Palm Harvester Project

[i]

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Submitted To:

Dr. Okoli

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Abstract

Palm oil is derived from the fruits of the oil palm tree. There is a need, worldwide, to develop a safer, more efficient process of harvesting these fruits. The bundles of fruits can weigh up to 40-55 lb and fall to the ground from about 40ft. This puts the laborer cutting these fruit bundles down at a high risk of injury. Our goal is to improve the design of the palm fruit harvester that was developed last year in order to make it safer, improve portability, and advance efficiency. These problems were identified when the previous year's palm harvester was assembled. When putting together the device the weight, complex assembly, and lack of stability were apparent. These design flaws lead to our goal of upgrading the material used for the telescoping pole, adding automation to the telescoping apparatus, and improving mobility with the budget of $2.500.

1 Introduction

The Palm Harvester project is a Senior Design Project at FAMU-FSU College of Engineering, sponsored by Dr. Okoli. Dr. Okoli is the Chair of the Industrial Manufacturing Department at the FAMU-FSU College of Engineering. He has sponsored the Palm Harvester project for the past few years, with the hopes that as the years go on the Palm Harvester mechanism becomes more efficient and hopefully one day make it through production for the public's use.

The overall idea behind the Palm Harvester project is to create a mechanism which safely removes the bunches of palm fruit from the oil palm trees, averaging 40 ft. in height. The palm fruit contains oil that is in high demand, globally, as it is a type of vegetable oil. The design of the mechanism is entirely up to the team as long as it improves the previous year's mechanism, fits within the budget, and produces the desired output. Currently, the 2014-2015 Oil Palm Harvester Senior Design Team is multidisciplinary and consists of three Industrial Manufacturing Engineering students, two Mechanical Engineering students, and an Electrical Engineering student. Portability, safety, and efficiency are the main focus of improvement.

2 Project Definition

2.1 Parts of the Project

Dr. Okoli, the sponsor, stated the purpose of creating the palm harvesting mechanism is to satisfy the oil palm Plantation worker's needs. The need is to create a mechanism that is feasible to use throughout the plantations. **Figure 1** below shows how large an oil palm plantation actually is[1].

Figure 1 An aerial view of NBPOL plantation located in Papua New Guinea

2.2 Background research

2.2.1 Background

Oil palm trees originated in the tropical region of West Africa[ii]. The palm tree plant was taken to the Americas between the 14th and 17th century and then taken to the Far East where it thrived. The top five producing nations of palm oil are Indonesia, Malaysia, Thailand, Nigeria, and Colombia[ii]. Due to its high demand, oil palms are grown as a plantation crop in countries with high rainfall in tropical climates within 10 degrees of the equator [ii]. There are small-scale oil palm farms, which may cover around 7.5 hectares, medium scale farm, which may cover around 10 to 500 hectares, and large-scale farms, which may cover around 500 hectares or more [ii]. The oil palm trees, can grow up to sixty feet, will begin growing fruit after thirty months after its planted and will continue to grow fruit for 20 to 30 years [i]. The palm fruit comes in bunches that could weigh anywhere from 10 to 40 kg [ii]. Below in **Figure 2** is an image of what a palm fruit bunch looks like [iv].

Figure 2 A Palm Fruit Bunch. The size a big factor when harvesting them

2.2.1 Application

The oil produced by the fruit is one in which is used in many West African cuisines[ii]. Additionally palm oil is used in soaps, washing powders, margarine, cereal, and many other common household food items [iii]. The reason many people aren't aware of palm oil is because it is often labeled as vegetable oil in most ingredient labels [iii].

2.2.1 Dangers

There are a variety of danger aspects caused by the palm fruit. The most important danger is the process of removing the palm fruit from the tree. Since the trees height ranges around forty feet, it makes it hard to remove the fruit from the tree. One of the more dangerous methods used can be seen in **Figure 3 (left)** where the worker actually climbs the tree to cut down the palm fruit. Another method used is where workers use a sickle mechanism to remove the fruit but when the fruit is loosened the palm fruit bunch begins to fall. The palm fruit bunch could potentially hit the workers on the ground because of the massive amount of fruits being cut down in the larger plantations. **Figure 3 (right)** below shows a plantation worker removing the palm fruit bunches from the tree. One can clearly see the height difference between the fruit bunches and the worker [vi].

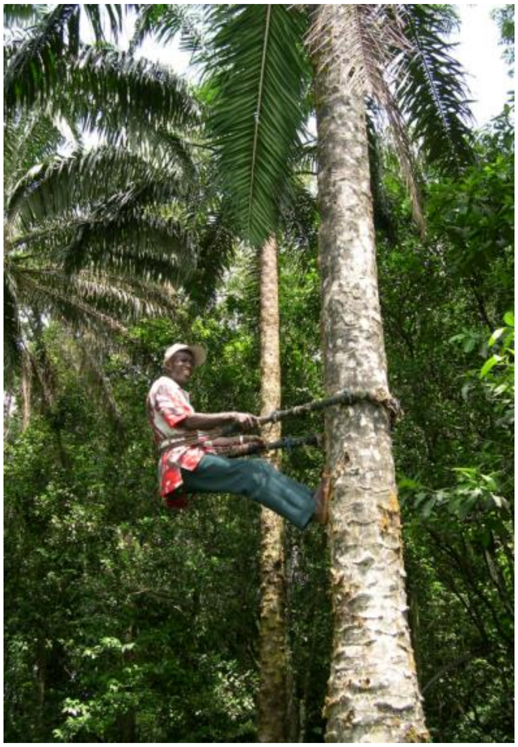

Figure 3 Palm Plantation Worker climbing tree to remove the bunches of fruit. (left). Worker removing Palm Fruit Bunches from oil palm fruit tree (right)

2.3 Project Scope, Assumptions, and Deliverables

2.3.1 Project Scope

In order to develop the previous year's mechanism there are a variety of improvements that must be made. These improvements include: replacing the PVC telescoping pole with a ductile aesthetically pleasing material, simplifying the pulley system, replacing the cutting mechanism, automating the telescoping pole, replacing the wheels, and revamping the cart. Due to the limited budget, which is $2.500, and time, it is not feasible to accomplish all these tasks, thus the team has selected four out of the six tasks stated. First and foremost, the telescoping pole material needs to be replaced with a ductile material with a square cross section to prevent any pole rotation that could cause the entanglement of wires. In order to prevent having to pivot the 130-pound pole each time assembly occurs, it has been decided that the pole will be automated. Currently, the pulley system has parts that are outside the pole which can cause them to be tangled or damaged when assembling next to a tree, this is why it has been decided that the pulley system be completely inside the pole as well as simplified. The last area that will be covered is the wheels. Their current condition is poor but they are relatively inexpensive to replace which would increase the mobility of the cart. If the four tasks selected have been completed with time and budget to spare, then the cutting mechanism will be assessed.

2.3.2 Assumptions

A variety of factors will play a key role in the design of the oil palm fruit harvester. Maximum cultivating height, weight of fruit bunches, and terrain amongst other criteria will be considered. Current cultivating methods will be examined in order to enhance the process of harvesting oil palm fruits. **Table 1** summarizes key dimensions and features of a typical oil pam tree as well as specifications of the plantation cultivating process. **Figure 4** depicts the typical layout of an oil palm plantation [ii].

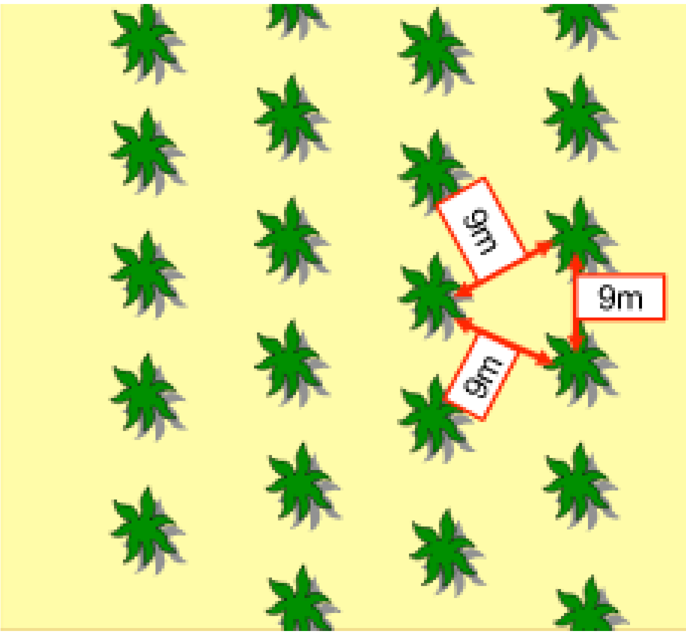

Figure 4 The typical layout of a plantation was taken into consideration when devising the size of our palm harvester.

Table 1 The key dimensions of a typical palm

Key Dimensions and Features of a typical palm	
Palm Fruit Weight	40 – 55 lbs
Number of Fruits per Bunch	Up to 200 fruits
Growing Temperatures	77 – 82° F
Plantation Planting Density	143 Palms per Hectare
Begins to Produce	3 – 4 years
Growth Height	40 ft
Diameter	0.75 – 2.5 ft
Amount of Sunlight	4-5 hours/day
Amount of Rainfall	Year-round

2.3.3 Deliverables

The table with the deliverable dates is located in **Appendix 8.1**, based on the Gantt Chart which can also be located **Appendix 8.2**. Our Gantt chart is constantly being updated and looked at, as it goes into nearly day-by-day plans.

3 Team Organization

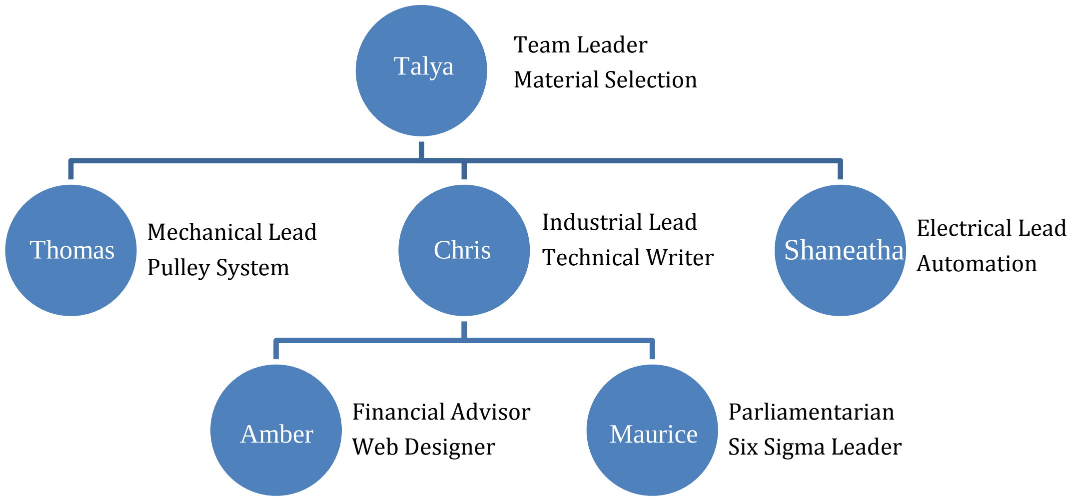

Figure 5 The hierarchy of our team as well as the titles and roles. Disclaimer: These are just titles as we all equally contribute towards the final product.

The team leader of the Define Phase is Talya Levin, she is also in charge of Material Selection. Given that Talya would like to focus on materials research post-graduate and has had additional coursework in material science based classes makes her the ideal candidate to determine the new material for the mechanism. Thomas Baker is the Mechanical Lead and in charge of designing the new pulley system; Thomas takes a hands on approach to his work and finds improvements in the current system easily making him the ideal candidate for this position. Chris Chiros is the Industrial Lead and Technical Writer on the team. Chris has had an internship at Caterpillar working within an engineering team in charge of providing technical documentation to move forward with engineering projects. Shaneatha Gates is the Electrical Lead and in charge of Automation; given her coursework within the Electrical Engineering department she has the knowledge and resources to accomplish this task. Amber Smith is the Financial Advisor and Web Designer; having been an application developer for JP Morgan and the National Science Foundation she has the expertise to design a functional website. Maurice Derius is the Parliamentarian and Six Sigma Leader; having a Green Belt in Six Sigma gives Maurice the credentials to ensure our project is aligned within the requirements of Six Sigma and overall industrial grade quality.

4 Project Charter and Business Significance

4.1 Project Charter

4.1.1 Business Case

The palm oil Industry is growing day by day. In the last decade, it is estimated that 45 million tons of palm oil have been extracted. The market is expected to grow more than 65% by 2020[vii]. The main exporters of this product are Indonesia and Malaysia. Oil palm represents 3.2% of the Malaysian gross domestic product, GDP, and 6% to 7% of the Indonesian GDP [vii]. The industry is inherently labor-intensive, requiring a global average of five workers per hectare. Competing oil crops often require approximately one worker for every 200 hectares[vii]. In Malaysia, the palm oil sector employs 590,000 direct workers (including many laborers imported from Indonesia) and in Indonesia, 3.7 million people are engaged in the palm oil industry and downstream industries[vii]. This fruit impacts a vast amount of people, and if we can find a way to efficiently and safely harvest these fruits without greatly increasing the current harvesting costs, it would greatly impact the industry as a whole.

4.1.2 Opportunity Statement

The basis of this project is to create an efficient, safe, and affordable way of harvesting palm fruit bundles from the oil palms. The reason so many resources are being

invested into this is because of the liquid gold one is able to extract from these fruits. Palm oil is the world's highest yielding oil crop. It yields an output five to ten times greater than other vegetable oils. On top of its high yielding rate, palm oil is lower in price, has relatively high shelf life, and is reported to have more nutritional benefits than other leading vegetable oils. It is a very versatile oil that is used in both food and non-food products. It is used to make condensed milk, coffee cream, ice cream and margarine. Palm oil is also used to make important raw material in the production of soaps, detergents, greases, lubricants and candles. One can clearly see the high consumption and need for this product in **Figure 6**[vii].

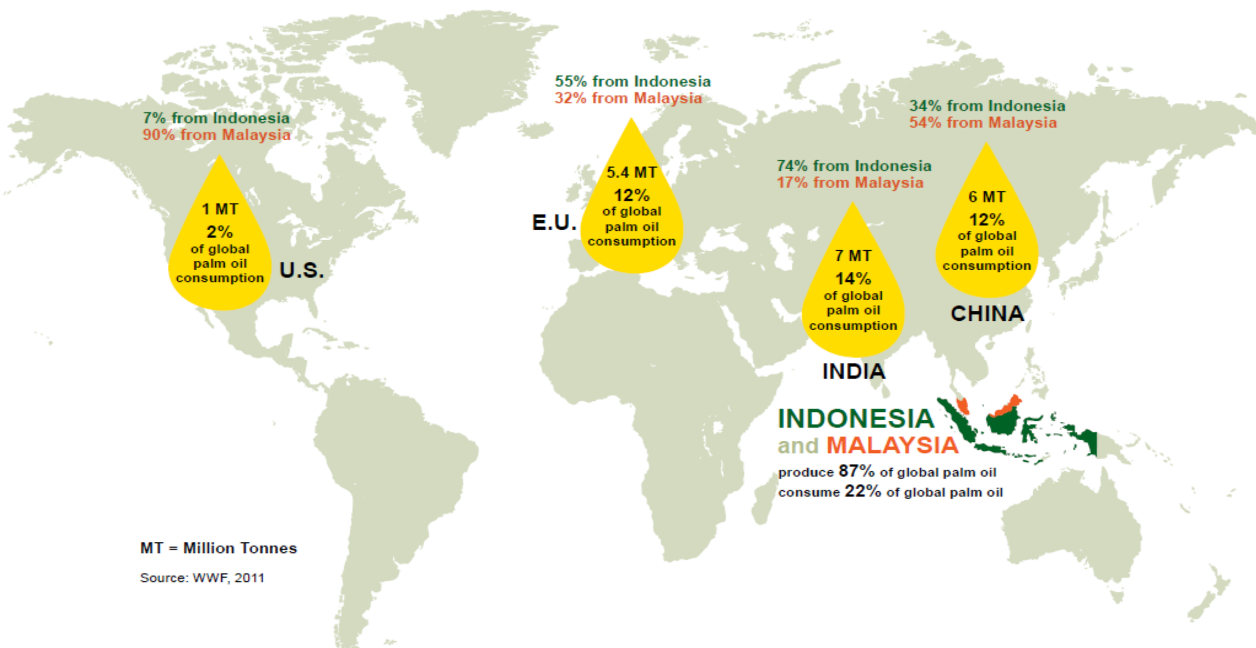

Figure 6 The trade flows of palm oil between the main production regions for palm oil (Malaysia and Indonesia), and their respective flows into the world's main palm oil consumer markets (India, Indonesia, China, EU, and the U.S.)

Soybean oil is the closest runner up to world oil production as seen in **Figure 7**. When comparing the price between palm oil and soybean oil, as seen in **Figure 8**, palm oil wins almost every time. It is clear to see palm oil is the way to invest and as global consumption increases, there will be a need for a more efficient way to harvest these fruits [vii].

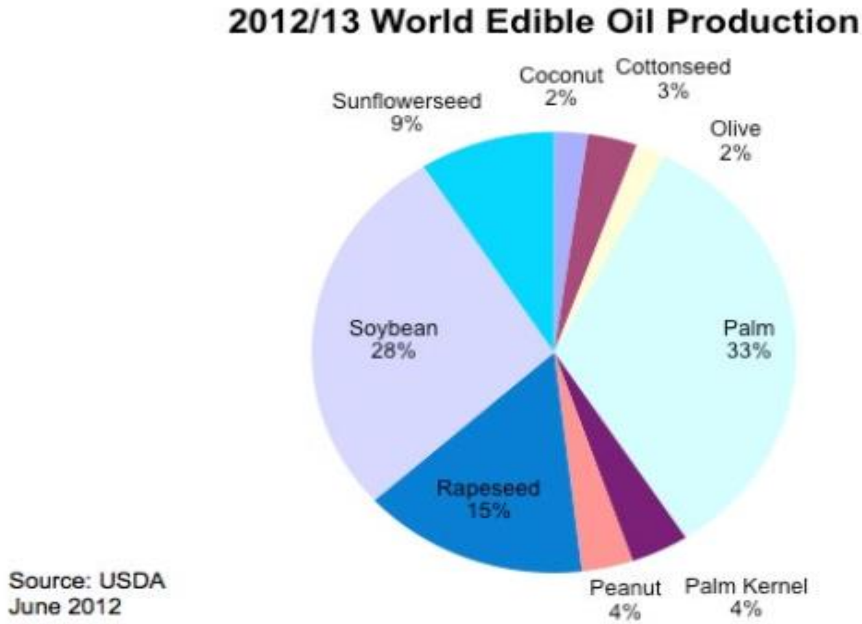

Figure 7 The production percentage of the rest of the important edible oils, and Palm oil is number one

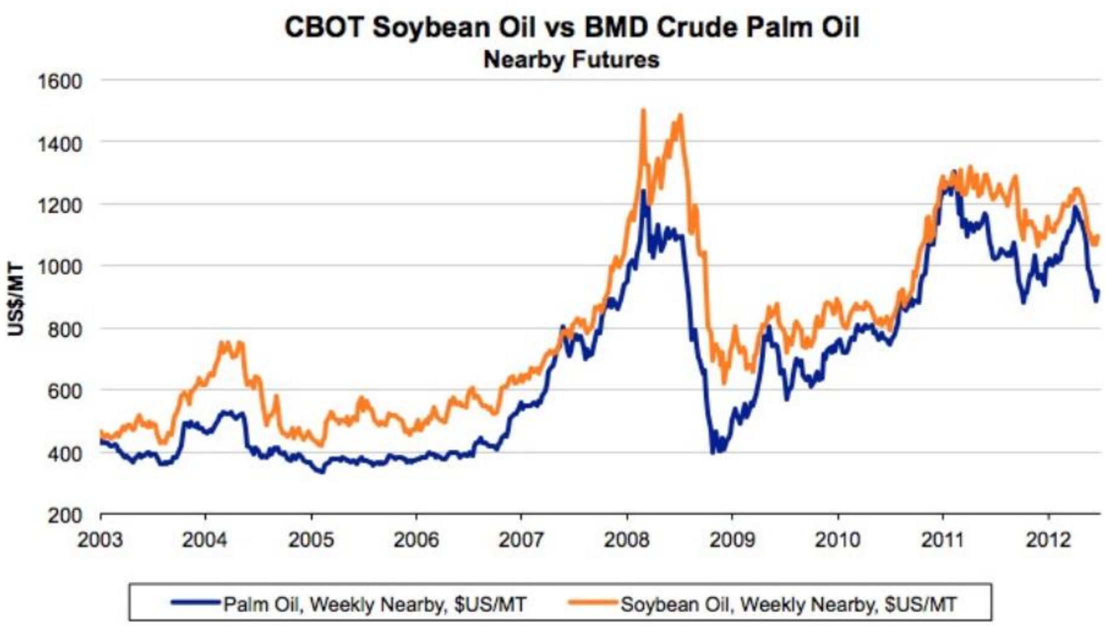

Figure 8 Palm oil compared to its top competitor, soybean oil, and palm oil knocks over the competition

4.1.3 Goal Statement

Currently the labor force either climbs the tree and cuts the fruit down, or uses elongated saws. Our goal is to replace this method by improving a device created by a previous senior design group. This device will be safe, effective, and remain low budget in order for it to be implemented in the oil palm plantations. Some of the points we would like to improve on from the previous device are maximize stability of telescoping pole, minimize risk of injury, and increase portability and mobility of the device.

4.1.4 Project Plan

The overall method to complete the Palm Harvester project is listed below along with a description.

- Visit Prototype- Build and assess previous years Palm Harvester prototype
- Brainstorm- Begin brainstorming ideas to improve the existing prototype
- Choosing Feasible Improvements- As a team the most feasible efficient improvements will be chosen.
- Analyze Design Components- Decide what components are needed in the chosen design and what materials they should be made of
- Build Scaled Model- Build a smaller scaled down model in order to test the chosen design and make sure it is feasible
- Test Scaled Model and Make Changes- Test the scaled down model to make sure that it performs in the intended manner and make changes based on the testing results

- ❖ Build Mechanism- Once the scaled down model has been approved, build the real mechanism
- ❖ Test Mechanism and Make Changes- Test the mechanism and analyze to see if any changes are necessary
- ❖ Present Final Mechanism- Once mechanism passes the testing phase it is time to present the final mechanism to the sponsor and faculty involved

To improve the existing mechanism, the team has decided that it would be most beneficial to improve the mobility of the mechanism, incorporate automation, change the material and shape of the telescoping poles, and modify the pulley system. The mobility of the mechanism will be improve by changing the wheels of the mechanism due suit the terrain. Automation will be incorporated in the mechanism; by having the telescoping poles remain in the vertical position and adding a motor to allow only vertical motion. The material and shape of the telescoping poles will be changed from circular PVC pipes to an Aluminum Alloy with a square cross section, thus removing the ability for the poles to rotate within each other. Lastly, incorporating it inside the poles to make it more visually appealing and less prone to entanglement will modify the pulley system. The approximate cost of these improvements is shown in **Table 3** below.

Table 2 Approximate Cost of Improvements

Improvement Area	Maximum Cost
Mobility	$100.00
Telescoping Pole Material	$1,300.00
Pulley System	$100.00
Automation	$500.00
Total	**$2,000.00**

The cost of the improvements shown in the table include a factor of safety incase of any problems that may arise. Also there is approximately $500 dollars left in the budget in order to account for additional improvements or any more problems that may occur.

4.2 Business Significance

Table 3 The threat and opportunities both short term and long term of our project

	Threats	**Opportunity**
Short Term	• Designing new pulley system • Determining circular or square cross-section	• Replacing PCV pipe • Incorporating mechatronics
Long Term	• Not faster than normal method • Not economically useful	• Patenting design • Manufacturing for commercial use

5 Analysis of Customer Requirements

5.1 Fishbone

To get a better understanding of the customer's requirements, a Fishbone diagram can be created to map out what is most important. Making our process more efficient than the previous years is the head of the diagram as it will guide us towards what we are trying to achieve. The main components of the fishbone are: Man, Methods, Machine, and Material. After breaking down each of these components an efficient process can be achieved.

The first component of the fishbone is the user. Our product will require minimum training, that is, it will be very easy to use. The other aspect of this component requires that its users to follow the ergonomic procedures, we want to make sure that our customers are free from liabilities and musculoskeletal disorders while using our product. The second component of the fishbone deals with methods. Considering that most palm trees are 40 feet tall we are creating a product that can reach that height. A telescoping pole and an automated crank will help us achieve this goal. The third component of the fishbone is concerned with machine. We want to create a product that is a safe as possible and will not cause any harm or injuries to its users. We also want our product to be power efficient and environmentally friendly that is why we will use recyclable materials and we will require that the users dispose of the batteries properly. When our customers buy our product they will expect it to last, they don't want something that's going to break down the next day. With this in mind, we will be using high quality materials so our product is stable and durable. This will enhance the reputation of our product on the market. Our final product needs to be waterproof as well because it will be used in unpredictable and harsh weather conditions. Another component of the diagram is portability; we need our product to be lightweight so it can be easily moved from tree to tree.

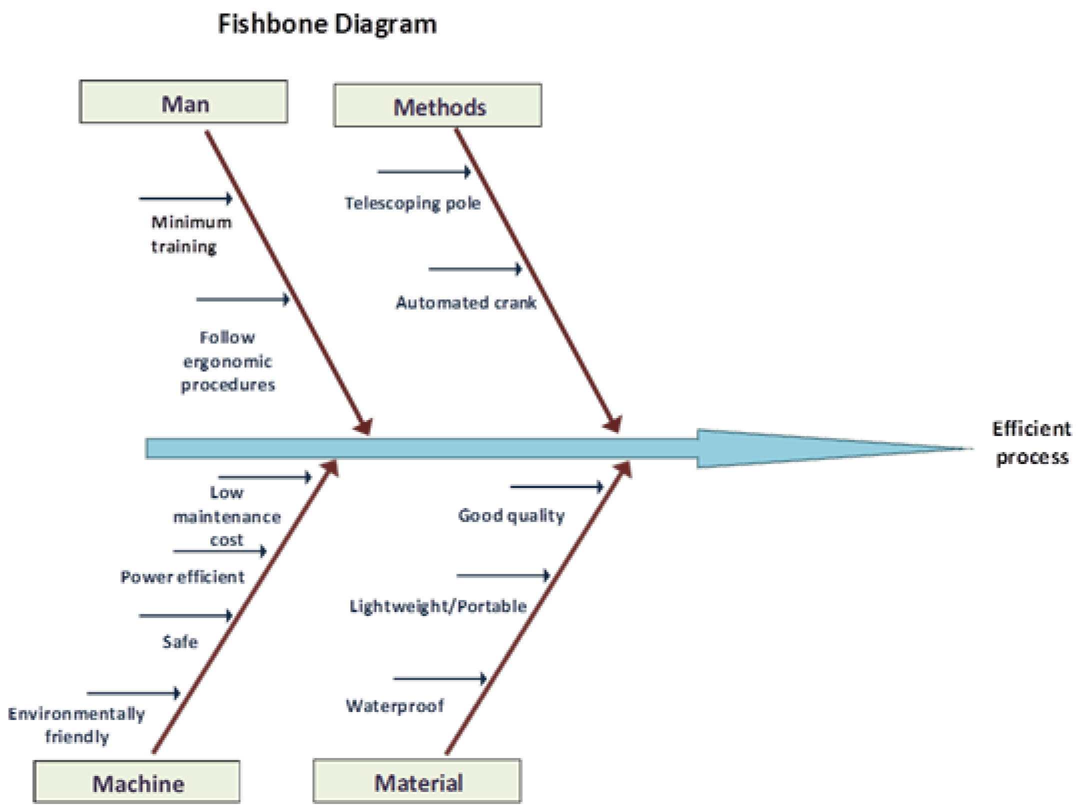

Figure 9 This fishbone diagram shows what needs to be tackled in order to create an efficient palm harvester

5.2 House of Quality

To understand exactly what the customer requirements are, a House of Quality (HOQ) was created. On one side is a list of the customer requirements, also called the "WHATS", which lists their quality demands. The HOQ was created based on the information our sponsor has supplied. Our sponsor, Dr. Okoli has ranked the importance of customer requirements on a scale of one to

ten, with ten being the most important:

- Automated
- Minimum power consumption
- Light weight
- Durable
- Easy to use
- Safe
- Fast
- Environmentally friendly
- Water proof

The next sets of requirements are the technical requirements. These are the “HOWS” when performing the project. We will use this process to achieve our goals, which is a fully automated process. Each technical requirement must be specified whether it is a maximized or a minimized requirement. These specifications are based upon what the project would benefit from the most. Below it’s a list of technical requirements:

- Weight of materials
- Quality of materials
- Speed of climb
- Battery capacity/Durability
- Size of cart
- Size of wheels
- Complexity of the design

The most important customer requirements are automation and minimum power consumption. Automation has an importance rating of 10, which shows that our customer wants the final product to be fully automated. Automation is the only customer requirement that has a

strong relationship with three of the seven technical requirements. Minimum power consumption is the other important customer requirement and has an importance rating of 9; this goes along with our customer's goal, which is making a final product that's energy efficient.

Portability, durability, safety and cost efficiency are some of the other customer requirements. Our final product needs to be portable/ lightweight as it will be easier to move from one plantation to another. It also has to be durable since the product will be frequently used to harvest palm fruits. We are also required to make a product that is safe as it won't cause any liability to harm its users. Staying within our budget is also important because we don't want to go over our $2,500 that was provided to create the final product.

The last but not least requirements are ease of use, fast, environmentally friendly and waterproof. Creating a device that is easy to use will improve its marketability because more users will want to buy it. As of right now, most palm fruit plantation owners are using human labor to harvest the palm fruit, so if we can create a machine that can be faster than man it will gradually eliminate the need of human labor. Our final product needs to be environmentally friendly, as it won't cause any harm or damage to the soil and the tree. Finally, we need to design a product that is waterproof because it will be used in unpredictable weather.

Each customer requirement was compared to each technical requirement and a correlation was determined. The correlations are either strong, moderate, weak, or none. Through these correlations, the significance each of them was determined.

The next set of relations for the house of quality is looking at each technical requirement and comparing it with the other technical requirements. This creates the roof for the House of Quality. They either have a strong positive, positive, strong negative, negative, or no correlation at all. The House of Quality is shown in **Appendix 8.3**.

5.3 Voice of the Customer

Creating a Voice of the Customer Tree will allow us to identify the main parts involved in this process. Making the process automated being the major requirement, we have broken down the tree into six subdivisions: easy to use, portable, safe, environmentally friendly and budget. Easy to use is one the biggest demand that our customer voiced. In order to achieve this requirement, we will make our design simple and we want to design the product so that it requires little to training, as it will make it easier for anyone over the age of 18 to use. Portability is another requirement that our voiced. We are designing a product that will be lightweight, as it will make it easier to move from one palm plantation to another. Our customer also voiced safety, and we will meet this requirement by following ergonomics guidelines so any musculoskeletal disorder can be prevented when using our product. Durability is another concern; we want to build a machine that won't break down after few months, that's why in our design we will be using good quality materials so that our product can last long. Staying an budget and creating a product that is environmentally friendly were the last two requirements that our customer voiced; for our design we were allocated $2,500 we need to stay within this budget by making smart choices when selecting the materials for the product. Our final product must be environmentally friendly, that's why we will build it will materials that won't cause any damages to trees and the soil when the palm fruits are being harvested, we will also require that our users dispose of the batteries properly when replacing them. The Voice of the Customer is shown in **Appendix 8.4.**

6 Conclusion

Dr. Okoli sponsors the Palm Harvester Project and is the chair of the Industrial Manufacturing Engineering department at the FAMU-FSU College of Engineering. The project team consists of three Industrial Manufacturing Engineering students, two Mechanical Engineering students, and one Electrical Engineering student. The goal of the project is to improve the existing mechanism in order to safely remove the bunches of palm fruit from the oil palm tree. The palm fruit contains oil that is used in many popular products such as soaps and cereals thus explaining why the palm fruit is in high demand. These oil palm trees reach heights of around forty feet and the palm fruit bunches can weigh 40-55 lb. Currently, oil palm tree plantation workers use sickle mechanisms to remove the bunches of fruit from the trees. By manually removing the bunches of fruit from the trees the workers are exposed to many dangers. The primary danger involved in removing the fruit from the tree is the risk of the bunches falling from the tree and hitting the plantation workers. It is important that the previous mechanism created be improved in order to increase portability, safety, and efficiency. In order to achieve this, the mobility of the current mechanism will be improved, automation will be incorporated, the telescoping poles material and shape will be changed, and the pulley system will be modified. By improving and incorporating these aspects, the resulting mechanism will be appealing to the intended customers, oil palm plantation owners and service industries, thus resulting in them purchasing the mechanism.

7 References

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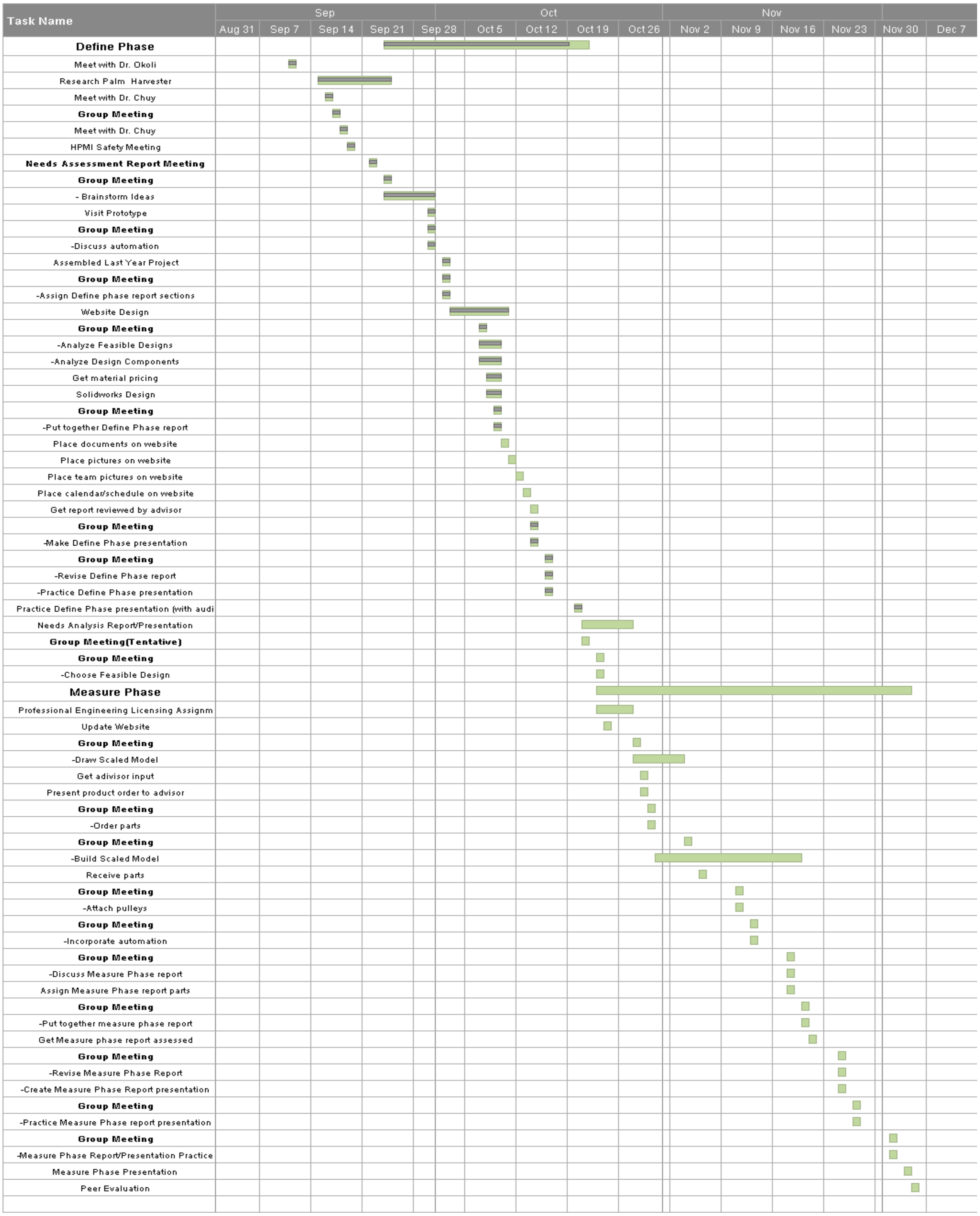
8 Appendix

8.1 Deliverable Table

Task Name	Duration	Start	Finish	Status
Define Phase	20	09/24/14	10/21/14	
Meet with Dr. Okoli	1	09/11/14	09/11/14	
Research Palm Harvester	8	09/15/14	09/24/14	
Meet with Dr. Chuy	1	09/16/14	09/16/14	
Group Meeting	1	09/17/14	09/17/14	
Meet with Dr. Chuy	1	09/18/14	09/18/14	
HPMI Safety Meeting	1	09/19/14	09/19/14	
Needs Assessment Report Meeting	1	09/22/14	09/22/14	
Group Meeting	1	09/24/14	09/24/14	
- Brainstorm Ideas	5	09/24/14	09/30/14	
Visit Prototype	1	09/30/14	09/30/14	
Group Meeting	1	09/30/14	09/30/14	
-Discuss automation	1	09/30/14	09/30/14	
Assembled Last Year Project	1	10/02/14	10/02/14	
Group Meeting	1	10/02/14	10/02/14	
-Assign Define phase report sections	1	10/02/14	10/02/14	
Website Design	6	10/03/14	10/10/14	
Group Meeting	1	10/07/14	10/07/14	
-Analyze Feasible Designs	3	10/07/14	10/09/14	
-Analyze Design Components	3	10/07/14	10/09/14	
Get material pricing	2	10/08/14	10/09/14	
Solidworks Design	2	10/08/14	10/09/14	
Group Meeting	1	10/09/14	10/09/14	
-Put together Define Phase report	1	10/09/14	10/09/14	
Place documents on website	1	10/10/14	10/10/14	
Place pictures on website	1	10/11/14	10/11/14	
Place team pictures on website	1	10/12/14	10/12/14	
Place calendar/schedule on website	1	10/13/14	10/13/14	
Get report reviewed by advisor	1	10/14/14	10/14/14	
Group Meeting	1	10/14/14	10/14/14	
-Make Define Phase presentation	1	10/14/14	10/14/14	
Group Meeting	1	10/16/14	10/16/14	
-Revise Define Phase report	1	10/16/14	10/16/14	
-Practice Define Phase presentation	1	10/16/14	10/16/14	
Practice Define Phase presentation (with audience)	1	10/20/14	10/20/14	

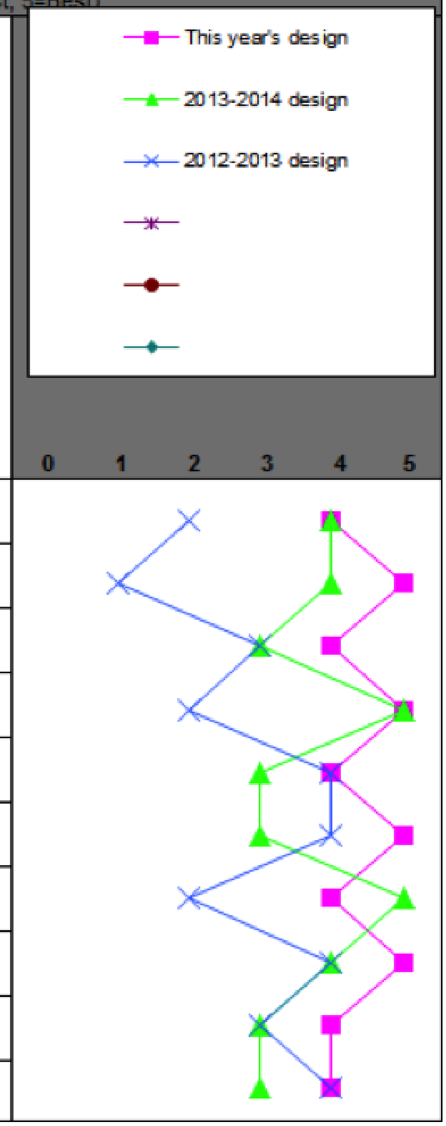
Needs Analysis Report/Presentation	5	10/21/14	10/27/14	
Group Meeting(Tentative)	1	10/21/14	10/21/14	
Group Meeting	1	10/23/14	10/23/14	
-Choose Feasible Design	1	10/23/14	10/23/14	
Measure Phase	31	10/23/14	12/04/14	
Professional Engineering Licensing Assignment	3	10/23/14	10/27/14	
Update Website	1	10/24/14	10/24/14	
Group Meeting	1	10/28/14	10/28/14	
-Draw Scaled Model	5	10/28/14	11/03/14	
Get adivisor input	1	10/29/14	10/29/14	
Present product order to advisor	1	10/29/14	10/29/14	
Group Meeting	1	10/30/14	10/30/14	
-Order parts	1	10/30/14	10/30/14	
Group Meeting	1	11/04/14	11/04/14	
-Build Scaled Model	14	10/31/14	11/19/14	
Receive parts	1	11/06/14	11/06/14	
Group Meeting	1	11/11/14	11/11/14	
-Attach pulleys	1	11/11/14	11/11/14	
Group Meeting	1	11/13/14	11/13/14	
-Incorporate automation	1	11/13/14	11/13/14	
Group Meeting	1	11/18/14	11/18/14	
-Discuss Measure Phase report	1	11/18/14	11/18/14	
Assign Measure Phase report parts	1	11/18/14	11/18/14	
Group Meeting	1	11/20/14	11/20/14	
-Put together measure phase report	1	11/20/14	11/20/14	
Get Measure phase report assessed	1	11/21/14	11/21/14	
Group Meeting	1	11/25/14	11/25/14	
-Revise Measure Phase Report	1	11/25/14	11/25/14	
-Create Measure Phase Report presentation	1	11/25/14	11/25/14	
Group Meeting	1	11/27/14	11/27/14	
-Practice Measure Phase report presentation	1	11/27/14	11/27/14	
Group Meeting	1	12/02/14	12/02/14	
-Measure Phase Report/Presentation Practice	1	12/02/14	12/02/14	
Measure Phase Presentation	1	12/04/14	12/04/14	
Peer Evaluation	1	12/05/14	12/05/14	
Completed				
Current				
Future				
Cancelled				

8.2 Gantt Chart

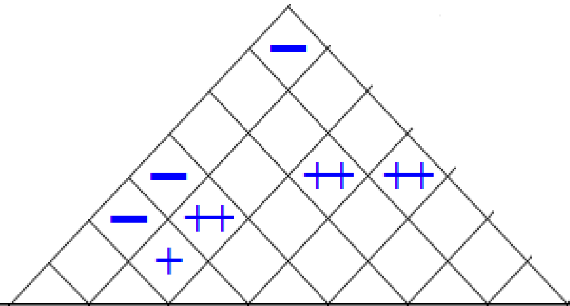


8.3 House of Quality

					Competitive Analysis (0=Worst, 5=Best)					
					This year's design	2013-2014 design	2012-2013 design			
1	3	7.3	6.0	Water proof	4	4	2			
2	3	8.5	7.0	Environmentally friendly	5	4	1			
3	9	8.5	7.0	Fast	4	3	3			
4	9	9.8	8.0	Cost effective	5	5	2			
5	3	9.8	8.0	Safe	4	3	4			
6	3	9.8	8.0	Easy to use	5	3	4			
7	3	11.0	9.0	Durable	4	5	2			
8	9	11.0	9.0	Light Weight	5	4	4			
9	9	12.2	10.0	Minimum power consumption	4	3	3			
10	9	12.2	10.0	Automated	4	3	4			



Legend		
⊖	Strong Relationship	9
○	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
▬	Negative Correlation	
▼ (blue)	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	



Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	Weight of materials	Quality of materials	Speed of climb	Battery capacity/Durability	Size of cart	Size of wheels	Complexity of design
				Column #	1	2	3	4	5	6	7
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	▲	▲	▲	▼	▲	▼
1	3	7.3	6.0	Water proof		○					○
2	3	8.5	7.0	Environmentally friendly	○	▲		○		○	▲
3	9	8.5	7.0	Fast	○	○	⊖	○			○
4	9	9.8	8.0	Cost effective		⊖		○	○	○	▲
5	3	9.8	8.0	Safe	▲	○			▲	▲	▲
6	3	9.8	8.0	Easy to use	▲	○	▲	▲	○	○	○
7	3	11.0	9.0	Durable		○		○	▲	○	○
8	9	11.0	9.0	Light Weight	⊖	○	▲	▲	○	○	▲
9	9	12.2	10.0	Minimum power consumption	○	○	○	⊖	○	○	○
10	9	12.2	10.0	Automated			⊖	⊖		○	○

	1	2	3	4	5	6	7
Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	4	6	5	6	4	4	4
Max Relationship Value in Column	9	9	9	9	3	3	3
Weight / Importance	206.1	304.9	243.9	353.7	148.8	232.9	222.0
Relative Weight	12.0	17.8	14.2	20.7	8.7	13.6	13.0

8.4 Voice of the Customer