement requires less precision because their larger movement will result in smaller movements of the blade.

With this model we also have the capability to calculate and change location of the wheel axle to improve precision for further models.

Figure 26: Calculations for changing blade and handle height

The purpose of this model was to help determine the changing handle height. We needed to know what movement the user must do to achieve a goal 6 inches in blade height variance. Based off material selection, the total length of the cart is set at 4 feet. However, there is room for variance in where to locate the wheel axle. The current lengths of 2.5 feet from axle to back frame and 1.5 from front frame to axle allow the user to move the handles a total of 10 inches to obtain a 6 inch variance. One of the biggest advantages to this operating height is that the user’s movement requires less precision because their larger movement will result in smaller movements of the blade. With this model we also have the capability to calculate and change location of the wheel axle to improve precision for further models.
This model was important to select key components of the prototype because we needed to know how fast the gears are going to move to move the rotating ropes. From this model we were able to pick the correct set of gears. We will be using bevel gears where the smaller gear (or pinion) will be driving the bigger gear. The maximum speed of the drill is 2,000 RPM and since the gear ratio is 2:1 that means the ropes will have double that speed which is what we want. The ropes need to move at a faster speed than the blade in order to accurately collect all the greens. For this it is important that the driver gear is half the size and has half the amount of gear teeth as the driven gear.
RPM to side-to-side movement of blade

\[ x = r \cos \theta + \sqrt{L^2 - r^2 \sin^2 \theta} = r \cos \theta + (L^2 - r^2 \sin^2 \theta)^{1/2} \]

Eqn for blade velocity:

\[ v = \frac{dx}{dt} = -r \dot{\theta} \cos \theta + \frac{-2r \dot{\theta} \sin \theta \cos \theta}{(L^2 - r^2 \sin^2 \theta)^{1/2}} \]

\[ V = -r \dot{\theta} \cos \theta \left( 1 + \frac{2r \sin \theta}{(L^2 - r^2 \sin^2 \theta)^{1/2}} \right) \]

where \( \dot{\theta} \) is the rotational velocity from the drill

Find \( V \) at a few different positions:

\[ \theta = 0 \text{ rad} \]

\[ V = -r \dot{\theta} \cos \theta \left( 1 + \frac{2r \sin \theta}{(L^2 - r^2 \sin^2 \theta)^{1/2}} \right) \]

\[ \theta = \frac{\pi}{4} \text{ rad} \]

\[ V = -r \dot{\theta} \cos \left( \frac{\pi}{4} \right) \left[ 1 + \frac{2r \sin \left( \frac{\pi}{4} \right)}{(L^2 - r^2 \sin^2 \left( \frac{\pi}{4} \right)^{1/2}} \right] \]

\[ \theta = \frac{\pi}{2} \text{ rad} \]

\[ V = -r \dot{\theta} \cos \left( \frac{\pi}{2} \right) \left[ 1 + \frac{2r \sin \left( \frac{\pi}{2} \right)}{(L^2 - r^2 \sin^2 \left( \frac{\pi}{2} \right)^{1/2}} \right] = 0 \]

Assume \[ V = -0.71 \dot{r} \left( 1 + \frac{L^2 + r^2}{(L^2 - r^2 \sin^2 \theta)^{1/2}} \right) = V_{\text{max}} \]

For our design, \( \theta_{\text{max}} = 2000 \) RPM = 209.44 rad/s, \( r = 1 \text{ in} = 0.167 \text{ ft} \), \( L = \sin \text{ in} = 0.167 \text{ ft} \)

\[ V_{\text{max}} = -0.71 \times (209.44 \text{ ft/s})(0.167 \text{ ft}) \left[ 1 + \frac{(0.167)(0.167 \text{ ft})}{(0.167)^2 - (0.167^2/2)^{1/2}} \right] = 39.2 \text{ ft/s} \]

Figure 28: Calculations for max blade speed
The model for translating rotation in the drill to translational motion of the blade helped us evaluate what speeds we were dealing with and also how much range of motion the blade had. We already had certain materials for the drill attachment that dictated length, but we used the model to understand how fast the blade would be moving. The power drill has a maximum speed of 2,000 RPM, so it’s important to know how that impacts the speed of the blade. Part of the prototype process is trying to find an optimum operating speed. This model allows us to change the speed independent of operating the drill at different speeds. This model also gives insight into the blade’s range of motion. This information was most applicable when calculating where to attach the blade to the cart’s frame. We needed to know the full range of motion so that the blade would not slip out of its track during operation.

5.3 Prototype Performance Goals:

Listed below are the three performance goals for both initial and final prototype testing:

1. Cuts and collects 90 percent of greens as it rolls.

2. Blade height has a variance of 6” while maintaining cutting and collecting effectiveness.

3. Basket holds greens for half of the bed.
5.4 Proofs-of-Concept

Proof-of-Concept Prototype

Figures 30, 31, and 32 are photos of three different proofs of concepts. The first two figures show concepts constructed by our team and the third is a photo of the customer’s current machine which we used as a valuable reference in designing our own prototype.

Figure 30: Proof of Concept for the lever operation
Figure 31: Proof of Concept for the couple rope and blade rotation
The proof-of-concept prototypes were key to start building the initial prototype. With these prototypes key decisions were made as how the whole prototype was going to be powered and how the blade and ropes of the greens harvester were going to move. From the proof-of-concept prototype we decided that the blade was going to be powered by an 18-volt drill. As shown in Fig. 30, the drill will be secured on the right side of the green harvester and it will be connected by a cable to a lever that will be attached to the handle of the harvester.

Figure 31 shows a proof of concept for translating the drill’s rotational power into perpendicular planes. This gear mechanism, which will be bevel gears in the final design, translates the rotation about a vertical axis to rotation about a horizontal axis. Additionally, different gear sizes will also accommodate different speeds between the blade and the rope.

We also included a photo of Earth Dance’s current technology because it also served some of the same functions as a proof of concept. The main goal of our design is to make a more user-friendly and efficient greens harvester. However, after inspecting and observing how the rotating ropes help collect the cut greens, we decided that this concept was important to include in our design. Because we had seen its successful function on another machine, we did not find it necessary to create a separate proof of concept.

**Initial Prototype VS. Selected Concept**

The selected concept from section 4 was just a guide to our initial prototype as the design was
changed a couple of times. At first, a conveyor belt was going to be added to the new design but it we decided later that this would make the design over complicated and prompted to failure. One of the biggest change was that only one drill was used to power the harvester instead of two. We changed this because it will make the harvester easier to operate and it will use less power. In the final prototype one drill will be used to move the blade and a set of gears and pulley will be used to move the rotating rope.

6 Working Prototypes

6.1 Initial Prototype

Our focus for the initial prototype was to construct a frame for our cart and successfully design and build individual components. For this reason, our initial prototype had a functioning rotating rope shaft and oscillating blade, but they did not have coupled rotation and needed to be powered by separate hand drills. We were not able to achieve the desired range of cutting height, but this was something that we could easily fix. Additionally, we were not able to use the prototype on a bed of greens; however, we achieved successful yields using printer paper and paper towels as a substitute. Figure 33 is a photo of our initial prototype.
6.2 Final Prototype

For our final prototype, we focused on upgrading parts of the design, such as the rope shaft and wheels. We also finished the designs for and assembled the gear system and cable powering mechanism. With improved wheels, we were able to achieve the goal range of cutting height for. We also further improved our collecting yield. Figures 34 and 35 show photos of our final prototype.
Figure 35: Final prototype with miter gear system
7 Design Refinement

7.1 FEM Stress/Deflection Analysis

We performed a finite element modeling analysis on the rotating rope sweeper shaft. This analysis shows the stress and deflection states of the steel beam due to loading from the ropes, rotation of the shaft, and reaction forces from the bearings.

Figure 36 shows the mesh and loads of the FEM shaft analysis.

![Figure 36: FEM Analysis Parameters](image)
Figure 37 shows the resulting stress state from the simulation. We find that the shaft will not yield.

Figure 38 shows the resulting deflections from the simulation. We find that the deflections are minimal in theory.
7.2 Design for Safety

7.2.1 Risk #1: Exposed Blade

**Description:** There is a sharp vibrating blade that is exposed when the machine is in use and at rest. This blade could cause severe cuts and other injuries.

**Severity:** Critical  
**Probability:** Unlikely  
**Mitigating Steps:** Machine user will be far away from the blade and with the power mechanism. Additionally, the blade will not be moving when they are close. We also encourage safe storage away from children.

7.2.2 Risk #2: Rotating Metal Parts Malfunction

**Description:** Metal parts attached to the rotating drill could break off and fly in any direction at high speeds, possibly injuring nearby people.

**Severity:** Critical  
**Probability:** Seldom  
**Mitigating Steps:** Balance the wheel to reduce vibration and possibly add chain guard.

7.2.3 Risk #3: Hair Getting Caught in Rotating Ropes

**Description:** The user’s hair could get caught in the rotating rope mechanism while adjusting the height.

**Severity:** Marginal  
**Probability:** Seldom  
**Mitigating Steps:** By making the greens harvester a single user machine, it is not possible for the ropes to be rotating when the user is close to the rotating shaft.

7.2.4 Risk #4: Machine Jamming

**Description:** Pieces of plant or dirt can get caught in the vibrating blade or rotating ropes and causing a jam while operating the machine

**Severity:** Marginal  
**Probability:** Occasional  
**Mitigating Steps:** If a jam occurs, the user can stop the machine by letting go of the handle. Also, we are adding height adjusters to the ropes which should decrease jams there.

7.2.5 Risk #5: Flying Debris

**Description:** Dirt, leaves, and rock could be displaced and projected towards the user and nearby people.

**Severity:** Marginal  
**Probability:** Likely  
**Mitigating Steps:** We recommend wearing safety glasses while operating machine. Additionally, we believe that flying rocks will be seldom.
Figure 39 shows a visual representation of the possible risks described above.

<table>
<thead>
<tr>
<th>Category</th>
<th>Probability that something will go wrong</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequent</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Immediately or in a short period of time; expected to occur frequently</td>
</tr>
<tr>
<td>Catastrophic</td>
<td>Red</td>
</tr>
<tr>
<td>Critical</td>
<td>Yellow</td>
</tr>
<tr>
<td>Marginal</td>
<td>Yellow</td>
</tr>
<tr>
<td>Negligible</td>
<td>Green</td>
</tr>
</tbody>
</table>

Figure 39: A Heat Map of possible risks evaluating priority of risks

From the Heat map in fig. 39, we prioritized our risks as follows:

1. Rotating metal parts breaking
2. Exposed blade injury
3. Flying debris
4. Machine jamming
5. Hair getting caught in rotating ropes

We prioritized the risk in this order by taking into account the heat map color code and severity simultaneously. We decided that the critical risks would be our highest priority because they would cause the most damage, even if they were unlikely to occur. The rotating metal parts breaking risk is above the exposed blade because of its higher probability. We then considered the next level of severity risks in the yellow region. Again, flying debris is above the machine jamming because of its higher probability. We then ranked machine jamming next. The hair would be last because it has the lowest severity and probability.
7.3 Design for Manufacturing

We currently do not have any moldable parts on our current prototype. However, we plan to add a cover to the gears. So, we performed a draft analysis for a part that would cover the gears. The draft analysis helps to show how fit this part would be for manufacturing.

Figure 40 shows the original draft analysis without any modifications. There is a square face around the outer edge of the part, the cylindrical face at the top, and the bolt holes. The analysis highlights these parts as needing a proper draft.

Figure 41 shows the draft analysis of the gear cover after modifications.
We also performed DFM analysis for a part that would cover the blade spindle. Figure 42 shows the result of the DFM analysis for whether the part is able to be made from injection molding. The results show that the part would not be fit for injection molding because its walls are too thick.

Figure 42: DFM Injection Analysis of Spindle Cover
Figure 38 shows the result of the DFM analysis for the part is able to be made using a milling machine. The results show that we could not mill the top hollow cylinder because the center cut would be too deep.

7.4 Design for Usability

1. **Vision Impairment** Vision impairment wouldn’t affect the usability of the green harvester. There is no need for someone to have a perfect vision because to use this machine the user only needs to have good physical health in order to carry the machine and to empty the greens from the basket. Also, making the machine function is as simple as turning it on and off by pressing on a lever that will power the drill while the user pushes along the bed of greens.

2. **Hearing Impairment** A hearing impairment wouldn’t affect the usability of this machine as explained above this machine only requires someone with a good physical health. A hearing impairment could only be a problem if the machine makes a weird noises caused by something getting stuck on the blade or ropes. This could be a warning meaning that the machine is not working correctly or that it is in danger of breaking down. In order to make the green
harvester more user friendly for someone with a hearing impairment, a emergency switch that lights up when something gets stuck between the ropes or the blade could be added to the machine.

3. **Physical Impairment** Physical impairments such as arthritis or muscle weakness would heavily influence the user’s ability to operate the harvester. Farming is an inherently physical task and requires lifting and force. We have made steps to make the harvester more ergonomic by making the harvester wheel driven. This improvement allows someone with back problems to operate the harvester because they do not have to be in a bent position for long periods of time. We hope that the "cart" design will also prevent the user from developing back problems or other injuries. However, the user still needs to apply force to push the harvester and must lift the harvested greens out of the bag.

4. **Control Impairment** Distraction, fatigue, or medication side effects will cause added risk to operating the greens harvester. Because there is inherent risk discussed earlier in this section, it’s vital that the user has full control and focus while operating. We have taken precautions to address the risk with the cutting mechanism and high speeds; however, we still advise that the user does not operate while they are experiencing any control impairments.

8 Discussion

8.1 Project Development and Evolution

*Does the final project result align with its initial project description?*

- Yes. We tried to keep the design and project as simple as possible so that we wouldn’t stray away from the project description.

*Was the project more or less difficult than expected?*

- We were surprised that it was more difficult than expected to decide on and move forward with single design idea. We kept thinking about other ways we could modify our design, but had to say no so that we could move forward into the prototyping stage.

*On which part(s) of the design process should your group have spent more time? Which parts required less time?*

- I think we would have appreciated more time for prototyping.

*Was there a component of the prototype that was significantly easier or harder to make/assemble than expected?*

- The cable was significantly harder to assemble because the cable we had could not be shortened, so we had to modify its connection so that the cable would be in enough tension to work.

*In hindsight, was there another design concept that might have been more successful than the chosen concept?*

- We think it would have been interesting to see how using a conveyor belt would have worked out.
8.2 Design Resources

How did your group decide which codes and standards were most relevant? Did they influence your design concepts?

- For us we focused mostly on looking at codes in the agricultural sphere. This was a pretty easy decision because the agriculture industry is so large and well-developed.

Was your group missing any critical information when it generated and evaluated concepts?

- We felt that we had sufficient information for our concepts.

Were there additional engineering analyses that could have helped guide your design?

- I think we could have done further FEM and vibration analysis for further prototypes.

If you were able to redo the course, what would you have done differently the second time around?

- I think we would have spent less time going back and forth about what design to go and used that time to develop our prototypes.

Given more time and money, what upgrades could be made to the working prototype?

- With more money, we would have liked to upgrade the frame, gears, and ropes on our harvester.

8.3 Team Organization

Were team members’ skills complementary? Are there additional skills that would have benefited this project?

- We had a good mix of conceptual knowledge, practical knowledge, and organizational skills for the project.

Does this design experience inspire your group to attempt other design projects? If so, what type of projects?

- Yes. It was a great experience in going through a design process. Some of our group members will be using their experiences from this project in their work on the WashU race team. Overall, we all would be open to many different types of design projects in the future.