FAMU-FSU COLLEGE OF ENGINEERING

# Palm Harvester Project-Analyze Phase

A report submitted to Dr. Okenwa Okoli
Industrial & Manufacturing Engineering Department

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The analyze phase is the third report amongst five progress reports. As part of the Six Sigma Methodology, this project is broken up into phases, "Define, Measure, Analyze, Improve, Control" (DMAIC). The Palm Harvester team will provide a complete analysis of the mechanism, as well as give an update on the status of the parts.

## Table of Contents

## List of Figures



## List of Tables

## Abstract

*The palm harvester senior design project consists of creating a mechanism in order to cut down palm fruit bunches from oil palm trees. These oil palm trees originated in West Africa and have migrated to places such as Indonesia, Malaysia, Colombia, Thailand, and Nigeria. These oil palm trees produce fruit that contain an oil used in the competitive vegetable oil market. In order to attain the fruit from the tree, the current method requires either a oil palm plantation worker to climb the tree with blade in hand to cut the bunches down or have a worker use a extended sickle blade to cut the bunches. Unfortunately, each of these methods have a high chance for the outcome to be dangerous, which is why there is a need for a new method. Last year, the palm harvester senior design team created a mechanism that is able to remove these bunches of palm fruit from the trees in a much safer method than the current one, however it's not efficient. This being said, this year's palm harvester team has decided to take the previous years mechanism and make improvements in order to attain an even more efficient method of harvesting palm fruit. Throughout this improvement project, the team has adopted the methodology from the Industrial Manufacturing Department where the project is subjected to phases in order to ensure proper completion of the project. The first phase was the Define Phase where the team defined the project and all the customer requirements. Then was the Measure Phase where the team did a time study on the setup of the previous year's mechanism and how it compared to the idea of the new mechanism. The new idea consisted of redefining the pulley system, changing the telescoping pole material, altering the cart, changing the wheels, and automating the telescoping pole. Currently, the project is subjected to the Analyze Phase where each component of the new mechanism, such as the motor, wheels, the square aluminum tubing, and the pulley design, were analyzed and made sure it is a feasible option. Once these components were confirmed to be feasible for the new design, the parts were ordered. More specifically, the current phase gives an update of the team's final design, status of the parts, and budget.*

# 1. Introduction

Dr. Okoli is the lead advisor for the Palm Harvester senior design team. He has given the team insight on the oil palm industry and explained the need for a mechanized way of harvesting palm fruits. The overall goal is to redesign and build a functioning palm fruit harvester able to be sold in the oil palm industry. The key factors used in the design process are functionality, mobility, and overall safety.

The palm oil industry is growing rapidly and the current harvesting processes are unable to keep up with demand. Current harvesting methods include laborers climbing oil palm trees that grow 40ft or higher with sickle blade saws in hand or stand at ground level and use elongated poles to cut down the 50lb bunches of oil palm fruits. With these current-harvesting processes in mind there is a need for an efficient and safe way to harvest palm fruits in order to satisfy the demand of palm oil as well as maintaining laborer safety. The previous year's senior design team designed and built a palm harvesting mechanism to aid in the harvesting process of palm fruits. The goal of the current senior design team is to improve last year's model in order to sell it commercially to oil palm plantations.

During the Measure Phase there were a few key design improvements to be implemented. The improvements consisted of adding automation to the telescoping pole, changing the telescoping pole design from circular cross sectioned PVC to square cross sectioned aluminum, lowering the center of gravity by moving the telescoping pole mechanism to the bottom shelf of the cart, increasing mobility by changing the wheels, and finally designing an internal pulley system.

Moving forward with this project leads to the current Analyze Phase, which will finalize all of the design improvements and create a business model for the palm fruit harvester.

# 2. Project Charter

## 2.1 Overview

Palm oil is used in everyday products such as soaps, washing powders, margarine, and cereal[i]. This palm oil is derived from palm fruit, which originated in West Africa[i]. Currently, the palm fruit is harvested in a dangerous manner where workers either climb the trees to cut down the palm fruit or they use a lengthened sickle blade to remove the fruit. Both of these methods are extremely dangerous because the palm fruit bunch could strike the workers on the ground and cause injury as well as the fact that the worker could injure themselves by climbing a tree with a blade in hand. **Figure 2 (right)** shows a plantation worker on the ground removing the palm fruit bunches from the tree [ii and iii].

**Figure 1**

**Figure 2**

**Figures 1& 2: Palm plantation worker climbing tree to remove the bunches of fruit (left); worker removing palm fruit bunches from oil palm fruit tree (right) [ii and iii]**

The goal of this project to create a mechanism that will replace these dangerous methods and will improve the previous senior designs mechanism. For this mechanism to be implemented in oil palm plantations, it must be affordable, effective, and safe. To improve last year's mechanism, the stability of the pole must be maximized along with the mobility and portability. The most important part of the mechanism that needs attention is minimizing the risk of injury.

### 2.1.1 Background and History

Oil palm trees originated in the tropical region of West Africa[i]. Between the $14^{th}$ and $17^{th}$ century, these oil palm plants were taken to the Americas and then to the Far East. Indonesia, Malaysia, Thailand, Nigeria, and Colombia are the top five producing nations of palm oil. Oil palms are grown as a plantation crop in countries with high rainfall in tropical climates within 10 degrees of the equator [i]. There are small-scale oil palm farms which cover up to 10 hectares, medium scale farms which cover 10 to 500 hectares, and large-scale farms which cover 500 hectares or more [i]. The oil palm trees can grow up to sixty feet and will begin growing fruit thirty months after planting. They will continue to grow fruit for 20 to 30 years [i]. The palm fruits comes in bunches that could weigh up to 55 lbs [i]. **Figure 3** is an image of what a palm fruit bunch looks like [iv].

**Figure 3: A palm fruit bunch [iv]**

### 2.1.2 Objectives and Expected Benefits

In order to improve the previous year's mechanism, a few factors have been chosen. The team has decided that it would be most beneficial to improve the mobility of the mechanism, to incorporate automation, to change the material and shape of the telescoping poles, and to modify the pulley system. The wheels of the existing mechanism will be replaced with more durable ones in order to suit the rough terrain. A motor will be added to the mechanism, which will result in an automated telescoping pole, allowing vertical motion. **Figures 5 & 6** shows the previous (left) and new (right) ideas for the telescoping pole. The previous pole was made of circular PVC pipes that lacked ductility and rotated within each other, whereas the new design consists of square aluminum pipes that are ductile.

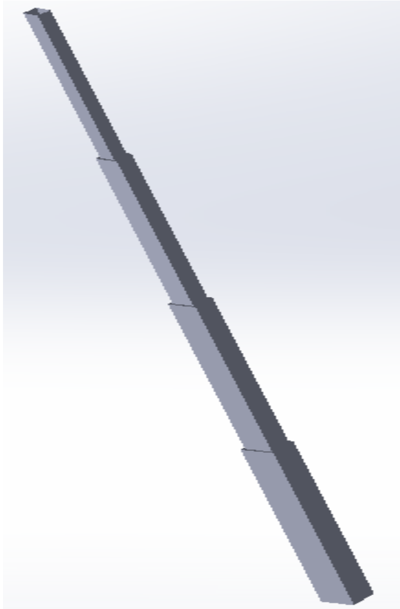


Figure 4 Figure 5

**Figure 4 & 5: Comparison of old and new telescoping poles (left: old pole, right: redesigned pole)**

### 2.1.3 Business Case

Approximately 45 million tons of palm oil has been extracted in the past decade indicating a growing industry[i]. Indonesia and Malaysia are the main exporters of palm oil and by 2020 the palm oil market is supposed to grow more than 65% [i].Palm oil plantations require an average of five workers per hectare whereas competing oil crops only require one worker for every 200 hectares[i]. Indonesia has 3.7 million people engaged in the palm oil industry while Malaysia has 590,000 people[i]. This shows that palm fruit impacts a large amount of people and with a way to safely and efficiently harvest the fruit the industry would benefit greatly.

The main reason behind this project is to create a safe and affordable way to harvest palm fruit. This project exists due to the fact that palm oil is profitable and high yielding and outputs five to times greater than other vegetable oil when comparing the oil harvested per tree [i]. The versatility of the palm oil, its high shelf life, low cost, and nutritional benefits compared to other leading oils give it edge amongst the other oils. **Figure 6** shows the need and high consumption of palm oil. In 2011, India consumed 7 million tons of palm oil which came out to be 14% of all of the global palm oil consumption[i]. This shows that there is a very strong opportunity for palm oil in the market.

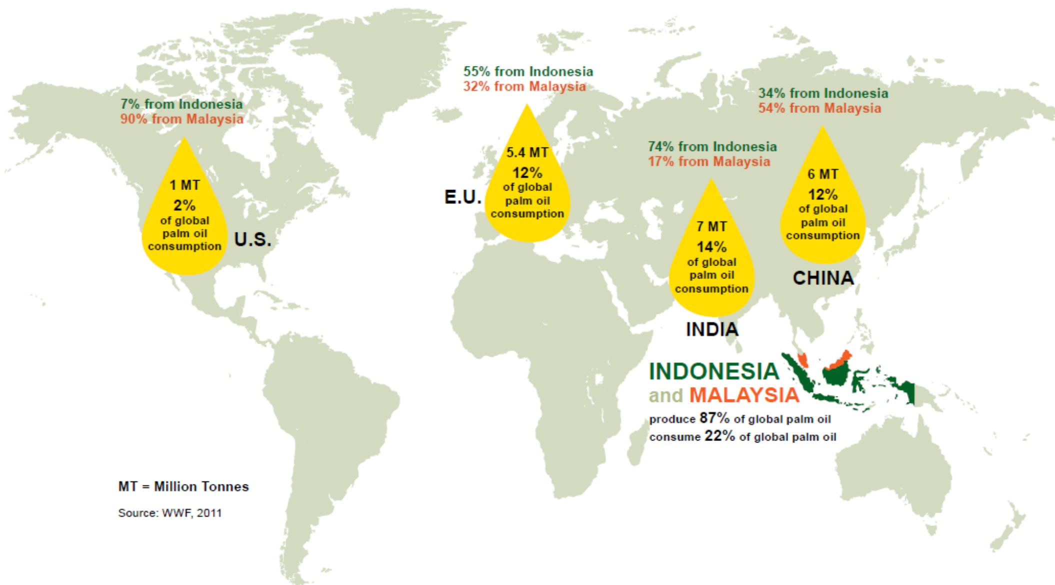



**Figure 6: Trade flows of palm oil between the main production regions for palm oil (Malaysia and Indonesia) and their respective flows into the world's main palm oil consumer markets [i]**

| | **Threats** | **Opportunity** |
|---|---|---|

**Table 1: Threat and opportunity matrix**

| | | |
|---|---|---|
| **Short Term** | • More injuries using the normal method<br>• May not be faster than normal method so plantation owners may not see a use for it | • Less injuries from workers<br>• Patent design<br>• Commercial manufacturing |
| **Long Term** | • Tree climber design if made could be competition<br>• Design may need to be modified at some point to meet needs | • Abundance of palm oil due to automation of process<br>• Prices of food with palm oil fall |

One of the short term threats include injuries due to the current method and that there is a risk that the new method may not be fast then the current method. On the other hand, the short term opportunities include less injuries to plantation workers, commercial manufacturing of the mechanism, and a potential patent design. Some long term threats affecting this project are that the automated tree climber which could be considered competitions due to the fact that it is smaller and more efficient than our mechanism. Depending on the markets needs long term, the mechanism may need to be modified to meet the customer’s needs. Long term opportunities include a decrease in price of food made of palm oil and an abundance of palm oil due to automating the process and eliminating fatigue in the worker.

### 2.1.4 Team Members/ Major Stakeholders

Dr. Okenwa Okoli is the key stakeholder and sponsor for this project. He is the chair of the Industrial and Manufacturing department. Dr. Frank is one of our advisors but also serves as the instructor of the Electrical and Computer Engineering senior design class. Dr. Shih and Dr. Gupta are the instructors of the Mechanical Engineering senior design class. Dr. Edrington serves as the Electrical Engineering advisor while Dr. Chuy serves as the Mechanical Engineering advisor. Dr. Edrington and Dr. Chuy have guided us in the process of selecting a motor. Margaret Scheiner and Emily Hammel serve as the Industrial and Manufacturing Engineering teaching assistants who help our project run smoother by answering all the teams' questions. Talya Levin is in charge of the material selection process; given that Talya would like to focus on materials research post-graduate and has had additional coursework in material science based classes, made her the ideal candidate to conduct the material selection process. 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. Christopher Chiros is the Industrial Lead, Technical Writer, and the team leader of the analyze phase. 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.

## 2.2 Approach

### 2.2.1 Scope

There are a variety of improvements that can be made to develop the previous years' mechanism. The scope of this project was determined by the overall improvements made to the original device. These improvements include: replacing the polyvinyl chloride (PVC) telescoping pole with aluminum, a ductile aesthetically pleasing material, incorporating an efficient easy-to-use and non-tangling pulley system, adding automation to the telescoping pole so that it may ascend and descend to and from the palm trees, replacing the wheels with an all-terrain, never run flat tires, and redesigning the cart to a fully fabricated, ready to manufacture device.

### 2.2.2 Assumptions & Constraints

A variety of factors will play a key role in the design of the oil palm fruit harvester. From the personal standpoint of this senior design team our assumptions and constraints are limited to the environment that we are yielded to as shown in **Table 2**. Being that the College of Engineering has no physical palm trees our assumptions are left to the average height, weight of fruit bunches, and other key factors that are found in statistical data. The team can also assume that specifications of weather conditions & working conditions by which we optimized our device to are accurate since gathered from computer aided software and nonphysical observations.

Constraints that the team has encountered are the limited amount of time and limited budget of just $2,500. It is not feasible to accomplish all the tasks to make a completely redesigned structure so as a result, the team has selected four out of the six tasks based on how much impact the improvement will have on the overall mechanism. If the four selected tasks are completed with time and budget to spare, then the cutting mechanism will be assessed.

**Table 2: The key dimensions of a typical palm [i]**

| | |
|---|---|
| **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 |

### 2.2.3 Deliverables

Upon the conclusion of this project the sponsor will be presented with the following:

- Functioning Palm Harvester
- Instruction Manual
- List of recommendations for the future teams

### 2.2.4 Milestones

During each phase of the Palm Harvester project a set of milestones must be completed to stay on track to successful complete the goal of improving the overall palm harvester mechanism, these milestones include;

Define Phase:

- Prototype Visit: Assemble and gather data from previous year's harvester
- Gather Requirements: Speak with sponsor on expectations and goals
- HPMI Safety Meeting: Certifying team members to access the HPMI building
- Finalize New Design: Determine the most feasible design that best suits expectations & product improvements.

Measure Phase:

- Build Scaled Prototype: Assemble a functioning prototype for sponsors.
- Incorporate Automation: Determine the most efficient product for automation of product.

Analyze Phase:

- Order Parts & Material: Submit all product & material orders to Industrial Office
- Plan Labor Assembly: Prepare plan of action to assemble actual palm harvester

Improve Phase:

- Assemble Actual Mechanism: Physically assemble the final palm harvester mechanism.

Control Phase:

- Test Mechanism: Operate & observe final mechanism & optimize for performance.
- Final Product: Fabricate or apply finishing to finalize overall manufactured look.

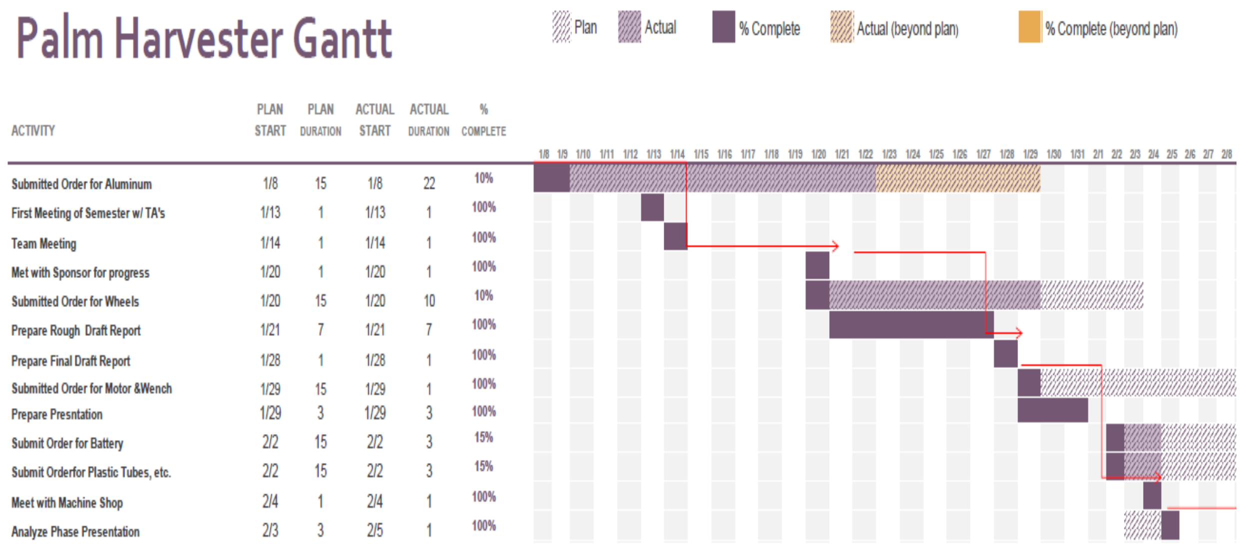



**Figure 7: Analyze Phase Gantt Chart.**

### 2.2.5 Budget

**Table 3: Money spent on this project as of 2/3/15.**

| Item | Vendor | Price |
|---|---|---|
| Trakker 1 HP Universal Winch | Lowes | $104.26 |
| Never Flat Wheel | Discount Steel | $236.80 |
| Aluminum Square Tube | Grainger | $640.26 |
| Power Source | O'Reilly | $94.99 |
| Vinyl Tubing | Lowes | $1.79 |
| Total | | $1078.10 |

The Budget is displayed on **Table 3** shows that a total of $1078.10 was spent of the $2500. This being said, there is still a large amount of money left in the budget leaving the project in good standing.

## 3. Defining Customer & Technical Requirements

In order to address the customer requirements, a House of Quality (HOQ) was created. The HOQ is divided into two main categories: The "Whats" and the "Hows". The "Whats" section lists the customer requirements, in other words what the customer wants from the product. The "Hows" depict the functional requirements; these requirements are the processes that will be used to meet the customer requirements. The most important customer requirements are listed in the following table. These requirements are ranked from a scale of 1 to 10, with 10 being the most important and 1 the least important.

**Table 4: Customer requirements by order of importance**

| | |
|---|---|
| Automated | 10.0 |
| Power efficient | 10.0 |
| Light-weight/ Portable | 9.0 |
| Durable | 9.0 |
| Easy to use | 9.0 |
| Safe | 8.0 |
| Cost effective | 8.0 |
| Fast | 8.0 |
| Environmentally friendly | 8.0 |
| Waterproof | 7.0 |

Notice that in the above **Table 4,** automation and power efficiency are ranked the highest due to the fact that the customer wants the final product to contain both these components. Waterproof is the only customer requirement that has lowest rank due to time and budget constraints.

After discussing with the team about the requirements, the group came up with the "HOWs" which are the processes required to satisfy the customer requirements. In addition, the House of Quality, in **Figure 8,** was created to help facilitate the order of importance of the quality characteristics.

The team came up with several quality characteristics, which are: weight of materials, quality of materials, speed of pole extension, battery capacity/durability, size of cart, size of wheels, and complexity of design. The weight of materials is very important in the implementation of the new design. Using heavy materials will require more force and power to push the cart and cause musculoskeletal disorders to the user. In other words, it would not be ergonomically safe to select heavy materials, as it will cause injuries to the user. The quality of the material needed for this design needs to accommodate the climate changes where the final product will be used. Since the product will mainly be used in tropical climates, the palm harvester will need to withstand hot and humid climates. The size of the cart is another important factor in this design because it was assumed the users will be implementing the mechanism in a plantation, therefore it should not be too big because it will be difficult for transportation. The wheel size needs to be at optimal size for stability and movement of the cart. When the initial push force is applied, the tires will experience some friction since the plantation's soil can be soft and muddy. The final product is going to be designed for owners of plantations where the oil palm trees grow the most (Indonesia and Malaysia), therefore it must be easy to use and have low maintenance cost. The speed of the pole extension of final mechanism needs to be quick in order to compete with the current harvesting methods, which is a human climbing the palm tree or using an elongated sickle pole. Furthermore, the goal of this team is to come up with a product that will be more efficient than the human climbing the tree or using a sickle blade.

The most important quality characteristics the design team came up with were the weight of the material, the quality of the material used, and the speed of pole extension. These quality characteristics need to be considered in the design and manufacturing of the final product.

The weight/importance row located at the bottom of the HOQ matrix determines the most critical customer requirements. The relative weights on the left of the HOQ were obtained by dividing each customer's rating index by the total of all the indexes, they summed up to 86. For example, environmentally friendly has a customer rating index of 7.0, therefore dividing 7.0 by 86 will give 8.1 %. This calculation was performed for each other relative weight. The weights were calculated by adding all the products resulting from multiplying the relative weight by the index number assigned to the relationship between the functional and the customer requirements. For example, there is a moderate relationship between environmentally friendly and the weight of the materials. Since a moderate relationship has an index value of 3 and environmentally friendly has a relative weight of 9.3, therefore multiplying 3 and 9.3 will give a portion of the technical weight. This calculation is performed for each relationship in the matrix and all the products are added together. Battery capacity and durability has the highest weight, and is therefore very important to take that into account when designing the final product.

The roof of the HOQ identifies the correlations that exist between each functional requirement. For example, there is a positive correlation between the weight of the materials and the speed of the pole extension, because the lighter the pole is the easier it will be able to extend. The box below the roof indicates the objective of functional requirements, whether it is minimized, maximized or hits the target. The HOQ helped to pinpoint the improvements that need to be made. Rather than having a broad focus, the HOQ allowed the criteria to be narrowed down to the most important factors.

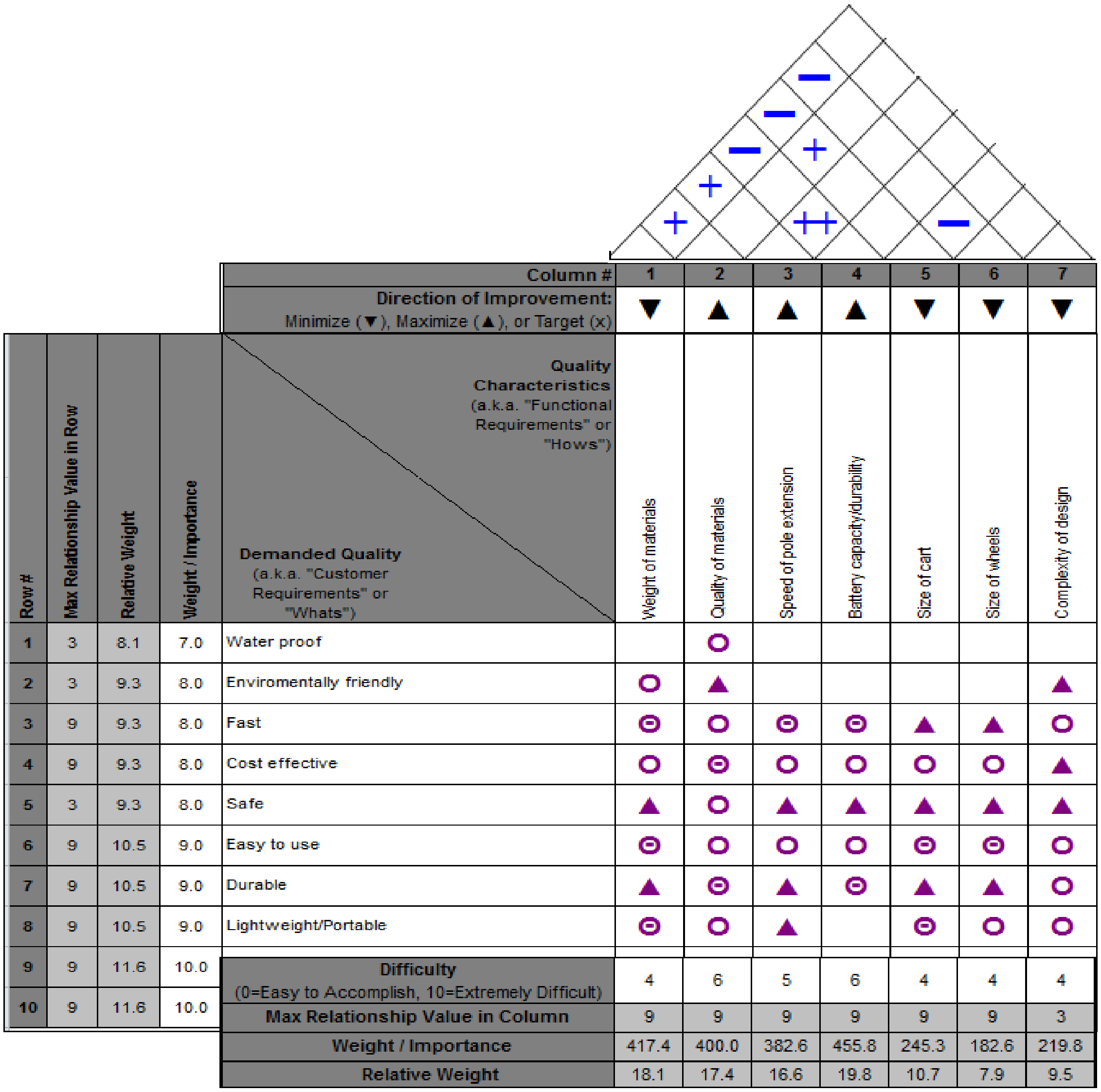



**Figure 8: House of Quality**

## 4. Measuring the Baseline Performance

In the Measure Phase the team tested the recommended improvements against the previous year's device. This proved the key areas of improvement were essential to having a more effective, efficient mechanism that will be one step closer to improving worker conditions on these plantations. The measurements taken included the time of assembly and disassembly and the stress experienced by the telescoping pole. The cart, pulley system, and the power and automation were also investigated and conclusions on those changes were made.

When the project began, the team agreed that an improvement to the assembly and disassembly of the cart was necessary. The time consumed in just putting the palm harvester together is something that is just not viable out in the fields. To show improvement between the old design and the new, the time of assembly was recorded and broken down to each step. The steps can be seen in **Figure 9** and the times can be seen in **Table 5**. It was concluded that automation will drastically cut this assembly time, as well as make the process a lot smoother and safer.

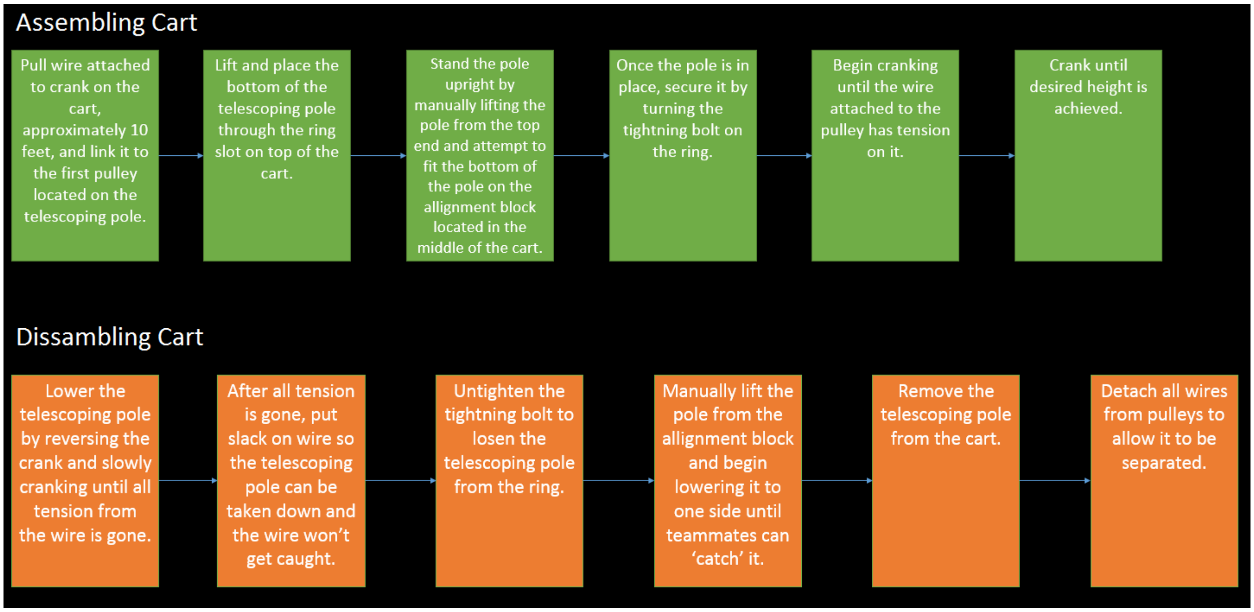



**Figure 9: Process Flow Diagram of Assembly (top) and Disassembly (bottom) of the cart**

**Table 5: Steps from Figure 8 and their respective times.**

| Steps | Assembling Time | Disassembling Time |
|---|---|---|
| **1** | 0:00- 0:39 | 0:00- 0:40 |
| **2** | 0:39- 1:15 | 0:40- 1:12 |
| **3** | 1:15-2:15 | 1:12-1:22 |
| **4** | 2:15-2:25 | 1:22-1:50 |
| **5** | 2:25-3:10 | 1:50-2:05 |
| **6** | 3:10-3:50 | 2:05-2:20 |

In the new design of the telescoping pole will change from circular to square cross sections. Having a square cross section will remove the need for the poles to rotate within each other. During this phase it was decided that the pulley system would be located within the poles but this idea changed in the Analyze Phase. The material of the pole is being changed from PVC to Aluminum 6063. A stress analysis for each telescoping pole was performed using PTC Creo Parametric, resulting in a Von Mises Stress diagram for each. In order to do an equivalent comparison, the same forces were applied to the two poles. These forces along with a legend are shown in the schematic in **Figure 10**. It was concluded that in PVC had a stress values that ranged from $3.2 \times 10^{-4}$ MPa to 113.76 MPa and the aluminum cross sections ranged from $4.8 \times 10^{-4}$ MPa to 28.45, therefore making the aluminum cross sections a better option.

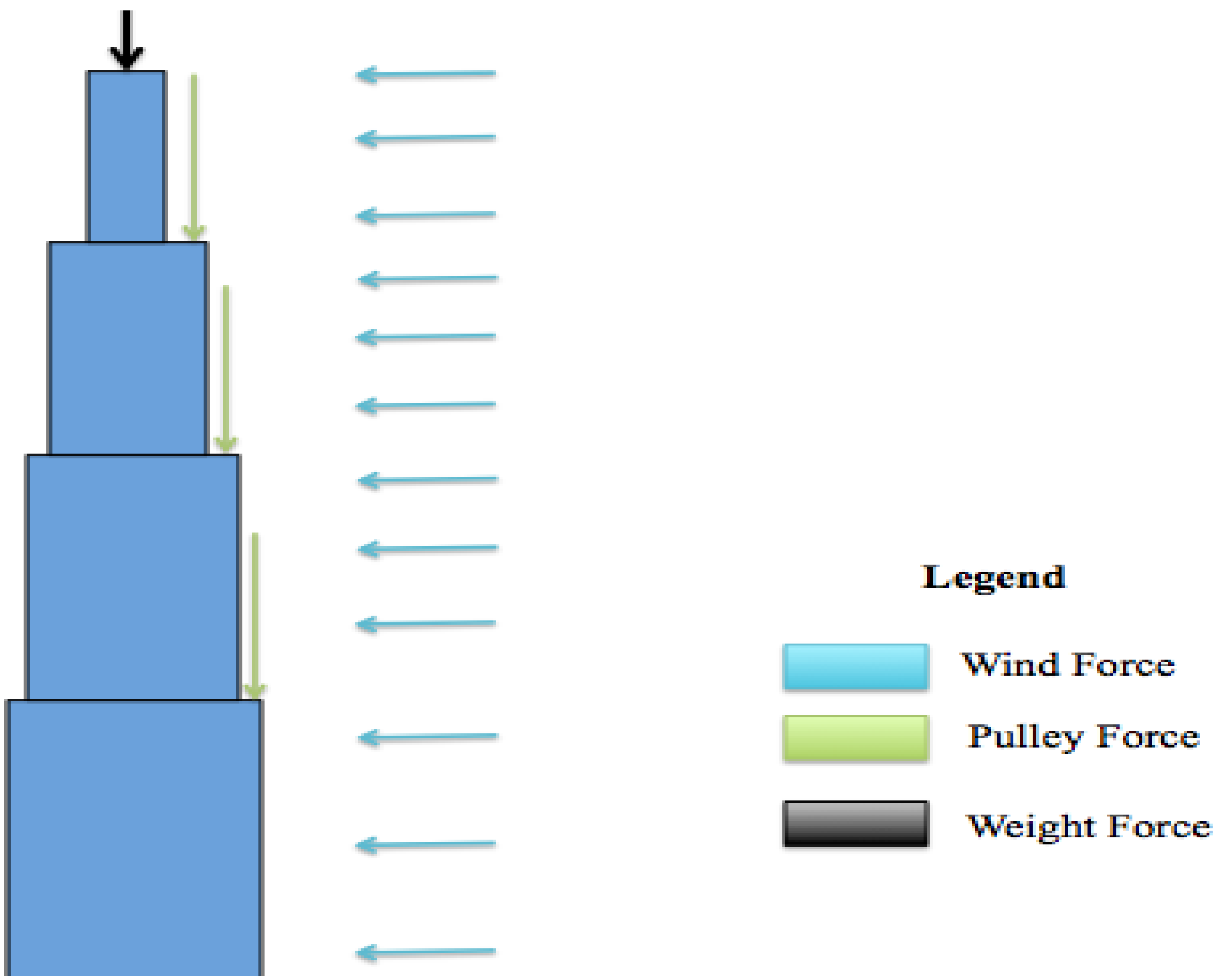



**Figure 10: Schematic of forces on telescoping pole**

Overall the measure phase was successful in helping the team to determine the necessary adjustments to the palm harvester. It was determined that the wheels will be upgraded to increase mobility in order to effectively traverse the oil palm plantation's rough terrain. The telescoping pole will be moved to the lower section of the cart in order to lower the center of gravity of the cart and improve the telescoping process. The team will add in a motor to make the process completely automated, to avoid the long setup time. Square cross sectioned Aluminum 6063 will be used in replacement of the circular cross section PVC and steel in order to increase the yield strength of the telescoping pole. During the measure phase it was decided that in order to decrease the chances of tangling, the pulley system will be moved from the outside to the inside of the telescoping pole.

# 5. Identifying the Root Causes

## 5.1 Telescoping Poles

As previously stated, the telescoping poles have been changed from circular Polyvinyl Chloride (PVC) poles to square aluminum poles (Aluminum 6063) in order to attain ductility [vi]. After analysis it was decided by the team, during the measure phase, that we would order four 3.05 m (10 ft) tall poles with cross sectional dimensions of 0.15 m x 0.15 m, 0.13 m x 0.13 m, 0.10 m x 0.10 m, 0.08 m x 0.08 m (6"x6", 5"x5", 4"x4", and 3"x3") which in total weighed 58.5 kg (129 pounds). Before ordering the poles, a final analysis was done to make sure the poles were exactly what was needed in respect to the motor, stress on the cart, weight, and budget. This final analysis showed that if the weight of the poles could be reduced then the stress due to the poles on the cart would be reduced, the cost would go down, and the amount of torque required to power the motor to lift the top three poles and the cutting mechanism would also be reduced. This being said, it was necessary for the team to find a way to lessen the weight of the poles. By reducing each cross sectional pole dimension by 0.03 m (1"x1"), the total weight of the four poles would go from 58.5 kg (129 pounds) to 48.1 kg (106 pounds), which is a 10.4 kg (23 pound) decrease. The decrease in weight and dimension of the poles, allowed us more money in the budget and more importantly enhanced the portability of the mechanism.

## 5.2 Wheels

The previous year's palm fruit harvester utilized 0.25 m (10") pneumatic swivel castor wheels, which are shown in **Figure 11[vii]**.

**Figure 11: Current tires on the Palm Harvester**

These particular wheels are said to be self-inflating, however currently the wheels are flat and dry rotted, making the palm harvester very difficult to maneuver on asphalt let alone on the soft soil found on an oil palm plantation. There was a major need to replace these wheels with a wheel that can withstand the weight as well as not deflate at any time. A zoomed in view of the condition of the current wheels is shown in **Figure 12**.

**Figure 12: Current tires on the Palm Harvester (zoomed in)**

The wheels that were chosen are 0.26 m (10.25”) never flat wheels, capable of a 158.8 kg (350 pounds) load for each wheel. In order to not have to replace the entire swivel castor assembly on the current cart, we chose a wheel that had the same axle diameter of 0.02 m

(5/8”) for easy replacement. This new tire is made of solid polyurethane, allowing the maneuverability of the cart to not be dependent on tire inflation. The new tires have been ordered and are expected to arrive within the next few days and are shown in **Figure 13 [viii].**

**Figure 13: New tires for the Palm Harvester [viii]**

## 5.3 Pulley System

Last semester it was decided that the pulley system, used to raise and lower the telescoping pole, will be located on the inside of the telescoping pole. This was decided for a couple different reasons: minimize risk of tangling and to protect pulleys and cabling from weather conditions.  Being able to access the pulleys and cabling for maintenance purposes is a huge selling point for the palm fruit harvester, therefore it was decided that moving the pulley system to the outside of the telescoping pole would be the best option. A sketch of the proposed exterior pulley system can be found in **Figure 14**. Imagine the situation of a laborer in the middle of an oil palm plantation, unable harvest because of a pulley failure or another small issue. The laborer would not be able to replace the pulley if it were located on the inside of the telescoping pole without bringing it back to the main facilities for repair. This would be costly for the plantation as well as unproductive. On the other hand, if the pulley were located on the outside of the telescoping pole, it would be easily accessible and able to be replaced in a reasonable amount of time.

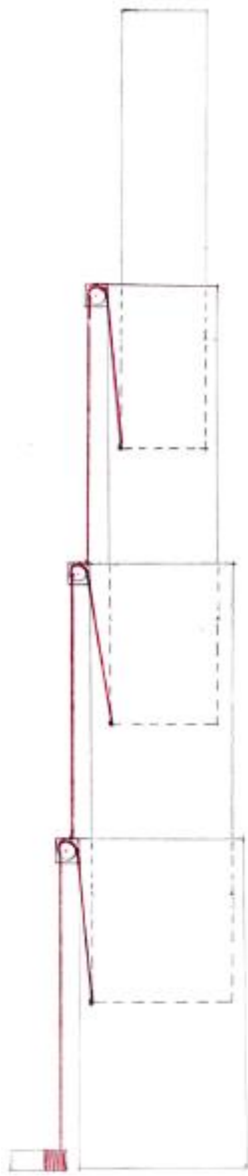


**Figure 14: External pulley schematic**

To prevent tangling of the cabling in tree limbs, sheathing will be added to the outside of the telescoping pole segments. This addition will prevent anything from obstructing the pathway of the cabling during the raising and lowering process. The sheathing will also act as a guide for the cabling to prevent the misalignment of the cabling on the pulleys. The previous version of the telescoping pole did not have any guides to keep the cabling in place, therefore more often than not, the cabling would come off of the pulley during the setup process. If any of the cables came off of their respective pulleys during setup or operation, the entire setup process would need to be performed again.

Since the pulley system was originally located on the inside of the telescoping pole, the pulleys needed to be very thin in order to fit in between the segments. These thin pulleys are not available commercially, so they would have needed to be fabricated from scratch. This would have cost the group and sponsor more money than originally planned for in the budget. Moving the pulley system to the outside allows for the pulleys from the previous telescoping pole to be reused, saving the group time and money.

## 5.4 Alignment Sleeve

The purpose of adding an alignment sleeve to the cart is to maintain vertical alignment of the telescoping pole. Vertical alignment is imperative in order to make sure the cart does not tip over during transportation and while in use due. The alignment sleeve will be mounted to the bottom shelf of the cart, directly in the center. Since the largest section of the telescoping pole is 0.127 m x 0.127 m (5” x 5”), the alignment sleeve must be larger in order be easily inserted and removed, yet small enough to maintain the upright position. The alignment sleeve will have eighth inch thick walls with inside dimensions of 0.128 m x 0.128 m (5.0625” x 5.0625”), which allows for a tolerance of one sixteenth of an inch all the way around the telescoping pole.

The telescoping pole will be held in place from moving with respect to the bottom shelf of the cart by its own weight. Since the entire telescoping pole mechanism will weigh upwards of about 72.6 kg (160 pounds) there is no need to constrain it in the vertical direction. This will save us time and money in the long run by going through with this option.

The stresses on the telescoping pole caused by the alignment sleeve, when compared to last year’s version of the palm fruit harvester, is spread out more evenly. The previous model had one single concentrated stress point on the circular PVC cross-section. Having this highly concentrated stress point made for a higher risk of failure as well as did not properly hold the telescoping pole in place. Since the new alignment sleeve covers a larger surface area of the telescoping pole, the stress will be distributed evenly across the face of the telescoping pole. The alignment sleeve will experience its largest stress points at the intersection of the bottom shelf and the alignment sleeve, therefore the alignment sleeve will need to be mounted so that is can withstand the maximum forces the telescoping pole applies to it.

## 5.5 Assembly

In order to attain the most accurate stress analysis, a model of the entire assembly (cart and pole) was created, as shown in **Figure 15**.

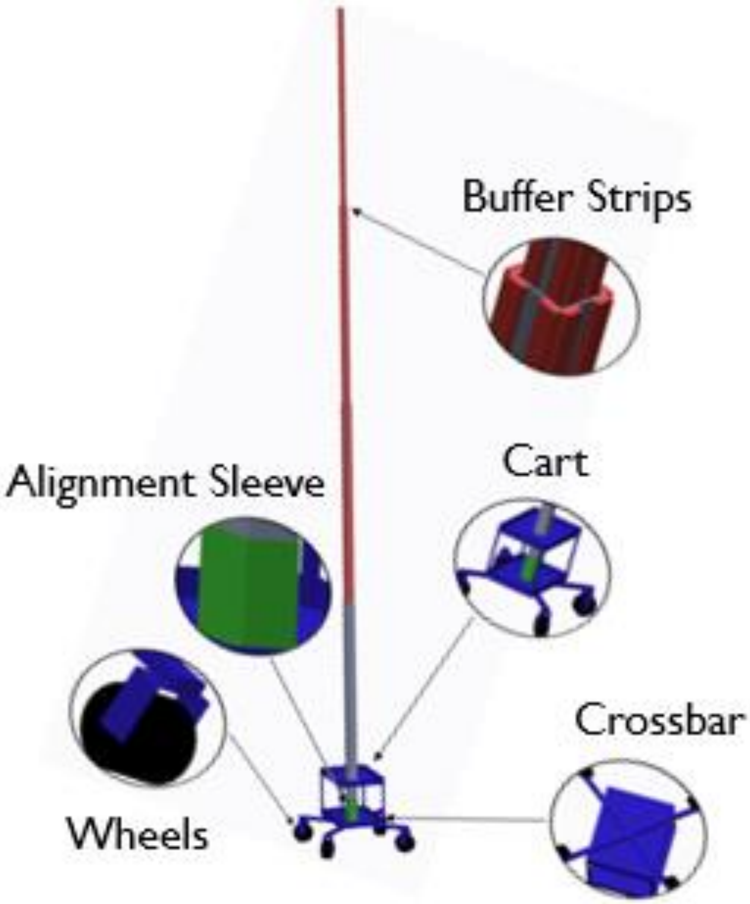



**Figure 15: Assembled view of mechanism with zoomed view of individual parts**

**Figure 15** is made up of many important parts, which are labeled with a zoomed view for a better understanding. The cross bar created by the previous years team, shown below the bottom level of the cart, serves a very important purpose. The purpose was to provide more support for the weights being applied to the cart. Another part is the buffer strips, which are attached to the outside (each side) of each of the top three poles. These buffer strips allow the poles to smoothly extend out of each pole and also eliminates the unwanted gap between each pole. The alignment sleeve is another part of the mechanism, which keeps the pole in place on the bottom shelf. The last crucial component is the wheels, which were, replaced with polyurethane no flat wheels in order to prevent the wheels from deflating due to the terrain.

### 5.5.1 Stress Analysis

Once the assembly was completed, it was time to put it to the test and see whether it could withstand all the wind and load forces. **Figure 16** shows the Von Mises stress diagram in MPa of the entire assembly.

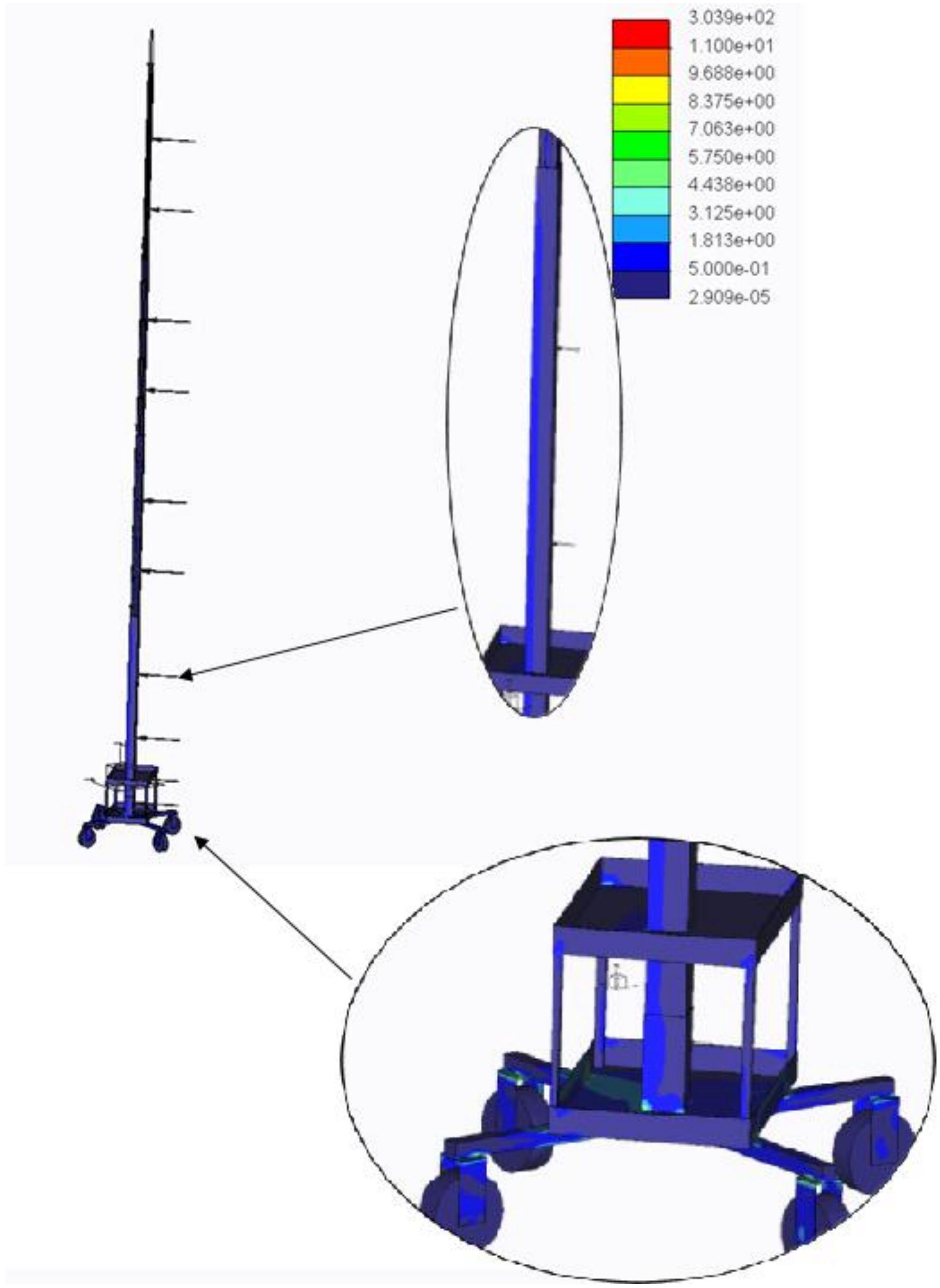



**Figure 16: Von Mises stress diagram of entire assembly with zoomed in views.**

**Figure 16** shows that the maximum stress distribution occurs on the bottom shelf of the cart where the crossbar is supporting, the telescoping pole is resting on, and where the motor and its components rest on. Starting from the bottom of the assembly, the brackets that hold the wheels feel the weight of the crossbar, which is why there is some blue distribution, indicating minimal stress. The connection between the crossbar and the wheels brackets show a wider variety of stress distribution with green being intermediate stress and red being maximum stress. This is due to the weight the crossbar feels from the cart that is placed on the end of each bar. As the bars reach the corners of the cart, a stress is revealed due to the weight the crossbars feel on the cart. Due to the fact that the cart and crossbar is in compression because of the weight of the pole and the ground pushing an equal but opposite force on the wheels, the bottom shelf of the cart shows a stress distribution that mimics the shape of the crossbar. This stress distribution can be considered moderate. Another aspect of the stress diagram that is crucial to understand is the telescoping pole. At the bottom of the telescoping pole, there is an alignment sleeve, which holds the pole in place on the shelf. Since the alignment sleeve contributes to the poles stability, the stress felt on the cart due to the pole on the top shelf is minimal. One thing that should be noted is that due to the wind forces, the telescoping pole experiences a minimal amount of stress on the side of the pole that is perpendicular to the force. Lastly, the buffer strips on each of the top three poles cause a minor stress on the poles because they are being pushed onto the poles by the previous poles for a tight fit. Overall the most crucial stress locations are at the connection point of the wheel brackets and the cross bar. The maximum stress felt here is somewhere between 9 and 11 MPa.

### 5.5.2 Deflection Analysis

The last analysis done on the assembly was the deflection, which is shown in **Figure 17**.

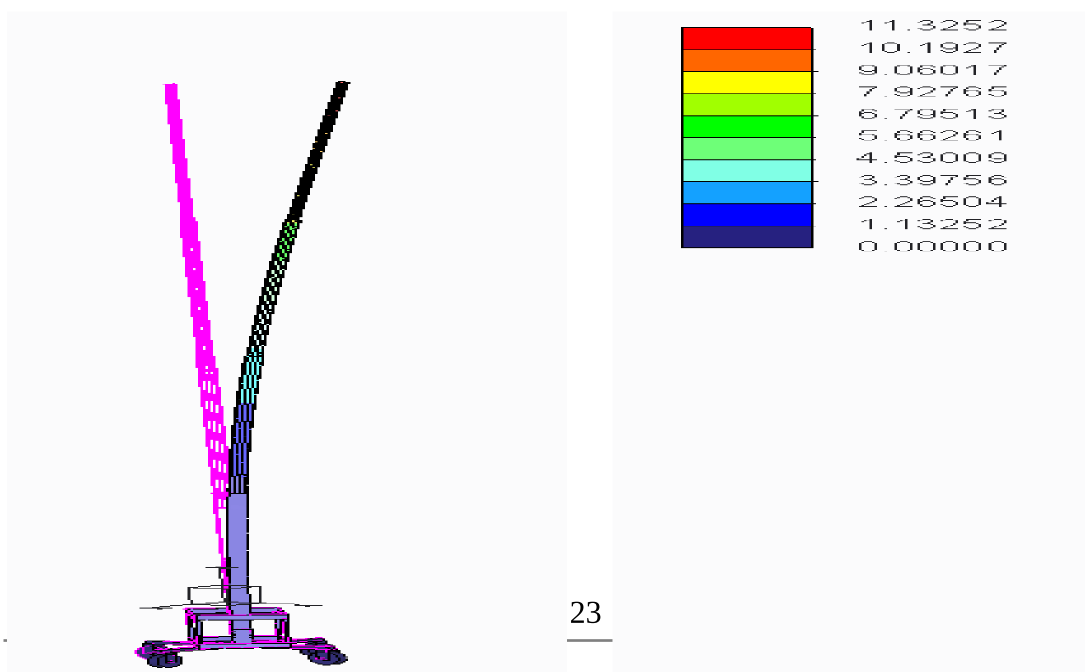





**Figure 17: Deflection of the mechanism due to the wind load.**

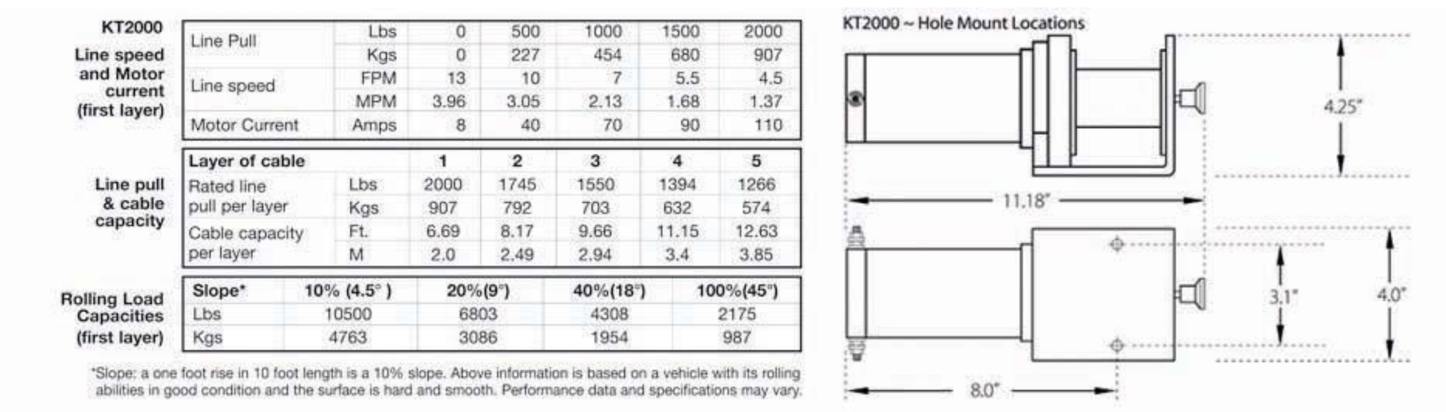
In **Figure 17** the maximum deflection of 11.3 mm is shown at the top of the telescoping pole. This maximum deflection occurs due to the lack of stability at the top of the mechanism. Since the value of the maximum deflection is in millimeters it does not pose any concern.

## 5.6 Motor

To reduce the manpower and time to harvest the palm fruit, our team has chosen to automate the machine. Incorporating this will also make machine marketable as opposed to having to manually crank the telescoping pole 40 feet. The mechanical engineers on our team collaborated to calculate the force and torque that our machine required leaving the electrical engineer to choose a motor based on the torque and power ratings. The calculations for force and torque can be seen in the appendices.

After reviewing these calculations with a technical advisor, a motor was selected. Our team decided to go with a winch and motor set by Trakker that has 1 HP [x]. This specific set, **Figure 18,** is capable of pulling up to 907.2 kg (2000 pounds) and will have no problem lifting our telescoping poles as we have reduced weight with this years' improvements. Some commercial benefits to this motor are that it is less than our allotted motor budget coming in at $104.26; also this choice includes a handheld switch making it user friendly. The technical benefits of this motor highlight the efficiency providing a projected telescoping pole rise of 3 minutes, addressing the goal of our machines competitiveness with present harvesting techniques. Other technical assistances that are built in the motor set are circuit breaker protection, low power consumption and size. These are all aids that will minimize production cost, increase safety and efficiency, all features that quality industry machines possess. A schematic of the Trakker motor is seen in **Figure 19** along with a load comparison table.


**Figure 18: Trakker motor [x]**



| KT2000 Line speed and Motor current (first layer) | | | | | | |
|---|---|---|---|---|---|---|
| Line Pull | Lbs | 0 | 500 | 1000 | 1500 | 2000 |
| | Kgs | 0 | 227 | 454 | 680 | 907 |
| Line speed | FPM | 13 | 10 | 7 | 5.5 | 4.5 |
| | MPM | 3.96 | 3.05 | 2.13 | 1.68 | 1.37 |
| Motor Current | Amps | 8 | 40 | 70 | 90 | 110 |

| Line pull & cable capacity | | | | | | |
|---|---|---|---|---|---|---|
| Layer of cable | | 1 | 2 | 3 | 4 | 5 |
| Rated line pull per layer | Lbs | 2000 | 1745 | 1550 | 1394 | 1266 |
| | Kgs | 907 | 792 | 703 | 632 | 574 |
| Cable capacity per layer | Ft. | 6.69 | 8.17 | 9.66 | 11.15 | 12.63 |
| | M | 2.0 | 2.49 | 2.94 | 3.4 | 3.85 |

| Rolling Load Capacities (first layer) | | | | |
|---|---|---|---|---|
| Slope* | 10% (4.5°) | 20%(9°) | 40%(18°) | 100%(45°) |
| Lbs | 10500 | 6803 | 4308 | 2175 |
| Kgs | 4763 | 3086 | 1954 | 987 |

*Slope: a one foot rise in 10 foot length is a 10% slope. Above information is based on a vehicle with its rolling abilities in good condition and the surface is hard and smooth. Performance data and specifications may vary.



**Figure 19: Motor Schematic with load comparison table [x]**

## 5.7 Budget and Gantt Chart

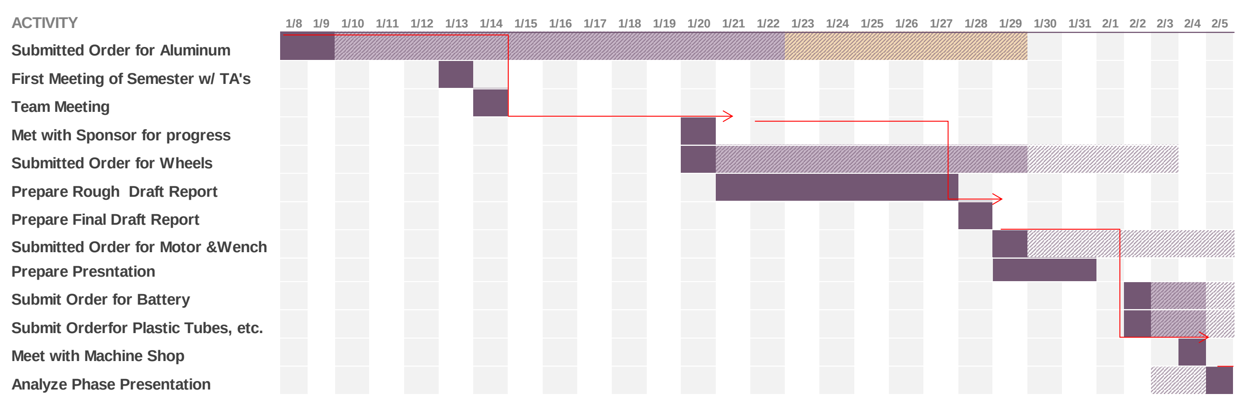
The total amount allocated for the Palm Harvester project is $2,500.00 however during the Define Phase it was determined that only $2,000.00 would be needed to make the necessary improvements. As of now we have $1,018.68 remaining of our projected $2,000.00 budget; that will go towards the power source, fabrication sheet metal, and miscellaneous items needed to put the mechanism together such as nuts and bolts. **Table 6** show the projected cost of materials and compares it to the actual money spent on parts.

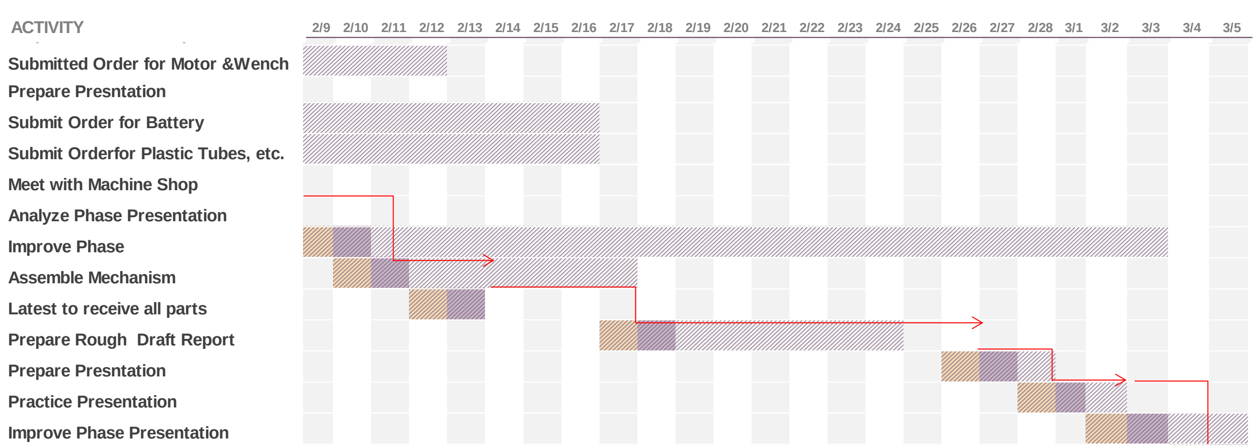
**Table 6: Projected vs. actual cost of project**

| Improvement Area | (Projected)Cost |
|---|---|
| Mobility | ($100.00) |

| | |
|---|---|
| Never Flat Tires | $236.80 |
| Telescoping Pole Material | ($1,300.00) |
| Aluminum Square Tube | $640.26 |
| Pulley System | ($100.00) |
| Automation | ($500.00) |
| Trakker 1 HP Universal Winch | $104.26 |
| **Total Projected** | **($2,000.00)** |
| **Total as of date** | **$981.32** |
| *Total Remaining* | *$1,018.68* |

The following Gantt charts displays the project plan for this upcoming spring semester. Each chart is separated by each phase. The Analyze Phase will result in a plan of assembly and submission of all product orders. The project plan projects that the mechanism will be built, operational, and fabricated to present as a manufactured product by April 7th. **Figure 20** shows the breakdown of phases and **Figure 21** shows the timeline of materials ordered.



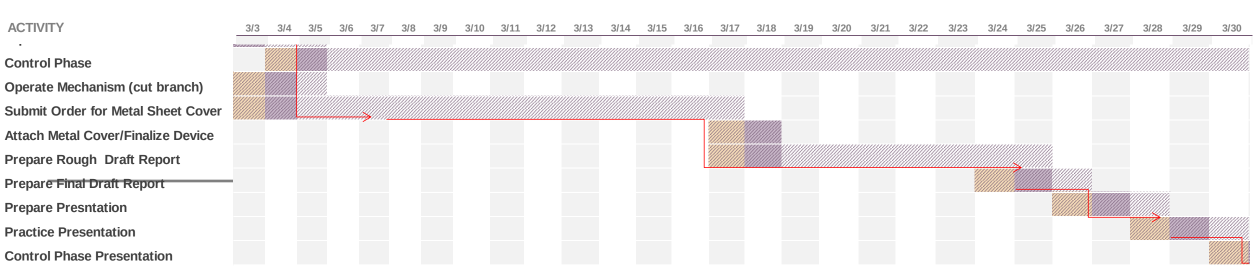




**Figure 20: Gantt Chart each section highlights each phase of the project.**

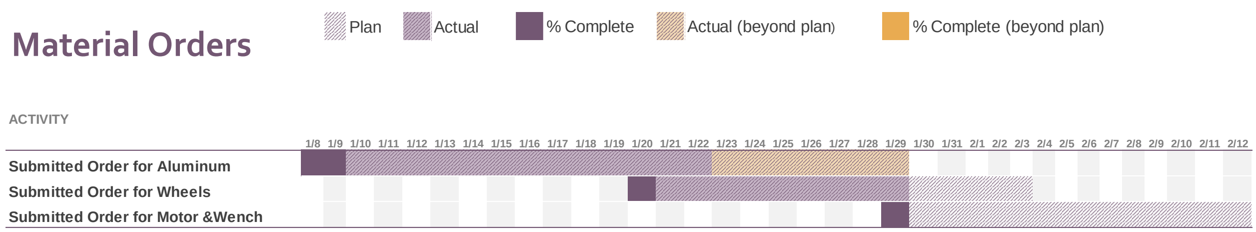
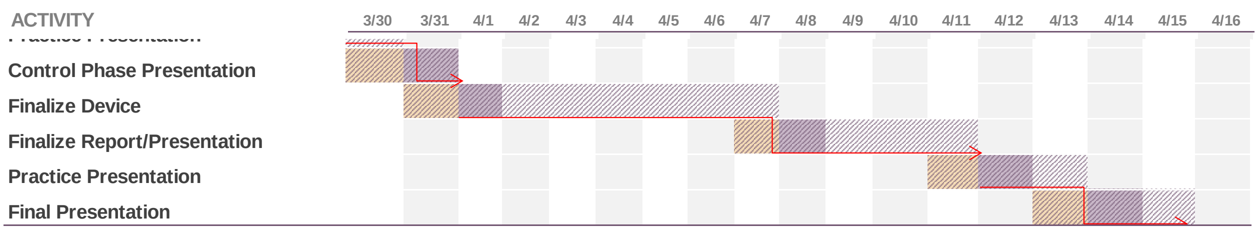



**Figure 21: Material orders Gantt chart**

## 6. Summary/Conclusion

As concluded in our overview, the traditional way to harvest palm fruit is: inconsistent,




expensive, and puts human life at risk. Therefore, our product goal still remains to deliver outstanding features that will minimize manpower. Through this analyze phase we were able to critique fine details of every improvement we aim to modify. From an industrial engineering stand point; the customer and sponsor requirements were determined. Decision making processes such as house of quality and measuring the performance yielded and effective priority list, thus leading to the analyze phase. As seen in this report the root causes were established and approached; these sources include the: telescoping poles, wheels, pulley system, alignment sleeve, and motor. Goals accomplished during this stage comprise of stress diagrams to identify stress distributions on the telescoping pole and force calculations to categorize the appropriate motor for the needed improvements. Based on these procedures our team was able to make purchases and will begin assembling in the immediate future. The next stage in our production journey is to begin assembling the proposed design. During this process we will also document useful advices for improvement keeping in mind the objectives for our mechanism. Our product objectives remain as follows: harvest the fruits, facilitate mobility on plantations, diminish ergonomic risks, exhaust the possibilities for user safety, and minimize human input with automation.

# 7. References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[x] "Trakker 1-HP 2,000-lb Universal Winch." *Shop Trakker 1-HP 2,000-lb Universal Winch at Lowes.com*. Web. 1 Feb. 2015. <http://www.lowes.com/pd_632857-50881-KT2000_0__?productId=50332867>.

# 8. Appendix

## 8.1 Required motor torque calculations

Weight of the top three poles (without the cutting mechanism)

$W := 69.28 lbf$
$W = 308.173 N$

Weight of the tope three poles (with the cutting mechanism)

$Wc := 109.28 lbf$

$Wc = 486.102 N$

The maximum weight force of the top three poles with the cutting mechanism (rounded up to take into account the friction of the pulleys)

$F := 500N$

The radius of rotation

$r := 3in$
$r = 0.076 m$

Maximum torque required for the motor

$T := F \cdot r$

$T = 38.1 \cdot N \cdot m$

## 8.2 Drag force calculations

Square Cross Section:

Height:

$h := 10ft$

Side measurement:

$s1 := 6in$

$s2 := 5.75in$

$s3 := 5.5in$

$s4 := 5.25in$

Density of Air:

$p := 1.2922 \frac{kg}{m^3}$

Average wind speed:

$v := 3.8 \frac{m}{s}$

Drag Coefficient:

$Cd := 1.05$

Surface Area:

$A1 := s1 \cdot h = 0.465 m^2$

$A2 := s2 \cdot h = 0.445 m^2$

$A3 := s3 \cdot h = 0.426 m^2$

$A4 := s4 \cdot h = 0.406 m^2$

Drag Force:

$Fd1 := 0.5 \cdot p \cdot v^2 \cdot Cd \cdot A1 = 4.55 N$

$Fd2 := 0.5 \cdot p \cdot v^2 \cdot Cd \cdot A2 = 4.361 N$

$Fd3 := 0.5 \cdot p \cdot v^2 \cdot Cd \cdot A3 = 4.171 N$

$Fd4 := 0.5 \cdot p \cdot v^2 \cdot Cd \cdot A4 = 3.982 N$

Circular Cross Section:

Drag Coefficient:

$Cd := 1$

Diameter:

$d1 := 6in$

$d2 := 5.75in$

$d3 := 5.5in$

$d4 := 5.25in$

Radius:

$r1 := \frac{d1}{2} = 0.076 m$

$r2 := \frac{d2}{2} = 0.073 m$

$r3 := \frac{d3}{2} = 0.07 m$

$r4 := \frac{d4}{2} = 0.067 m$

Surface Area:

$A1 := \pi \cdot r1 \cdot h = 0.73 m^2$

$A2 := \pi \cdot r2 \cdot h = 0.699 m^2$

$A3 := \pi \cdot r3 \cdot h = 0.669 m^2$

$A4 := \pi \cdot r4 \cdot h = 0.638 m^2$

Drag Forces:

$Fd1 := 0.5 \cdot p \cdot v^2 \cdot Cd \cdot A1 = 6.807 N$

$Fd2 := 0.5 \cdot p \cdot v^2 \cdot Cd \cdot A2 = 6.524 N$

$Fd3 := 0.5 \cdot p \cdot v^2 \cdot Cd \cdot A3 = 6.24 N$

$Fd4 := 0.5 \cdot p \cdot v^2 \cdot Cd \cdot A4 = 5.957 N$