ERGONOMIC IMPROVEMENT ON THE FARM/GARDEN HOE

BY

YUAN CHAO JIANG

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Checked by: _________________________ Approved by: ______________________________
Abstract

The hoes are widely used in the farms and home gardens in the United States. Many existing hoes are not ergonomically designed because they require a lot of back bending and wrist bending during use. Back bending often causes lower back injuries, and wrist bending often causes carpal tunnel syndrome. It can be very expensive to cure these injuries. The objective of this project is to reduce back bending and wrist bending by redesigning the hoe in an ergonomic perspective. In order to achieve the objective, ergonomics and human factors concepts are applied in the design. Two additional side handles are added to the traditional long handle. The user will have the option to choose one additional handle or two additional handles. Therefore, the redesigned hoe will be able to reduce back bending and wrist bending. An experiment and a statistical analysis are provided to justify whether the improvements on the redesigned hoe are statistically significant or not. The result of the statistical analysis shows that there is significant improvement on back bending and wrist bending. The economic analysis shows that the additional material and labor cost are relatively small in comparison to the medical cost for treatment of farm tool related injuries.
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Introduction

Hoes have been used for a long time in the history of agriculture. Today it is still the most common farm tools in agriculture and gardening. Farm workers and gardeners constantly use hoes to move soil, to cultivate and to create trenches for seeding. However, many hoes are not ergonomically designed and require wrist bending, body bending, awkward posture, etc. These factors may cause unexpected injuries, such as carpal tunnel syndrome, musculoskeletal disorder and lower back injuries. These injuries are not only painful and may take a long time to cure but also cost a significant amount of money for medical care.

The objectives of this senior project are to

- Evaluate and measure the current available hoes
- Improve the design of holding and using hoes from an ergonomic perspective

As a result of the improvement, the tool would be easier to use and reduce risk factors, such as wrist bending, body bending and awkward posture which may causes injuries. The new design would also reduce energy expenditure and increase the efficiency of performing farm work.

This project will focus on redesigning the handle of the traditional hoes to make ergonomic improvements through Computer-Aided Design (CAD) software, which is called SolidWorks. Two additional side handles will be added to the existing handle on the traditional long handle. Both of the additional side handles are adjustable and can move along the holes on the traditional handle. The traditional tool will be purchased, and the tool will be modified and assembled into a prototype. A statistical analysis will be performed to test the prototype between the initial state and the improved state, helping to justify whether the additional ergonomic
changes are necessary and significant. At the end, an economic analysis will justify the improvement’s cost effectiveness.

A successful ergonomic improvement would reduce the risk of injuries, make farm work more efficient and decrease annual medical costs because fewer people would be injured.

The next section will be background and literature review, which will address the context of the project. The literature review will provide information and backgrounds on the studies that people have done in the past. The following sections will be design and experiment. The design section will explain the specific criteria of the ergonomic improvements and the experiment will explain the statistical result of the tool performance analysis. At the end, conclusions and recommendations will be provided.
After the discussion about the farm tools with Dr. Lizabeth Schlemer, who is a professor in the Industrial and Manufacturing department at California Polytechnic State University, this senior project was created.

Many of the existing hand held farm tools require some degree of physical discomfort. Most of the existing hoes, which are available at local stores, such as Home Depot, have only one handle. A one handled tool may require repetitive and uncomfortable body twisting and bending and some awkward posture to perform tasks. In the long term, awkward posture may lead to injuries, such as back related problems. The National Institute for Occupational Safety and Health reports that back related injuries happen frequently. In order to avoid and reduce the risk of injuries, Ergonomics and Human Factor concepts can be applied to solve the problems. Human Factor is the study of factors that affects human work performance, and the factors include environment, psychology, physical body, equipment, workload capacity, etc. From this perspective, people can be more productive and feel less fatigue while they are working. Such improvements will be very beneficial for farm works because they simply make them easier to work.

Moreover, repetitive motions can increase fatigue and the probability of incurring work related injuries. The adjustable handles will give people more freedom to change postures, and will increase the comfort level. Therefore, people can work longer.
Furthermore, the traditional long handle or traditional handle can always be referred to Figure 1. The additional side handles or additional handle can always be referred to Figure 15 in this report.

Figure 1 Traditional long handle
Literature Review

Hoes and shovels are widely used in agriculture and gardening throughout the world, and their handles are both similar to each other. People use them frequently to complete their farm tasks. Both of them require similar motion, such as gripping, lifting, holding, etc. Many design factors can significantly affect how tools and human interact. Ergonomic improvement of tools would not only reduce the injuries but also make people work more productively and efficiently. Better tools design would make people work faster and safer and expend less energy. This literature review will include fifteen sources to provide good reviews and backgrounds of hoe and shovel on ergonomic improvement.

Tool related Injuries

Cumulative trauma disorder is a very common farm injury in the working field. The book, *An Introduction to Human Factors Engineering* lists different types of cumulative trauma disorder. One type of the cumulative trauma disorder is carpal tunnel syndrome, which can be an injury from using a shovel or a hoe because these hand tools require wrist bending and gripping. Injuries may occur between the finger tendons and the structure of the carpal tunnel due to tendon inflammation and swelling (Wicken, Lee, Liu and Becker 2004). As a result, good tool design should minimize wrist bending in order to avoid carpal tunnel syndrome.

In addition, a case study of Northern India reports there are many farm hand tool injuries, involving spades and hoes (Kumar, Singh, Mohan and Varghese 2008). Spades and shovels are very similar to each other. Both spades and shovels can cause common injuries because they
both require gripping. This case study reports that gripping force and postures can cause cumulative trauma disorder (Kumar, Singh, Mohan and Varghese 2008). The gripping forces and postures are essential factors in the project design because ergonomic improvements on this issue can eliminate these types of injuries.

Not only is cumulative trauma disorder an injury, but musculoskeletal disorder is also one of the injuries of using farm tools. The study of musculoskeletal disorder and its connections with ergonomics illustrates that “forceful use of hoes” and lifting heavy loads are two of the most important causes of musculoskeletal disorder (Fathallah 2010). Because shovels involve lots of lifting, it is very important to improve the current shovel. In addition, the fields involving these two factors accounts for 6.7% of the farm tool related injuries in United States (Fathallah 2010). Therefore, it is very essential to consider the weight of the tool itself and the required energy expenditure. Implementation of these considerations will significantly improve the potential for injury.

Furthermore, lower back injuries are very common problems in the farm field. Lifting can often cause lower back injuries (Ness 1996). Newsweek reports that the treatment of back and neck pain cost $85.9 billion in 2005 (Springen 2008); thus, this should be a very big concern of the project. An improved ergonomic hoe design can save lots of medical costs annually.

**Design characteristics**

There are many ergonomic considerations in tool design. The tool should be designed appropriately for different people. The Article, “Hand anthropometry survey for the Jordanian population” shows that hand dimensions are different between males and females. In addition, the same genders of different national populations also have different hand dimensions
(Mandahawi, Imrhan, Al-Shobaki and Sarder 2008). The authors suggest that the tool design should consider the impact of the gender and population difference among the different users (Mandahawi, Imrhan, Al-Shobaki and Sarder 2008). This study gives an excellent statistical analysis of how differences in different populations need to be considered for tool design and how important it is.

Gripping feature is one of the most important design characteristics of ergonomic design. The study of the handle measures hand grip force, heart rate and electromyography of the muscles and the statistical result shows that the shovel with hollow fiberglass handle performs better (Chang, Park and Freivalds 1999). It is “12% more efficient than either the wood handle or the solid fiberglass handle” (Chang, Park and Freivalds 1999). On the other hand, another evaluation was performed on form rubber handle grips and shows that the grip is unsuccessful because of “loss of control feeling” (Fellows and Freivalds 1991). In addition, the handle should be bent, and the wrist should not be bent (Sanders and McCormick 1993). This can directly reduce the number of injuries to the hands. Thus, incorporating a good design of the handle to the project is very important to avoid injuries and enhance efficiency. However, the bad handle can be harmful for users and may cause adverse effect with possible injuries.

Moreover, handle diameter is another important factor which directly affects hand gripping ergonomics. The study of cylindrical handle diameter illustrates that a 40 millimeter diameter handle is the most comfortable for males and a 35 millimeter diameter handle is the most comfortable for females (Kong and Lowe 2005). This study provides a very good sense of design specifications and this information would help improve users’ gripping experience. Therefore, it is important to select appropriate handle size to reduce the gripping force because the reduction of gripping force can increase the efficiency of the performance.
The hoe length is one of the most important factors of the design. Appropriate length would minimize stress and fatigue. A study was done by 48 female vegetable farmers in Gambia, which is in western Africa. The result shows a longer hoe with 141 centimeters requires much less time to complete the same task than the shorter hoe with 49 centimeters (Vanderwal, Rautiainen, Kuye, Peek-Asa, Cook, Ramirez, Culp, Donham 2010). Moreover, the study of Nigerian’s traditional hoe proves a short handle will result in lower back pain and requires more energy expenditure to perform the same task (Nwuba and Kaul 1986); thus, the long hoe is more efficient and it is a better ergonomic design. This study demonstrates the importance of appropriate length. The design of assembled length for the project should avoid being too long and too short.

In addition to the length, the study from University of Buffalo compares the traditional straight handle shovel and bent shovel. It concludes that bent shovels can also reduce the probability of lower back injuries (Huang and Paquet 2002). This study can be very helpful to develop innovative design and to approach ergonomic improvement. Incorporating this idea study will be very beneficial to both increase efficiency, as well as decrease injury.

Moreover, material selection is very important. The occupational ergonomic guideline suggests the weight of the shovel should be below 1.5 kg (bhattacharya and McGlothlin1996). Light weight would obviously reduce the energy expenditure, so all the material used in the assembly should be light weight.

Furthermore, a multipurpose farm tool would be easier to carry and saves the weight of extra handle. An ergonomic evaluation of performing on multipurpose shovel-cum-hoe, and the evaluation demonstrates that the tool is capable to perform the same task as hoe and shovel (Sen
and Sahu 1996). The statistical analysis shows there is no significant difference of work heart rate and a survey shows 74% of the workers agree with the ease of use (Sen and Sahu 1996). This idea is very important to the project because it proves the acceptance from people. It also shows the combination of two tools is successful to satisfy the functional purposes.
Design

Evaluation
These two hoes are the very typical hoes in the market at large stores such as Home Depot.

This Ames forged garden hoe in Figure 1 is sold for $15.97 at Home Depot. The hoe handle is made of ash wood. The total length of the hoe is 57.5 inches and hoe handle is 54 inches. The diameter of the handle is 1.25 inches, and the diameter of the grip is 1.4 inches. The grip is 10 inches long and its weight is 2.9 lb. The design of this hoe is simple and the hoe blade is strong and durable; however, the handle lacks ergonomic features. The use of this hoe requires some degree of bending of the body and wrist, which may cause injuries. Since the length of the handle is fixed, it is not suitable for every single person. (See Figure 2)
Another example is the Ames fiberglass forged garden hoe in Figure 3. It is made of fiberglass, and it is very similar to the previous example. It is also sold at Home Depot. It is 51 inches long in total and the green part is 46 inches long. The grip is 6 inches. It is 2.5 lb, which is slightly lighter than the previous wooden hoe. This hoe has the same issues as the example in figure 1. It lacks ergonomic features, and it requires some degree of body bending and wrist bending to perform tasks.

**Design Criteria**

The purpose of this project is to create an ergonomic solution to the existing hoe. Implementing an additional side handle would be beneficial to the user and would reduce wrist bending and body bending. This would ultimately reduce the possible back bending injuries and the risk of carpal tunnel syndrome.

The fixed handle position cannot fit appropriately for all users because people have different heights, body lengths and arm lengths. Therefore, this feature is not ergonomically designed. For example, a short person may not be satisfied with the design because he or she does not need a long handle. A long handle position can require unnecessary energy expenditure for short people.

In addition, it is inappropriate to use one size to fit all people. People have different preferences for the holding posture, so an adjustable handle design will be more suitable for people’s needs. In order to create this feature, two rows of holes are drilled on the traditional long handle. One row of holes is horizontal and the other is vertical.

Anthropometric data is very important and useful to identify the desired appropriate dimensions. According to anthropometric data in *Introduction to Human Factors Engineering*. 
arm lengths of the 5th, 50th and 95th percentile are 22.6 inches, 25.6 inches and 29.3 inches (Wickens, Lee, Liu and Becker, 251). The average difference among the percentiles in arm length is 3.3 inches. The elbow heights of the 5th, 50th and 95th percentile are 38 inches, 42 inches, and 45.8 inches (251). The average elbow height difference among the percentiles is about four inches. In addition, there is a two inch difference between males and females for arm length and waist height on average (251).

Consequently, the holes in one row on the traditional long handle are four inches apart. By considering the manufacturing design and the longevity of the product, both the vertical holes and horizontal holes need to be offset by two inches. This implementation ensures that the holes do not intersect with each other, which can reduce the possibility of breaking the handle. The design is illustrated in the Figure 14 of Appendix E.

The handle is screwed perpendicularly into the traditional long handle because it is the most efficient. When the handle is attached vertically on the top of the traditional long handle, the user’s wrist is forced to be straight, which consequently reduces wrist bending. When the handle is attached vertically at the bottom, the user would stand with a straighter posture, which reduces back bending. Based on the moment theory, vertical attachment requires the least energy expenditure because it does not have any angle resistance when force is applied.

Moreover, the additional handles are circular, so they are easy to grip. This design also allows the users to adjust the position of their hands. A circular handle is the most appropriate because it has very few constraints on the gripping position. The threaded end of the handle is sanded into a semicircular shape, which will be able to fit on the traditional long handle to make the additional side handle more stable. Thus the handle will not move during the work motion.
Plasti Dip, one kind of rubber coating, is used in the prototype to prevent slipping during the working motion. As a result, the coating can reduce energy expenditure from gripping and enhance the comfort level of the handle grip. (See Figure 15 in Appendix E)

The user can change the position of the additional side handle along the traditional long handle. The position of the additional side handle can be adjusted based on the user’s arm length, height and personal needs. The user will be able to bend his or her back less and to stand straighter than when using the traditional hoe. The wrist would also be straighter. Furthermore, the user will be able to choose using between one additional side handle and two additional sides handles based on his or her personal needs and preference. (See Figure 6 and Figure 7 in Appendix A)

**Design Specification**

The traditional long handle is 55 inches long and 0.65 inches wide in diameter. The additional handles are 7 inches long and the diameter is 1.26 inches. The handle grip has a thickness of 0.08 inches, so the total diameter of the additional side handle is 1.42 inches. According to the study in the literature review, these dimensions are chosen to provide the most appropriate comfort level. The dimensions are shown in Figure 14 and Figure 15 of Appendix E.

The thread insert, with an inside thread diameter of 5/16 inches, screws into the additional side handle and attaches to the traditional long handle with the bolt. (See Figure 8 and Figure 9) The thread insert has a major diameter of 0.6 inches, and the tap drill should create a hole of 0.5 inches in diameter in the center of the handle end. (See Figure 15) The force would be applied more evenly on the handle, allowing it to withstand more force. Moreover, a two-inch
long, 0.05lb, coarse type hex bolt of 5/16 inches is used to attach the additional side handle. In order to accommodate the bolt, the hole diameter on the traditional long handle need to be 5/16 inches. The size of the counterbored holes on the traditional long handle is 17/32 inches in diameter. The clearance diameter is 11/32 inches. The allowance is ±0.01 inches, so the bolt is not threaded too tight or too loose. The hole is drilled all the way through to the other side. The counterbored feature on both sides makes it easier to insert the bolt on either side. The counterbored holes are able to make the additional side handles more stable. There are 6 vertical holes and 6 horizontal holes because the distance between the first hole and sixth hole is nearly half of the length of the traditional long handle. The CAD design can be viewed in Figure 6, Figure 7, and Figure 14.

Furthermore, the formulas \( \sigma = \frac{\text{Force} \times \text{length} \times \text{radius}}{\text{Moment of Inertia}} \) and Force=\( \frac{\text{Moment of Inertia} \times \sigma}{(\text{length} \times \text{radius})} \) are used to calculate how much force the additional side handle can bear, when \( \sigma \) is the wood stress of 7000 psi and Moment of Inertia=\( \frac{\pi}{64} \times \text{diameter}^4 \). The result of the calculation shows that the additional side handle can bear about 196 lbs of force before it breaks. It is almost impossible to apply such a huge amount of force while using the hoe. Therefore, the additional side handle is strong enough to attach to the traditional long handle.

At the end, a prototype of the design is created for the experiment.
Method

Statistical experiments are performed to analyze the redesign of the garden hoe. The objective of the statistical analysis is to measure the difference between the initial state and improved state, comparing back bending and wrist bending when using the traditional hoe to the redesigned hoe. The traditional hoe refers to the hoe without additional handles, and the redesigned hoe refers to the hoe with the additional side handles. The experiment has two groups. The first group compares the traditional hoe and the redesigned hoe with one additional side handle. The second group compares the traditional hoe and the redesigned hoe with two additional handles.

First Group

The first group in the experiment compares the back bending angle between the traditional hoe and redesigned hoe with one additional side handle while using them.

Hypothesis:

H₀: There is no difference in back bending between the traditional hoe (µ₁) and the redesigned hoe with one additional side handle (µ₂).

H₁: There is a difference in back bending between the traditional hoe (µ₁) and the redesigned hoe with one additional side handle (µ₂).

H₀: µ₁ = µ₂

H₁: µ₁ ≠ µ₂

Procedure:
First, each participant was asked to use the traditional hoe, which did not have an additional side handle. Pictures of each participant using the traditional hoe were taken to measure back bending. The shoulder height and waist height were measured. Next, one additional side handle was attached onto the traditional hoe by screwing in the bolt. The additional pictures of each participant using the redesigned hoe were taken to measure back bending. Then the shoulder height and waist height were measured while the participant was using the redesigned hoe. The back bending angle was primarily measured through the pictures, and the shoulder and waist measurements would also help to identify the angle of back bending. Therefore, the back bending could easily be compared between the traditional hoe and redesigned hoe.

Each participant was asked to fill out a set of survey questions based on his or her experience. The survey is shown in Appendix C. The survey compared the wrist bending and each participant’s comfort level while using the traditional hoe to the redesigned hoe.

The first question on the survey asked, “Is there an improvement in back bending while using redesigned hoe?” The participants could answer “Yes,” “No,” or “Somewhat.” The second question had two parts. Part A asked, “Is there an improvement in wrist bending while using redesigned hoe?” Part B asked each participant to rate the comfort level of the wrist while using the hoe. This part was asked first for the traditional hoe and then asked for the redesigned hoe. The score scale ranges from 1 to 10. A score of 1 indicates the lowest comfort level and a score of 10 indicates the highest comfort level. As a consequence, the score would be able to show how much improvement the participant felt. The third question asked, “Do you feel more comfortable while using this redesigned hoe with additional side handle overall?” The participant can answer “Yes,” “No,” or “Somewhat.” The survey is shown in Appendix C.
Second group

The second group of experiments compares the back bending angle between the traditional hoe and the redesigned hoe with two additional side handles while using them.

Hypothesis:

H\(_0\): There is no difference in back bending between the traditional hoe (\(\mu_1\)) and the redesigned hoe with two additional side handles (\(\mu_2\)).

H\(_1\): There is a difference in back bending between the traditional hoe (\(\mu_1\)) and the redesigned hoe with two additional side handles (\(\mu_2\)).

H\(_0\): \(\mu_1 = \mu_2\)

H\(_1\): \(\mu_1 \neq \mu_2\)

Procedure:

The procedures of taking pictures and measurements in group 2 are exactly the same as in group 1 except using the redesign hoe with two additional side handles. Each participant was asked to fill out a set of survey questions based on his or her experience. The survey is the same one as in the first group, which can be found in Appendix C. The survey compares the wrist bending and each participant’s overall comfort level while using the traditional hoe to the redesigned hoe with two additional side handles.
Result

When all the data is recorded, a normality plot is created to check if the data distribution is normal. Since the p-values of the normality plot in Figure 10, Figure 11, Figure 12 and Figure 13 of Appendix D are all larger than 0.05, and all the points are in control, it can be concluded that the data is normal.

Since the same person is used to compare the back bending when using the traditional hoe to the redesigned hoe, a paired t test is used to determine whether the statistical difference is significant or not. The main purpose of using a paired t test is to analyze the statistical difference in back bending between the traditional hoe and the redesigned hoe.

In the first experiment, while using the redesigned hoe with one additional handle, back bending has improved by 4.56 degrees. The p-value is less than 0.05, so the null hypothesis is rejected. As a result, it can be concluded that the difference between the traditional hoe and the redesigned hoe with one additional handle is statistical significant. (See Appendix D)

The first question and the second question on the survey asked if there was an improvement in back bending and wrist bending. The results showed that participants who answered “Yes” instead of “No” or “Somewhat.” The answers to the first survey question on the redesigned hoe with one additional handle showed that 69% of the participants said there was an improvement in back bending. The answer to the second question showed that half of the participants agree that there was an improvement on the wrist bending. Based on the scale of 10, the participants give a score, which was on average, 1.4 higher for wrist bending while using the redesigned hoe compared to the traditional hoe. The third question showed that 69% of the
participants said the redesigned hoe with one additional handle increased their overall comfort level.

The information is summarized in Figure 4, which is shown below:

![Figure 4 Improvement on redesigned hoe with 1 additional handle](image)

Figure 4 Improvement on redesigned hoe with 1 additional side handle

In the second experiment, while using the redesigned hoe with two additional handles, back bending has been improved 5.94 degrees. The p-value is less than 0.05, so the null hypothesis is also rejected. As a result, it can be concluded that the difference between the traditional hoe and the redesigned hoe with one additional handle is statistical significant. (See Appendix D)

The analysis method of survey in group 2 is the same as in group 1. The first survey question on the redesigned hoe with two additional handle showed that 78% of the participants said there was an improvement in back bending. The answer to the second question showed that 72% of the participants agreed that there was an improvement on the wrist bending. Based on the scale of 10, the participants give a score, which was on average, 2.1 higher for wrist bending while using the redesigned hoe compared to the traditional hoe. The third question showed that
83% of the participants said the redesigned hoe with two additional handles increased their overall comfort level.

The information is summarized in Figure 5, which is shown below:

![Improvement redesigned hoe with 2 additional handles](image)

Based on measuring back bending and conducting a survey, the results were expected. The back bending measurements and the questions on the survey both prove that the improvements in both group 1 and group 2 are statistical significant. The second question on the survey proves that the wrist bending problem has been reduced. The third question on the survey shows the overall comfort level had been improved. In other words, the majority of the participants agree that the redesigned hoe is more comfortable than the traditional hoe. For these participants, the redesigned hoe ultimately reduced either back bending or wrist bending. In addition, the survey showed that more participants agreed the redesigned hoe with two additional side handles improves back bending and wrist bending. However, it cannot be concluded that the
redesigned hoe with two additional side handles is better than the redesigned hoe with one additional side handle. It would be better to allow the user having the option of choosing one additional side handle or two additional side handles.
Economic Analysis

This economic analysis compares the manufacturing cost per unit to benefits received by the user. The cost of redesigning the hoe includes material cost, and labor cost.

The material cost is the total cost of all the materials, which includes a traditional garden hoe, threaded inserts, bolts, wood poles, epoxy glue and Plasti-Dip. A traditional garden hoe can be purchased for $15.97 from Home Depot. A pack of ten threaded inserts can be purchased for $5.07 on Amazon.com. A box of 100 bolts can be purchased for $17.97. The wood pole is purchased at $0.96 per feet at Home Depot. 25ml of Epoxy glue can be purchased at $3.99 from Ace Hardware. Plasti Dip can be purchased at $6.88 from Home Depot. A summery table will be provided, see Table 1.

Table 1 cost of each component

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
<th>Cost of each material</th>
</tr>
</thead>
<tbody>
<tr>
<td>hoe</td>
<td>1</td>
<td>$15.97</td>
</tr>
<tr>
<td>threaded insert</td>
<td>1</td>
<td>$0.51</td>
</tr>
<tr>
<td>bolt</td>
<td>1</td>
<td>$0.18</td>
</tr>
<tr>
<td>bolt washer</td>
<td>1</td>
<td>$0.41</td>
</tr>
<tr>
<td>Wood</td>
<td>1</td>
<td>$0.96</td>
</tr>
<tr>
<td>Epoxy</td>
<td>25ml</td>
<td>$0.08</td>
</tr>
<tr>
<td>Plastic Dip</td>
<td>14.5 FL. OZ</td>
<td>$6.88</td>
</tr>
</tbody>
</table>
The bill of material (Table 2) shows the quantity needed to manufacture one redesign hoe and the cost of each component. The total material cost per unit is $23.27.

The operators are assumed to have average experience in manufacturing tasks. The labor cost is assumed to be $15 per hour and to have a benefit package of 15%. Consequently, the total labor cost is $17.25 per hour.

The time allocation for each step of manufacturing the hoe falls between one and twelve minutes. Locating the position of the holes on the traditional long handle for drilling process takes about 5 minutes. Drilling these holes on the traditional long handle takes about 12 minutes. Drilling the counterbored part of the holes takes another 10 minutes. The process of drilling the hole on two additional side handles takes about 1 minute. Drilling each of the semi-circular part of the handle takes 1 minute. Sanding each additional side handle takes about 2 minutes. Screwing in the threaded inserts on each additional side handle takes about 2 minutes. Applying
epoxy glue to reinforce the handle at the outer part, between the threaded insert and the wood of the additional side handle, will take another 2 minutes. Finally, sanding all the parts to smooth the surface takes 5 minutes. Therefore, the cycle time is 46 minutes. In addition, 10% allowance of the production time is given to the operators and possible defects. As a result, the standard time will be 50.6 minutes, and the labor cost will be $14.55 per unit. The table of the processing time and labor cost (Table 3) is illustrated below:

Table 3 Processing time information

<table>
<thead>
<tr>
<th>Process</th>
<th>time required in minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>locating holes on handle</td>
<td>5</td>
</tr>
<tr>
<td>Counterbored feature</td>
<td>10</td>
</tr>
<tr>
<td>hoe on additional handle</td>
<td>2</td>
</tr>
<tr>
<td>drilling semi-circular part</td>
<td>2</td>
</tr>
<tr>
<td>sand</td>
<td>4</td>
</tr>
<tr>
<td>attach thread insert</td>
<td>4</td>
</tr>
<tr>
<td>apply epoxy</td>
<td>2</td>
</tr>
<tr>
<td>sanding surface</td>
<td>5</td>
</tr>
<tr>
<td><strong>cycle time</strong></td>
<td><strong>46</strong></td>
</tr>
<tr>
<td><strong>Allowance</strong></td>
<td><strong>10%</strong></td>
</tr>
<tr>
<td><strong>Standard time</strong></td>
<td><strong>50.6</strong></td>
</tr>
<tr>
<td><strong>Standard time in hour</strong></td>
<td><strong>0.843</strong></td>
</tr>
<tr>
<td><strong>Total labor cost</strong></td>
<td><strong>$14.55</strong></td>
</tr>
</tbody>
</table>
Conclusion

The objective of this project is to help reduce the back and wrist strain while using the hoe. The design is created after evaluating the existing hoe, and then a prototype is built to conduct the experiment.

By implementing this design, the experiment shows the ergonomic redesign has accomplished the objective. The experiment shows that the statistical difference between the traditional hoe and the redesigned hoe is significant, so the ergonomic improvement of the redesigned hoe is significant. As a consequence, the implementation will prevent unnecessary farm tool related injuries, such as back injuries, carpal tunnel syndrome. The results show more participants like two additional side handles; however, it cannot be concluded that two additional side handles are optimal. The option of selecting one or two handles accounts for user preferences, which allows the freedom to change postures. The additional labor and material cost for the redesigned hoe is relatively low when compared to the medical costs of treating possible injuries.

In the future, this project can be improved by conducting an experiment for a longer period of time, such as a month because it will provide more detailed feedback on the design.
Appendix

Appendix A

Figure 6 Redesigned hoe with 2 additional side handles
Figure 7 Redesigned hoe with 1 additional side handle
Appendix B

Figure 8 Threaded insert and handle

Figure 9 Additional side handle
Appendix C

Survey

The following questions are used to evaluate the ergonomic quality of the traditional hoe.

**The score is ranged from 1 to 10. A score of 1 indicates the lowest comfort level and a score of 10 indicates the highest comfort level.**

Please rate the comfort level of your wrist while using the hoe

Score _______

The following questions are used to evaluate the ergonomic quality of the redesigned hoe with additional side handle.

**The score is ranged from 1 to 10. A score of 1 indicates the lowest comfort level and a score of 10 indicates the highest comfort level.**

1. Is there an improvement in back bending while using redesigned hoe

   Yes  No  Somewhat

2a. Is there an improvement in wrist bending while using redesigned hoe

   Yes  No  Somewhat

2b. Please rate comfort level of your wrist while using the hoe

   Score _______

3. Do you feel more comfortable while using this redesigned hoe with additional side handle overall?

   Yes  No  Somewhat
Appendix D

Group 1

The traditional hoe vs the redesigned hoe with one additional side handle

![Probability Plot of traditional hoe](image1)

**Figure 10** Normality plot of traditional handle in group 1

![Probability Plot of redesigned hoe with 1 handle](image2)

**Figure 11** Normality plot of redesigned hoe with one additional side handle in group 1
Paired T-Test and CI: traditional hoe, redesigned hoe with 1 handle

Paired T for traditional hoe - redesigned hoe with 1 handle

<table>
<thead>
<tr>
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<th>Mean</th>
<th>StDev</th>
<th>SE Mean</th>
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<td>10.97</td>
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95% CI for mean difference: (2.947, 6.178)
T-Test of mean difference = 0 (vs not = 0): T-Value = 6.02  P-Value = 0.000

Group 2

The traditional hoe vs the redesigned hoe with two additional side handles

![Probability Plot of traditional hoe](image)

Figure 12 Normality plot of traditional handle in group 2
Probability Plot of redesigned with 2 handles

Figure 13 Normality plot of redesigned hoe with two additional side handles in group 2

Paired T-Test and CI: traditional hoe, redesigned with 2 handles

Paired T for traditional hoe - redesigned with 2 handles

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</table>

95% CI for mean difference: (4.604, 7.284)
T-Test of mean difference = 0 (vs not = 0): T-Value = 9.36  P-Value = 0.000
Figure 14 Traditional handle
Figure 15  Additional side handle
Works Cited


