FAMU-FSU COLLEGE OF ENGINEERING

Development of a Semi-Autonomous Oil Palm Fruit Harvesting Device

IME Group 10: Define Phase

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

Diez, Gabriel
Gerstenblitt, Matthew
Gonzalez, Enrique
Howard, Patrick
Machado, Alberto
Morin, Derek
Vetencourt, Maria Daniela

October 20, 2015

This report is the first of five progress reports. It defines the opportunities and constraints of this project, following the Six Sigma methodology of "Define, Measure, Analyze, Improve, Control" (DMAIC). The team's approach, deliverables the team will provide at the termination of the project, a detailed description of the customer requirements, and a discussion of preliminary design concepts are provided.

Table of Contents

List of Figures

List of Tables

Abstract

In this report, the development of an electromechanical system to harvest oil palm fruit is discussed. An analysis of the global oil market was conducted and illustrated that approximately one third of all oil produced is made from oil palm fruit. Since oil palms yield approximately 3,300 pounds of palm oil per planted acre per year and are the most efficient oil-producing crop, there is a large demand for palm oil. The current oil palm fruit harvesting method consists of a worker climbing a tree that is a maximum of 40-feet tall, manually cutting the fruit bunch, and then descending the tree. Dr. Okenwa Okoli, Chair of the Department of Industrial and Manufacturing Engineering at the College of Engineering of Florida Agricultural and Mechanical University and Florida State University, believes that the current harvesting method is dangerous and inefficient. He has sponsored this project with the intent of replacing the current climbing process by developing a portable and simple electromechanical device that improves workers' safety and productivity. Dr. Okoli's design requirements and the timeline for the entire project are discussed extensively in this report. $2,500 was allocated for the development of the device, while a target selling price of $2,000 was established to ensure that the device can be sold in developing countries. Finally, this report discusses three basic design concepts for developing a device that meets the sponsor's requirements. The first involves modifying the Class of 2015's ground-based mobility platform. The second involves increasing the extension length of an existing pole pruner. Finally, the third concept involves developing a tree-climbing robot that wraps around the trunk of the tree.

1. Introduction

The oil palm can easily be called the greatest oil-producing crop in the world. Capable of producing up to approximately 3,300 pounds of palm oil annually per acre of oil palm trees planted, it is the ideal plant to meet the global food market's demand for cooking oil [1]. It is not surprising, then, that it is responsible for 36% of all oil produced globally, while only encompassing 5% of the farm land used for oil [1]. Therefore, even a slight modification to the oil palm harvesting process could increase production capacity.

Currently, the process by which oil palm fruits are harvested involves a worker ascending a tree and manually cutting each fruit bunch [2]. Since the trees are grown in developing countries whose workers are paid very low wages, this process is fairly inexpensive [3]. However, there are many disadvantages to this manual process. Laborers experience poor working conditions, such as climbing a maximum of 40 feet by wrapping their arms around the oil palm tree's trunk. These conditions result in workers being diagnosed with various musculoskeletal disorders [2]. Additionally, the process of ascending oil palms is slow and exhausting, necessitating a large work force. For example, a 6,400-acre oil palm plantation requires 333 workers. Therefore, one worker is theoretically responsible for walking approximately 19 acres per day; roughly two Imperial tons are expected to be harvested each day. Thus, workers are usually assigned in teams of two to the aforementioned 19-acre area [4].

The project's sponsor, Dr. Okenwa Okoli, chair of the Department of Industrial and Manufacturing Engineering (IME) at the College of Engineering of Florida Agricultural and Mechanical University and Florida State University (FAMU-FSU College of Engineering), believes that the current process for harvesting oil palm fruit can be improved. Since the multibillion dollar palm oil industry [5] depends on such an inefficient harvesting method, developing a device to improve current harvesting methods would increase oil palm fruit production capacity and result in millions of dollars of increased revenue and savings for companies involved in the industry.

The team's task is to develop an electromechanical device that can safely and easily harvest ripe oil palm fruit in a way that is less expensive and more productive than hiring a person to do it. Since this device is intended to replace the work of one person, the sponsor has specified that it must require no more than one operator. Furthermore, this electromechanical device must be able to operate in the equatorial tropical regions where oil palm trees are planted [2]. Finally, since the farmers that grow oil palm trees generally live in developing countries [1], it is essential that the selling price of the final design be low enough to make it marketable.

Two different approaches to designing a harvesting device have been attempted in the past years. The Class of 2012's design involved a tree-climbing robot that would gradually climb up to the top of the tree and cut fruit [6]. However, once the prototype was built, it was too heavy to transport from tree to tree and Dr. Jonathan Clark strongly advised the project's team not to program it to climb the tree, because it would endanger individuals on the ground. The project was not assigned to the Class of 2013 [7]. The Class of 2014 designed a system that utilized telescoping polyvinyl chloride (PVC) poles that were transported on a cart; the poles extended a saw upward to cut oil palm fruit bunches [8]. The Class of 2015's design replaced the PVC poles with aluminum [9]. Upon completion, the design was too heavy to be pushed through the rough terrain of an oil palm fruit plantation and too unstable to ensure the safety of the operators.

In this report, the requirements for developing an electromechanical palm fruit harvester are defined. First, background research of the palm oil industry and an analysis of the market potential of an oil palm fruit harvester design are presented. Next, the technical requirements necessary to complete the customer's needs are determined. Finally, the entire project's schedule is outlined and several rudimentary design concepts are discussed.

2. Project Charter

2.1 Project Overview

2.1.1 Objectives and Expected Benefits

The objective of this project is to design a mechanism and build a prototype of a device that can harvest oil palm fruit semi-autonomously with only one operator. The mechanism must be able to reach the top of the palm tree, allow the operator to determine which bunches of fruit are ripe, and cut the ripe bunches. This project prohibits the device's operator from being physically lifted to the top of the oil palm tree and cutting the oil palm fruit. However, a worker is permitted to operate the device from the ground. The detailed requirements obtained from the team's meetings with Dr. Okoli are described in Table 1.

Table 1: Project Sponsor's Requirements

Requirement	Description
1. Low cost	The device must be able to be sold at a retail price of no more than $2,000. The device must also only require minimal maintenance to assist in minimizing the cost of ownership.
2. Portable	The device must be able to maneuver from oil palm to oil palm in rough terrain. For a freestanding design, this means the prototype must be lightweight.
3. Efficient	The device must be able to harvest oil palm fruit faster than human workers are able to harvest them. In addition, the harvesting time should be no greater than 20 minutes. Furthermore, the device is to be operated by no more than one worker.
4. Easy to Use	The device must be operable by current oil palm fruit harvesters. This means that the prototype must have simple controls that require only a short training period.
5. Durable	The device must be able to withstand tropical conditions, as well as be able to traverse through rough terrain effectively. Furthermore, the device must be able to withstand any impacts from the oil palm trees it might encounter.
6. Safe	The device must minimize the risk of injury or death to the operator or bystanders when it is being used. This means that any cutting mechanisms attached to the device must be secured physically, without the use of adhesives.
7. Environmentally Friendly	The device cannot cause any damage to the oil palm trees when it is harvesting fruit.

There are many ways meeting the objectives described in Table 1 would benefit society. Developing a low-cost harvesting device would allow plantation owners to be able to justify the expenditure in the long run, while making the device portable, efficient, and safe would allow a worker to harvest oil palm fruit in a much more effective manner than the current methods used [2]. Making the device is easy to use will allow the current harvesters to be able to operate it, while ensuring the device does not damage the tree will allow oil palm fruits to be harvested again in the future. Furthermore, the most tangible benefit of a successful prototype is the improved safety of the oil palm harvesters that currently climb trees as high as 40 feet to cut oil palm fruit bunches [2].

2.1.2 Business Case

There are four oils that account for 99% of annual global oil production by mass. These oils and their respective compositions are depicted in Figure 1 [1].

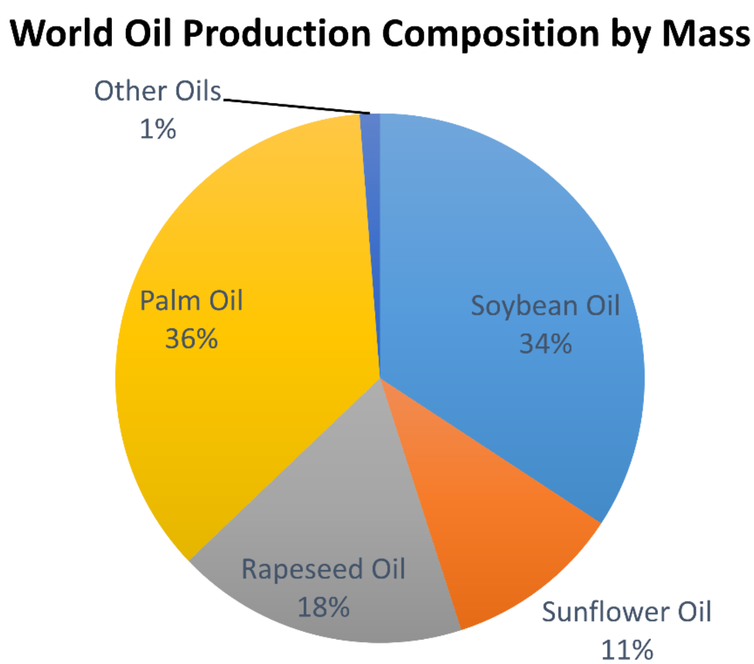


Figure 1: Composition of World Oil Production by Mass [1]

Figure 1 illustrates that palm oil is the most produced oil each year. Currently, the palm oil industry is valued at $44 billion [5] and is projected to increase by more than 65% by 2020 [10]. Additionally, 50% of consumer products that are used daily contain palm oil [11].

Oil palm fruits also yield a much larger quantity of oil than soybeans, rapeseeds, and sunflowers. The yearly average yield of each crop [1] in pounds per acre planted is depicted in Figure 2.

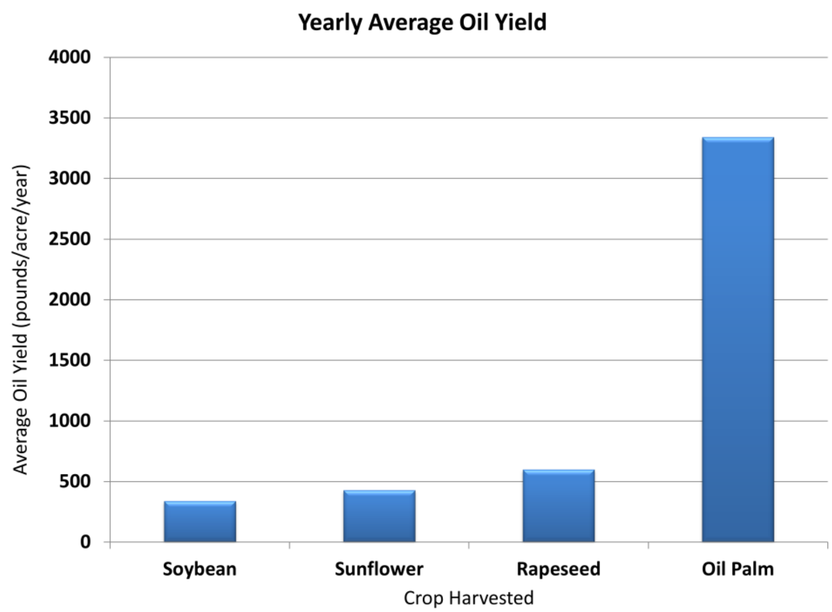


Figure 2: Average Oil Yield in pounds per acre of the Top Four Oil Sources [1]

In addition to oil palm fruits being used to produce 36% of the world's oil (Figure 1), the fruits also produce approximately seven times more oil than rapeseeds, the crop with the second highest yield per acre (Figure 2). The composition of oil crops by area is depicted in Figure 3 [1].

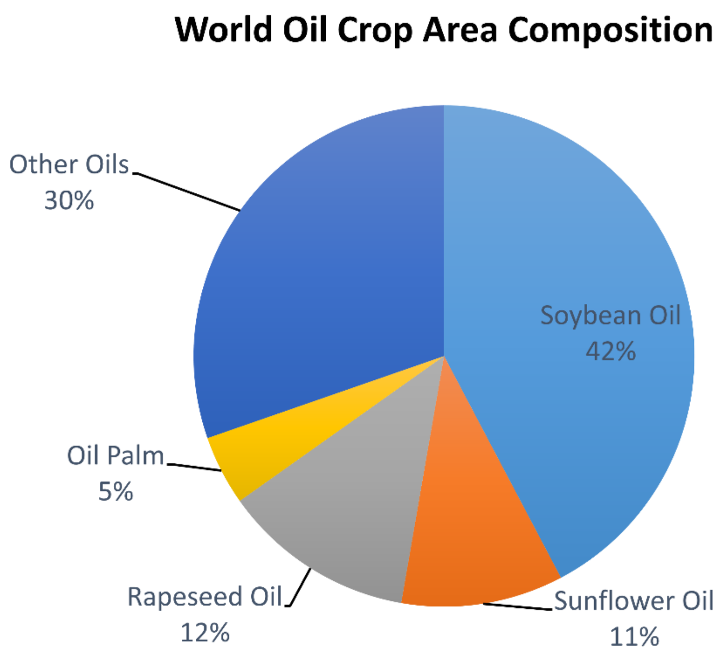


Figure 3: Composition of World Oil Crop Area [1]

In addition to oil palm fruits having the most efficient yield of any crop, Figure 3 illustrates that the fruits comprise the smallest area among all planted oil producing crops. Oil palm trees' relatively small crop area, coupled with oil palm fruits' high oil yield, helps explain why oil palm fruits are the most popular source of oil. However, oil palm fruits are currently harvested in a hazardous and inefficient manner. Laborers must climb oil palm trees that are 40-feet high, identify if the fruits are ripe, cut the proper ripe fruit bunch, and then descend the tree, while avoiding the many protrusions of the oil palm tree's trunk, and avoiding damaging the remaining fruit bunches [2].

It is evident that oil palm fruits are important to worldwide oil production; however, current harvesting techniques can be improved. From a business standpoint, there is a $44 billion market [5] that currently has no competition or innovation in improving oil palm harvesting techniques. As the world's population continues to increase, demand for palm oil, used in 50% of consumer goods [11], will also increase. There will be increased pressure to harvest only crops that have high oil yields to ensure that customers from many countries can afford to purchase them. Thus, there will be a great demand for efficient sources of oil, such as palm oil. Currently, the target consumers of an oil palm fruit harvesting mechanism are oil palm plantation owners and workers in Indonesia and Malaysia, because these two countries produce 85% of the world's palm oil [12]. In addition, plantation owners or workers in any country that wish to increase harvesting efficiency are also considered target consumers. The threats are displayed in red and opportunities are displayed in green. More information regarding short-term threats and opportunities is given in

Table 2, while further descriptions of long-term ones are given in

Table 3.

Short Term (Less than 6 Months)		Long Term (More than 6 Months)	
Threats	**Opportunities**	**Threats**	**Opportunities**
No feasible design developed	Conceive an innovative design	Harvesters will continue to be endangered	Harvesters will have a safer work environment
More unskilled laborers hired to harvest oil palm fruit	Decrease amount of harvesters needed	Palm oil prices will continue to increase	Decrease palm oil prices by increasing harvesting efficiency
Prototype could damage oil palm trees	Develop a device that does not harm oil palm trees	Harvesting methods do not change	Ability to revolutionize the palm oil harvesting industry
Prototype could harvest unripe fruits	Develop a device that can discern ripe oil palm fruit	Oil palm fruit efficiency research decreases	Oil palm fruit harvesting efficiency research increases

Figure 4: Threats and Opportunities Matrix

Table 2: Descriptions of Short-Term Threats and Opportunities

Threat	Threat Description	Opportunity	Opportunity Description
No feasible design developed.	This means that the project will not be able to be completed, because a prototype cannot be improved if it does not exist.	Conceive an innovative design.	This means that an original design could be developed that will be able to harvest oil palm fruit without a worker climbing the tree.
More unskilled laborers hired to harvest oil palm fruit.	Palm tree plantation owners will have to continue searching for unskilled laborers willing to ascend oil	Decrease amount of harvesters needed.	A harvesting device would decrease the amount of harvesters that are needed to climb and cut oil palm fruit,

	palm trees to harvest oil palm fruit.		because the device will be able to harvest more fruit than a human can.
Prototype could damage oil palm trees.	If the prototype is not designed correctly, it may result in fatal damage to the tree that would prevent fruits from being harvested in the future.	Develop a device that does not harm oil palm trees.	A device must be developed that does not harm the oil palm tree and cause it to stop producing fruit.
Prototype could harvest unripe fruit.	If the prototype does not have a way of detecting whether fruit is ripe, unripe fruit may be harvested accidentally.	Develop a device that can discern ripe oil palm fruit.	Any prototype constructed must have a way for the user to discern if an oil palm fruit bunch is ripe before harvesting it.

Table 3: Descriptions of Long-Term Threats and Opportunities

Threat	Threat Description	Opportunity	Opportunity Description
Harvesters will continue to be endangered.	Workers will continue to risk their lives climbing trees that are 40-feet tall.	Harvesters will have a safer work environment.	A harvesting device will allow workers to remain on the ground when harvesting oil palm fruit.
Palm oil prices will continue to increase.	As labor costs inevitably increase over time, the cost of palm oil to consumers will increase.	Decrease palm oil prices by increasing harvesting efficiency.	A harvesting device will allow workers to harvest fruit more efficiently and help lower labor costs, which will prevent the consumer from

			paying higher palm oil prices.
Harvesting methods do not change.	Current harvesting methods will not change and oil palm fruit will continue to be harvested in an inefficient manner.	Ability to revolutionize the oil palm harvesting industry.	A proof-of-concept prototype would allow the oil palm industry to realize that the harvesting process's efficiency can be improved.
Oil palm fruit harvesting efficiency research decreases.	Harvesting efficiency research might decrease if a successful prototype is not constructed.	Oil palm fruit harvesting efficiency research increases.	Research into ways to improve a constructed prototype might increase.

2.1.3 Project Stakeholders and Team Organization

The project's sponsor is Dr. Okenwa Okoli, who is the Chair of the IME deparment at the FAMU-FSU College of Engineering. The IME department is providing the funding for this project. Dr. Okoli informs the team of any prototype's functional requirements and is the project's main stakeholder. The team has weekly meetings with Dr. Okoli to discuss the project's progress. Since this project also involves the Department of Mechanical Engineering (ME) and the Department of Electrical and Computer Engineering (ECE), Dr. Nikhil Gupta and Dr. Jerris Hooker, supervisors of each department's respective senior design courses, are also project stakeholders. Furthermore, Ms. Margaret Scheiner and Mr. Ryan Adams, the IME senior design Teaching Assistants, are also stakeholders in this project. The FAMU-FSU College of Engineering, IME, ME, and ECE departments are also stakeholders in this project. Finally, the team is also a stakeholder in this project, in order to ensure the project is completed.

The team's hierarchy is depicted in Figure 5. A discipline leader is one that is responsible for that discipline's segment of the entire project. The team reports to Dr. Okoli, the project's sponsor. Matthew Gerstenblitt was elected as the current Phase Leader, because he has experience working in research and development, as well as project management skills. The team desired a leader for the first phase that would be able to set goals for the entire project. Matthew was elected as the IME Lead because of these skills, as well as parliamentarian (for team contract purposes). Gabriel Diez was elected as the ME Lead, because he has experience in mechanical design and machining. Gabriel is also the Historian, who is responsible for taking and maintaining audio recordings of each team meeting. Enrique Gonzalez was elected the team's Safety Inspector, because he has experience working in machine shop management, as well as supervising manufacturing and job shop production lines. Enrique is aware of the risks involved in machining parts and constructing prototypes. Patrick was elected the team's Material Analyst, because he has experience with automobiles and is currently taking a graduate technical elective on vehicle design. Alberto was elected as the ECE Lead, because he has extensive leadership experience in managing individuals. Alberto is also our Secretary, who is responsible for taking and uploading the group's meeting minutes to the Blog and File Exchange on Blackboard. Derek was elected as the group's webmaster, because he is a computer engineering major with HTML, CSS, and JavaScript experience. Finally, Maria was elected as the team's business analyst, because she is also a business management major and has experience analyzing the business applications of technical projects.

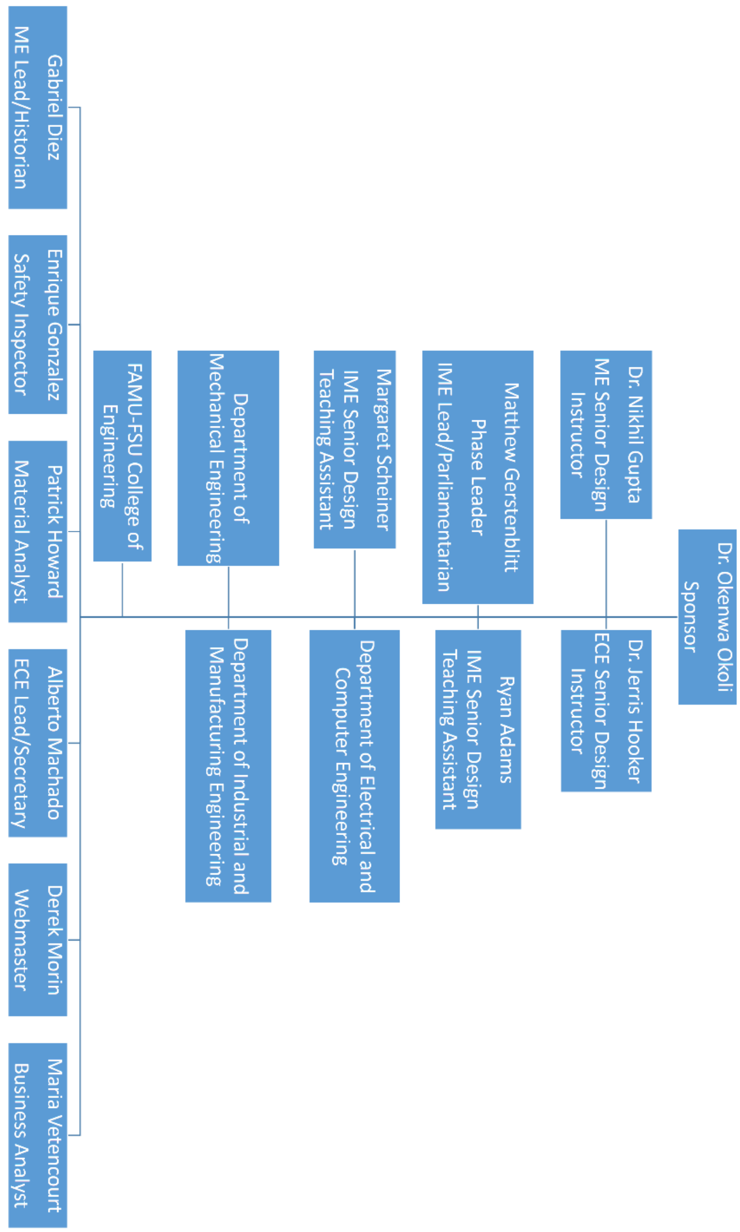


Figure 5: Team Organization Diagram

2.2 Approach

2.2.1 Scope

The scope of this project focuses mainly on developing an electromechanical device to harvest oil palm fruit. In order to construct such a device, the group will research oil palm trees and fruit, as well as current oil palm fruit harvesting methods. Once this research is completed, the team will brainstorm electromechanical design ideas that are consistent with the sponsor's requirements discussed in Section 3.1.1. Once a design is selected that meets all of the sponsor's criteria, the group will design a prototype utilizing PTC Creo Parametric software and analyze its functionality. Based on the results of the team's analysis, the prototype will be optimized to harvest fruit in the shortest possible amount of time. Finally, documentation will be created that will instruct workers how to operate the device. However, there are several items that are outside the scope of this project. The team is not required to market the product to potential buyers, but only design a device that could be sold by the sponsor. Furthermore, optimizing the production of the designed device is also outside the scope of this project. Finally, the team is not required to obtain feedback from harvesters using the device, because the team will be unable to transport the device to any potential users.

Since the Class of 2015's team was not able to meet Dr. Okoli's requirements successfully, most of the prototype's components were discarded. Only assorted small parts remain from the device. Therefore, an entirely new design is required. Since the team is still able to access the Class of 2015's reports and documentation, their failures should be able to be avoided in this project.

After researching the Class of 2012's report [6], the Class of 2014's report [9], and the Class of 2015's report [13], the team learned that there are two design approaches to improve the oil palm fruit harvesting process. The first is a ground-based system that extends from the ground to the top of the tree and cuts the fruit bunches. This has the benefit of being simpler and more feasible to design and build, as well as being less expensive to sell. (It is possible that a different design approach may be conceived when discussing improvements to this design.) The second approach involves designing a system that uses the tree for support and autonomously climbs it to reach the fruit. While this would probably be lighter, easier to operate, and transport, it is more complicated and may not be feasible to finish within the time and budget constraints provided.

This year's goals could consist of one of two approaches. The first approach would be to design and build a subsystem for the Class of 2015's prototype and develop a design for the finished prototype for following years to complete. Some examples of this approach include a robotic arm with a cutter and a tree climbing mechanism. The second approach would consist of a proof-of-concept prototype to demonstrate that the design concept is feasible, but it would still need to be improved by succeeding years. Regardless of the approach selected, the team will still have a prototype constructed and delivered by the end of the Control Phase.

The scope of this project has been defined through meetings with the sponsor, and the team will continue to have weekly meetings with the sponsor throughout the entire project. Dr. Okoli will notify the team if the scope of the project needs to be changed, based on the team's feedback and progress.

2.2.2 Assumptions and Constraints

Since oil palm trees require a tropical rainforest climate to grow [11] and there are no oil palm trees in Tallahassee, Florida, there are many assumptions that must be made regarding the trees. These assumptions inevitably constrain how any harvesting mechanism can be designed. These constraints provide the project with the direction and necessary standards that must be met before it can be considered completed. Based on the background research discussed in Section 1 [2], conversations with the project's sponsor, and the Class of 2015's documentation [9], a series of assumptions and their corresponding constraints for project are listed in Table 4 [2], [9], [11].

Table 4: Project Assumptions and Constraints [2], [9], [11]

Assumptions	Constraints
Oil palm trees grow 40-feet high [9].	The mechanism must be capable of reaching a height of 40 feet.
Oil palm plantations have very rough ground and very soft soil.	The device must be lightweight and maneuverable.
Trees are planted approximately 30 feet apart over vast acres of land [9].	The design must be easily portable.
Oil palm trees are grown in a tropical rainforest climate that is prone to high heat and heavy rainfall [2].	The mechanism must be heat and water resistant.
Oil palm trees are grown in very poor regions of the world.	The device must be inexpensive and have a maximum selling price of $2,000.
Users of any device are unlikely to have experience with sophisticated electromechanical systems.	The prototype must be easy to use.
Any design must lower the cost of harvesting oil palm fruit.	The number of users must be minimized. Two users are allowed to move the device from a truck to the ground, but only one user is allowed to operate and move the machine on the ground of the plantation.
Oil palm fruits weigh 40–60 pounds [2].	Any design must be able to be operated from a safe distance.

2.2.3 Deliverables

Table 5 lists all items the team will deliver by the end of this project and accounts for the ECE, IME, and ME departments' requirements. The dates for phases other than the Define Phase are subject to change.

Table 5: Project Deliverables

Deliverable	Due Date
Define Phase	
Define Phase Gate Review Report	October 20, 2015
Define Phase Gate Review Presentation	October 20, 2015
Risk Assessment	October 20, 2015

Define Phase Peer Evaluation Forms	October 20, 2015
Measure Phase	
Technical Poster 1 Draft	November 24, 2015
Initial 3D CAD* Renderings	December 1, 2015
Initial Bill of Materials	December 1, 2015
Initial Mechanical Analysis	December 1, 2015
Measure Phase Gate Review Report	December 1, 2015
Measure Phase Gate Review Presentation	December 1, 2015
Measure Phase Peer Evaluation Forms	December 1, 2015
Final Technical Poster 1	December 3, 2015
Project Completion Form	December 4, 2015
Analyze Phase	
Analyze Phase Gate Review Report	February 2, 2016
Analyze Phase Gate Review Presentation	February 2, 2016
Analyze Phase Peer Evaluation Forms	February 2, 2016
Final 3D CAD Renderings	February 2, 2016
Final Mechanical Analysis	February 2, 2016
Final Bill of Materials	February 2, 2016
Improve Phase	
Improve Phase Gate Review Report	March 1, 2016
Improve Phase Gate Review Presentation	March 1, 2016
Working Prototype	March 1, 2016
Improve Phase Peer Evaluation Forms	March 1, 2016
Control Phase	
Technical Poster 2 Draft	March 4, 2016
Control Phase Gate Review Report	March 29, 2016
Control Phase Gate Review Presentation	March 29, 2016
Final Design Specifications	March 29, 2016
Prototype Operating Instructions	March 29, 2016
Final Technical Poster 2	March 29, 2016
Control Phase Peer Evaluation Forms	March 29, 2016
Post-Control Phase	
Business Analysis Report	April 12, 2016
Business Analysis Presentation	April 12, 2016
Business Analysis Peer Evaluation Forms	April 12, 2016
Project Completion Form	April 12, 2016

*CAD refers to computer-aided design software, such as AutoCAD.

2.2.4 SIPOC Diagram

To help visualize the project's process, a Supplier-Inputs Process-Outputs-Customers (SIPOC) diagram was created and is depicted in Figure 6.

Oil Palm Fruit Harvesting				
Suppliers	**Inputs**	**Process**	**Outputs**	**Customers**
Vendors	Materials and parts	1. Define customer's requirements		
		2. Create design that meets all requirements		
Dr. Okoli	Project budget	3. Select final design	End of Phase Reports and Presentations	Dr. Okoli
		4. Order materials	Risk Assesment	
Written project information	Project scope	5. Assemble prototype	CAD Drawings	
	Project parameters	6. Analyze prototype	3D CAD Renderings	
		7. Improve prototype	Mechanical Analysis	
		8. Finalize design and operating procedures	Technical Poster 1	
			Project Completion Forms	
			Working Prototype	
			Technical Poster 2	
			Final Design Specifications	Oil Palm Plantation Owners
			Prototype Operating Instructions	Oil Palm Harvesters

Figure 6: SIPOC Diagram

The SIPOC diagram depicted in Figure 6 displays the suppliers, inputs, process, outputs, and customers for the oil palm fruit harvesting device. The suppliers providing resources for the project are our sponsor, Dr. Okoli, vendors from which we will obtain parts to build the prototype, and all written information regarding the project provided to the team. Dr. Okoli provides the project budget to obtain all needed items to complete the project, such as the parts needed to build a working prototype. Any parts needed will be ordered from a vendor and then assembled by the team. Thus, the project's inputs include materials and parts, the project's budget, the project's scope, and the project's parameters. The process column in Figure 6 lists the high-level steps necessary for completing the project. Outputs for this project depicted in Figure 6 include, but are not limited to, each phase's respective report, presentation and peer evaluation forms, as well as the final prototype's operating instructions. Computer-aided designs are also used to develop an oil palm fruit harvesting device design and perform a mechanical analysis on all parts that will be used. Finally, the customers that will benefit at the conclusion of this project include the sponsor, Dr. Okoli, as well as oil palm plantation owners and workers. The plantation owners will be able to increase the output of their oil palm crops, while the harvesters will benefit from a safer and more efficient workplace.

3. Defining Customer and Technical Requirements

3.1.1 Customer Requirements

According to the sponsor, the purpose of this project is to improve the method by which palm fruits are harvested. Currently, this involves a laborer climbing a 40-foot tree and cutting each fruit manually [2]. Dr. Okoli wishes to improve the productivity and safety of this process by using an electromechanical device. The customer's requirements were converted into a diagram and are depicted in Figure 7. Descriptions of each requirement are given in Table 6.

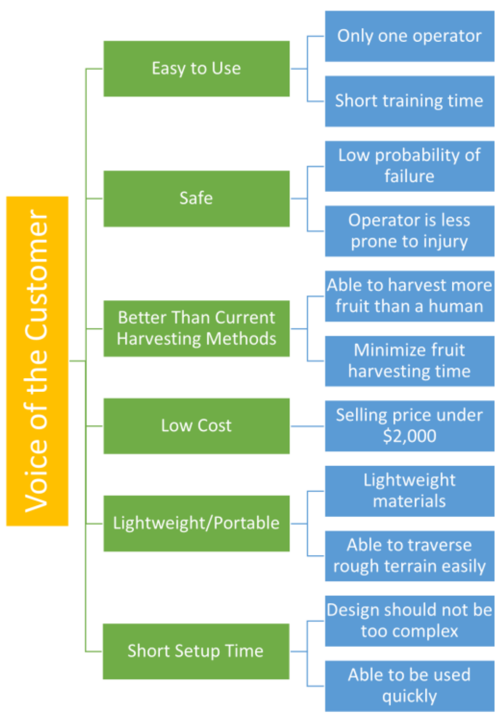


Figure 7: Voice of the Customer Diagram

Table 6: Descriptions of Customer Requirements

Customer Requirement	Description
Easy To Use	The device should be able to be used by current oil palm fruit workers that have limited skills [2]. Since each tree is currently harvested by only one worker, any machine that requires two operators would immediately double the cost of production, by doubling the labor costs per tree. Therefore, any design that requires more than one person to operate it is not acceptable to our sponsor.
Safe	Since the current process is dangerous [2], worker safety must be improved. This includes ensuring the design is safe and that the operator does not risk injury from the device.
Better Than Current Harvesting Methods	Since the purpose of this project is to improve a process that is currently performed by humans, it is critical that the device be superior to a human worker. This includes factors such as fatigue. A well-designed prototype is only limited by its power source. Therefore, the machine must be able to reach the top of the tree faster and harvest more fruit than a human can in the same amount of time.
Low Cost	Since the regions where the device is expected to be used are generally very poor, the sponsor specified that the

	final machine cannot have a sale price of more than $2,000.
Lightweight/Portable	Since oil palm plantations occupy vast stretches of land [2], portability is extremely important. Otherwise, the time to go from tree to tree would increase, causing a decrease in productivity. One simple way to increase portability would be to make the design as lightweight as possible.
Short Setup Time	Since a human worker can immediately grab onto the tree and start climbing, the time for the design to be ready to operate must be minimized. Otherwise, it cannot be considered a superior alternative to current harvesting methods.

Meeting each of the customer's requirements will be prioritized by utilizing a house of quality, which is discussed in Section 3.1.4.

3.1.2 Technical Requirements

The technical requirements needed to ensure the customer requirements discussed in Section 3.1.1 are described in Table 7.

Table 7: Descriptions of Technical Requirements

Technical Requirement	Description
System Weight	Minimizing the weight would make the device more portable and would make any forces acting on it cause less severe damage. From an efficiency standpoint, a lightweight design would theoretically use less material.
Modular	A modular design would improve the device's portability and make it easier to ship. Furthermore, it would lower the maintenance costs and selling price of the design.
Strength of Materials	Since the machine will be encountering heavy fruit bunches at heights of up to 40-feet, the strength of its materials must be high in order for it to survive

	any accidents that may occur.
Energy Capacity	Whether the energy source of the machine is stored chemically with gasoline or electrically with a battery, it must be able to last for an entire day of harvesting.
Shielded Electronics	Since the electronics are highly vulnerable to both water and impact, it is crucial that any design protects them from both of these factors.

Fruit Visibility	Oil palm fruits ripen at different rates [2]. Therefore, not all oil palm fruit bunches may be ready to be harvested at the same time. A human climber can easily determine which fruit bunches must be cut and which bunches should remain. The oil palm fruit harvesting machine must be able to either determine which fruit bunches are ready to be cut or allow a human operator to make the decision from the ground.
Electromechanical Components	While electromechanical components may make the achievable goal easier by means of programmed intelligence and endurance, they add a level of delicacy and expense to the design.
Setup Time	Since a human climber can immediately grab onto the tree and start climbing, the time for the design to be ready to operate must be minimized. Otherwise, it cannot be considered to be a superior alternative to the current harvesting methods.
Autonomy	More autonomy would require less human input and would decrease the amount of skill necessary to operate the system. Theoretically, a completely autonomous system would eliminate the need for workers to monitor the device. However, that assertion is currently outside the scope of this project.
User Control System	As the control the user has over the system increases, the number of individuals necessary to operate the system decreases. Therefore, the number of controls should reflect the goal of requiring only one operator.
Harvesting Time	The time for the machine to arrive at a tree and harvest a fruit bunch must be less than that of a human, in order to improve productivity.
Training Time	It would be ideal for this design to require as little training as possible, to allow individuals with minimal skill to be able to operate it. Additionally, training a worker takes time and costs money and should therefore be avoided as much as possible.

In order to complete a design that meets the goal of improving this process, the technical requirements from Table 7 were inputted into the house of quality depicted in Figure 10. (The house of quality is discussed in Section 3.1.4.)

3.1.3 Current Harvesting Process

The process being improved is oil palm fruit harvesting. The purpose of studying this process is to improve the poor methods currently used. When workers first arrive at the plantation, they receive their tree climbing and cutting tools. Oil palm fruit harvesters then walk through oil palm plantations looking for a ripe fruit bunch. A typical worker walks 7–10 acres per day [2]. These bunches are identified if a tree has loose fruit on the ground or any fruit bunches visible have a red or brown color to them. After the worker cuts a fruit bunch, it must be moved to a designated collection point on the plantation. Cutting fruit from trees less than 20-feet tall is not an issue, because there are cutting tools that exist for performing this task [2]. However, cutting fruit from trees that are 20-feet to 40-feet high presents a problem. If the fruit bunches are not visible from the ground, a worker may climb a tree and find that no fruit bunches are ready to be harvested. Even if a worker does climb the tree successfully, the worker has a high risk of injury when ascending and descending the tree [2]. For this process to function properly, there must be unskilled laborers willing to climb oil palms. The current harvesting process for trees that are 20-feet to 40-feet tall (hereinafter referred to as “tall trees”) is depicted in Figure 8 [2]. The goal of this project is to allow workers to determine if fruit bunches are ready to be harvested and allow workers to use an electromechanical device to harvest the fruit, from the ground.

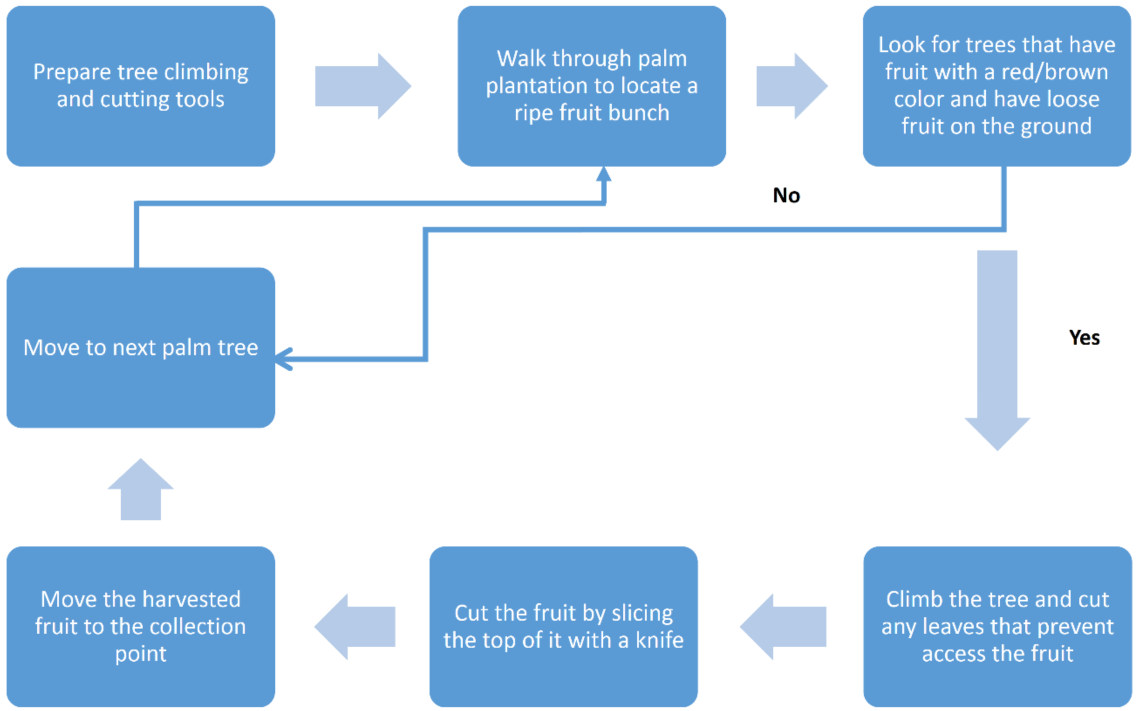


Figure 8: Current Oil Palm Fruit Harvesting Method for Tall Trees [2]

The process depicted in Figure 8 works properly when workers are able to identify a tree that has ripe fruit bunches from the ground, ascend the tree, cut the fruit, descend the tree, and then move the fruit to the designated collection point. However, there is a major flaw with this process. A worker could climb tall trees for an entire day and not find any ripe fruit bunches to be cut. This is inefficient and puts the worker in unnecessary danger. Allowing workers to determine if oil palm fruits are ripe and then harvest them from the ground would significantly improve the process. An Ishikawa diagram of the issues with the current harvesting process is depicted in Figure 9. Figure 9 helps direct the project because important factors in the harvesting process are highlighted and they need to be considered throughout the development of the project. Among these factors, one can find the variables related to the Palm Tree. These trees are approximately 40 ft. tall, easily damaged and require from four to six years to bear fruit. The personnel also has to be taken into consideration since the complexity of the process depends on the workers. To be able to create an effective method for harvesting palm fruits, previous methods have to be analyzed. The environment also has to be observed to make sure design withstands the necessary environment conditions.

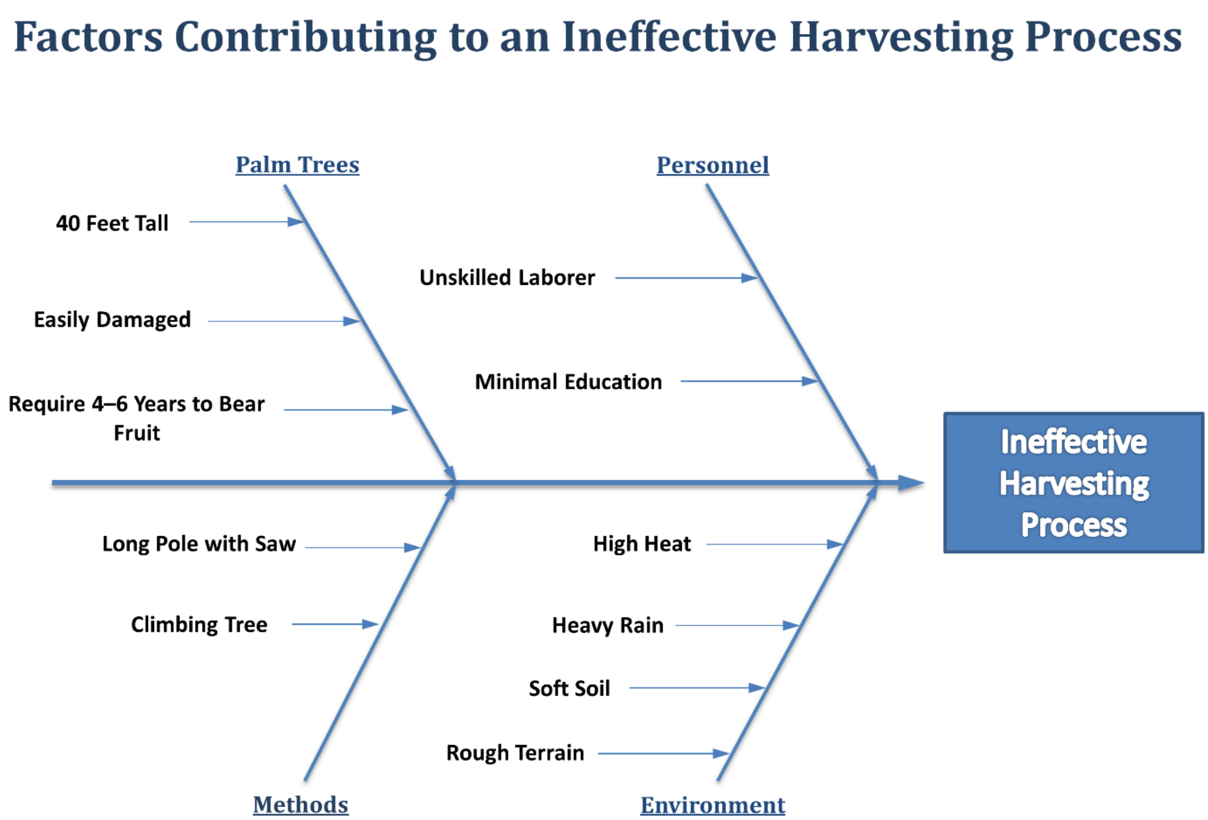


Figure 9: Ishikawa Diagram of the Palm Harvesting Process [2]

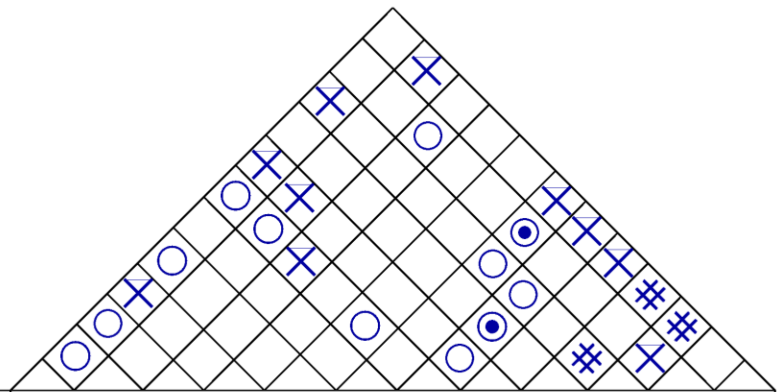
3.1.4 House of Quality

A house of quality was created to assist with this project and is depicted in Figure 10. The house of quality is important, because it allows the customer's requirements to be converted into technical requirements and shows the team's prioritization of tasks [14]. The team's house of quality was constructed after meeting with the project's sponsor and then brainstorming any technical requirements that may be needed for future designs.

Customer requirements (also known as the demanded qualities) are listed on the left side of Figure 10 and were discussed in Section 3.1.1. These functional requirements for the final prototype were divided into the following categories: Easy to Use, Performance, and Cost. In order to meet these customer requirements, the team devised several quality characteristics (also known as technical requirements) that are related to the customer's demands. These technical requirements were divided into the categories Design and Operation, shown in Figure 10 and were discussed in Section 3.1.2. The Customer Importance column assigns a quantitative value to each of the customer's demands. A score of "1.0" denotes it is the least important, while a score of "9.0" denotes it is the most important; these rankings were determined based on the team's meetings with the sponsor. The Organizational Difficulty row in Figure 10 utilizes the same numerical scale, but denotes the difficulty of the team accomplishing each of the technical requirements.

The cells above the technical requirements in Figure 10 denote any positive or negative correlations among all technical requirements, while the cells in the center of the figure denote any strong or weak relationships between the customer requirements and the technical requirements. A positive correlation between two technical requirements means that the two requirements support one another, while a negative correlation means that they contradict one another. Relationships measure the effect that meeting a design requirement will have on a customer requirement. Each correlation symbol and relationship symbol is assigned a numerical value that is denoted in the legend in Figure 10. The Weighted Importance row multiplies any relationship symbols in each technical requirement's column by the corresponding customer importance value in its respective row [15]. Positive correlation symbols are assigned positive values, while negative correlation symbols are assigned negative values. The values of each symbol are depicted in Figure 10. All of these values were then computed and summed vertically to yield a weighted importance value for each technical requirement, which is a quantitative measure of how strongly each technical requirement satisfies the customer's requirements [15]. The Relative Importance row expresses the percent contribution of each technical requirement to all of the technical requirements. Finally, the Rank column ranks the importance of each technical requirement in relation to meeting all of the customer's demands. A rank of "1" indicates it is the most important technical requirement, while a rank of "12" indicates it is the least important. All calculations were computed using QFD Designer 5 [15].

Figure 10 illustrates that the three most important technical requirements are the electromechanical components, the system's weight, and the system's modular design. These requirements will be met by minimizing the number of electromechanical components in any prototype design, selecting the lightest material that provides all required functions of any design concept, and decreasing oil palm fruit harvesting time by allowing the worker to remain on the ground.



Palm Harvester			Customer Importance	Quality Characteristics/Technical Requirements											
				Design							Operation				
				System Weight	Modular	Strength of Materials	Energy Capacity	Shielded Electronics	Fruit Visibility	Electromechanical Components	Setup Time	Autonomy	Number of User Controls	Harvesting Time	Training Time
Customer Requirements				↓	↑	↑	↑	↑	↑	↓	↓	↑	↓	↓	↓
Demanded Quality	Easy to use	One Operator	8.0	◉	○					△		◉	◉		
		Lightweight/Portable	7.0	◉	◉	○	○	△		◉	○		△		
	Performance	Better than Current Harvesting Methods	8.0		△		◉	△	◉	○	◉	◉	△	◉	○
		Waterproof	9.0					◉	○	○		△			△
		Durable	7.0		△	◉	△	◉		△		△	△		
		High Capacity Power Source	8.0	◉			◉					△	△	△	
	Cost	Below $2,000	9.0	△	◉	△		△	△	◉	△	○	○		
		Low Maintenance Expenses	5.0	○	◉	◉		◉		◉		○	○		
Organizational Difficulty				9.0	3.0	6.0	5.0	5.0	5.0	7.0	4.0	7.0	3.0	7.0	2.0
Weighted Importance				231.0	228.0	138.0	172.0	213.0	108.0	255.0	102.0	210.0	144.0	80.0	33.0
Relative Importance				12.1%	11.9%	7.2%	9.0%	11.1%	5.6%	13.3%	5.3%	11.0%	7.5%	4.2%	1.7%
Rank				2	3	8	6	4	9	1	10	5	7	11	12

Legend

	Symbol	Meaning	Value
Relationships	◉	Weak Relationship	1
	△	Medium Relationship	3
	○	Strong Relationship	9
Correlations	⋇	Strong Negative Correlation	-3
	✕	Negative Correlation	-1
	○	Positive Correlation	3
	◉	Strong Positive Correlation	9
Optimization	↓	Smaller The Better	0
	↑	Larger The Better	0

Figure 10: House of Quality

3.1.5 Work Breakdown Structure

A work breakdown structure (WBS) was created using the information from Table 5 and is depicted in Figure 11. The purpose of the WBS is to organize the team's work (by phase) into manageable sections. The WBS depicted in Figure 11 is subject to change in future phases.

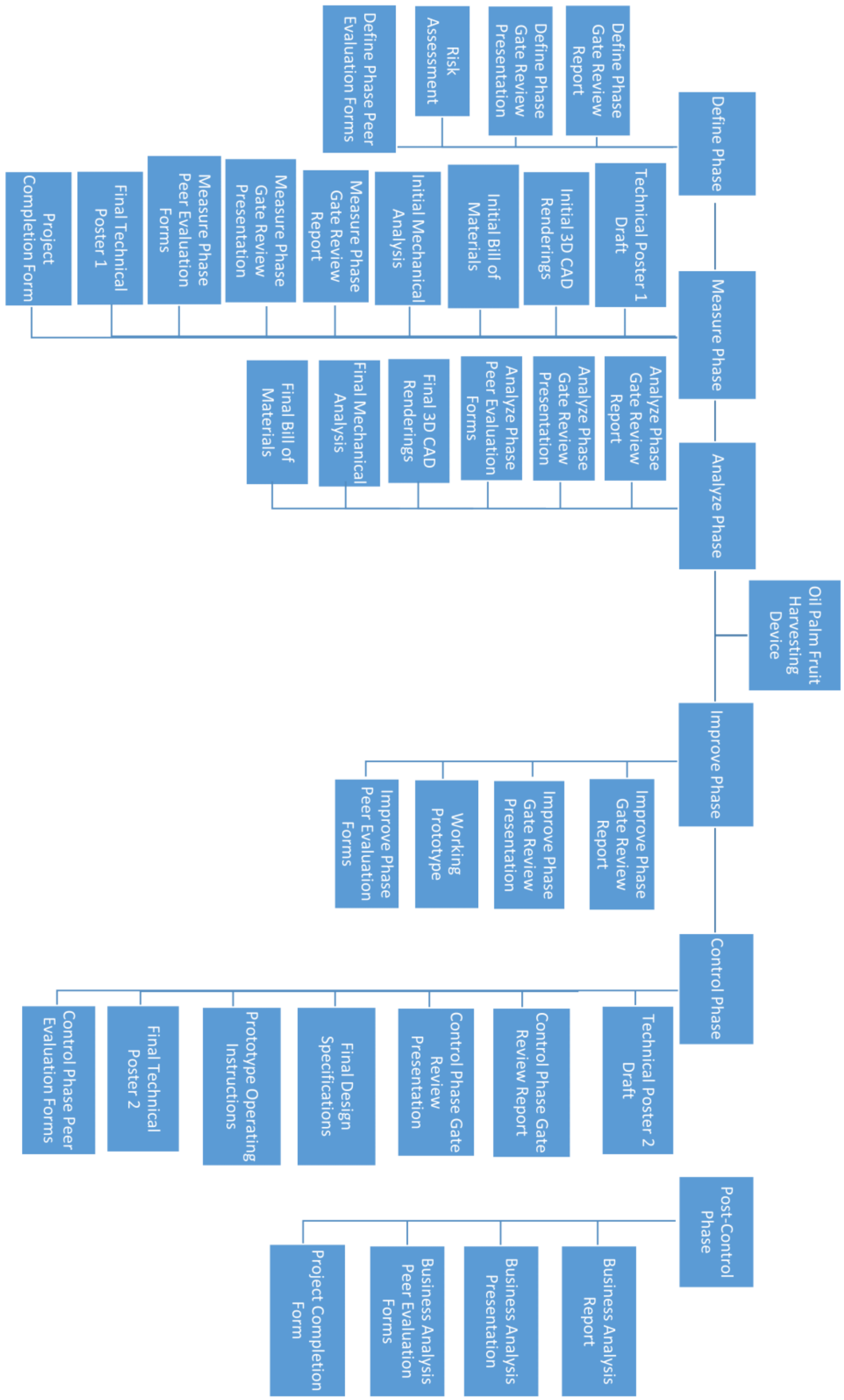


Figure 11: Work Breakdown Structure

3.1.6 Responsibility Assignment Matrix

A responsibility assignment matrix (RAM) was created from the deliverables described in Table 5 and is depicted in Figure 12. The RAM describes which team members are responsible for each work package and is subject to change in future phases.

Oil Palm Fruit Harvesting Device							
Task/Person	Matthew Gerstenblitt	Gabriel Diez	Patrick Howard	Enrique Gonzalez	Maria Vetencourt	Alberto Machado	Derek Morin
Define Phase Gate Review Report	R	I	A	C	C	A	I
Define Phase Gate Review Presentation	R	A	C	I	C	I	A
Risk Assessment	C	C	I	R	A	C	A
Define Phase Peer Evaluation Forms	R	R	R	R	R	R	R
Technical Poster 1 Draft	A	I	A	C	R	I	C
Initial 3D CAD Renderings	I	R	A	I	I	C	C
Initial Bill of Materials	I	A	R	I	I	C	C
Initial Mechanical Analysis	I	R	A	I	I	C	C
Measure Phase Gate Review Report	A	C	C	I	R	I	A
Measure Phase Gate Review Presentation	A	I	A	C	R	C	I
Measure Phase Peer Evaluation Forms	R	R	R	R	R	R	R
Final Technical Poster 1	C	R	A	A	I	C	I
Project Completion Form	I	I	C	R	A	A	C
Analyze Phase Gate Review Report	C	R	A	A	C	I	I
Analyze Phase Gate Review Presentation	A	A	I	I	C	R	C

Analyze Phase Peer Evaluation Forms	R	R	R	R	R	R	R
Final 3D CAD Renderings	I	R	A	I	I	C	C
Final Mechanical Analysis	I	R	A	I	I	C	C
Final Bill of Materials	I	A	R	I	I	C	C
Improve Phase Gate Review Report	I	C	R	I	C	A	A
Improve Phase Gate Review Presentation	C	I	A	C	I	A	R
Working Prototype	A	R	C	C	A	I	I
Improve Phase Peer Evaluation Forms	R	R	R	R	R	R	R
Technical Poster 2 Draft	A	C	C	I	A	I	R
Control Phase Gate Review Report	C	A	I	C	A	R	I
Control Phase Gate Review Presentation	R	I	I	A	C	A	C
Final Design Specifications	A	C	R	I	A	C	I
Prototype Operations Instructions	I	R	C	I	A	A	C
Final Technical Poster 2	C	I	A	A	I	R	C
Control Phase Peer Evaluation Forms	R	R	R	R	R	R	R
Business Analysis Report	I	A	I	R	C	C	A
Business Analysis Presentation	A	A	I	C	R	I	C
Business Analysis Peer Evaluation Forms	R	R	R	R	R	R	R
Project Completion Form	A	I	C	C	I	R	A

Code:	Represents:	This Person Is:
R	Responsible	Responsible, the one doing the work
A	Accountable	Accountable, the one expected to justify actions or decisions
C	Consult	To be consulted, one whose expertise may help the one completing the work
I	Inform	To be kept informed, one who does not fit into the preceding three categories

Figure 12: Responsibility Assignment Matrix

3.1.7 Need for an Electromechanical Harvesting Device

The current oil palm fruit harvesting process involves a worker climbing a tree and manually cutting ripe fruit bunches. In addition to the dangers associated with climbing 40 feet numerous times per day, it is exhausting work that limits the number of trees a worker can climb [2]. Since no devices currently exist to assist workers harvesting oil palm fruit from tall trees, the team's solution is to create an electromechanical system that would eliminate the risk a worker faces when harvesting fruit bunches. Also, the device would be able to ascend the height of the tree with speed and ease, thus increasing the number of oil palm fruits that one worker could harvest. With a greater number of oil palm fruit harvested, oil palm plantation owners would be able to increase their profits, and laborers would experience a safer and more efficient work environment.

4. Business Analysis

4.1 Economic Analysis

Last year's team was allotted a budget of $2,500 to build an oil palm harvesting device [9]. However, this device did not meet the customer's requirements, because it was not portable. Our team is tasked with designing a portable harvesting device with the same budget of $2,500. (The budget is discussed in more detail in Section 5.3.) Maintenance costs of any harvesting device will be discussed in future reports, after materials are selected and the prototype's functionality is tested. Despite the high initial cost of purchasing a mechanical harvesting device, the product should cost less to maintain than an annual worker's salary in the long run. Data for Malaysian workers were used to calculate the return on investment, since Malaysia is a leading producer of oil palm fruit [3]. These calculations assume that a Malaysian worker earns a minimum wage of $297 per month, oil palm plantations contain hundreds of trees, oil palms are harvested daily for eight hours [2], and that the device would be sold for $2,000 (Table 1). This yields a return on investment of 78.20% (Appendix A), which means that the long-term labor savings outweigh the high initial purchase price. Currently, the only money lost to current harvesting methods involves the equipment and human labor required to climb trees and manually cut fruit bunches [2]. This section will be updated in future reports with more information, once a final design is selected.

4.2 Environmental Impact

Since our team has not yet selected a final design, the final manufacturing process cannot be determined at this time. Nevertheless, the production and performance of any design will not directly affect the environment. While production will involve the mechanical assembly of modeled parts, there will not be any components made from toxic or caustic materials. Although the energy source for the final device has not yet been determined, it is unlikely that it will transfer any hazardous waste to the surrounding environment. The main environmental concern for this project is damaging the oil palm tree when our harvesting device is used. The team must not puncture the tree's trunk. Thus, only applied, concentrated, and fixed forces should exist in the prototype, to ensure that the device will not damage the oil palm tree when being operated. Therefore, it is recommended that any device constructed should not be used in water crossings, since it could damage aquatic wildlife. Once a final design is selected, this section will be updated with any more environmental interactions the device may have.

4.3 Ethical Considerations

Since a final design has not yet been selected, it is difficult to determine the possible harm that may occur to the individual operating the device. However, there is also a cost to using any efficient oil palm harvesting device, because increasing oil palm fruit production is directly related to increasing deforestation [11]. Deforestation poses a threat to the endangered species that inhabit the rainforests in these areas [11]. Any documentation our team creates for the final device will inform the operator that there is a tradeoff between increasing oil palm fruit production or decreasing deforestation. This section will be updated in future phases with more ethical issues that may arise based on the design selected.

4.4 Health and Safety

Table 8 depicts ergonomic risk factors for workers on oil palm plantations [16]. As the project progresses and more risk factors are identified, this section will be expanded with further details and analysis.

Table 8: Ergonomic Risk Factors on Oil Palm Plantations

Commonly affected body part/region (potential MSDs)	Task movement / Ergonomic risk factors	References
Neck disorders	Repetitive work Forceful work Static contraction Extreme working postures	NIOSH (1997); Walker-Bone & Palmer (2002); Rosecrance *et al*. (2006); Davis (2007); Osborne *et al*. (2010); Fathallah (2010)
Shoulder disorders	Repeated or sustained exertions Forceful exertion Awkward or sustained posture (shoulder flexion or abduction	NIOSH (1997); Walker-Bone & Palmer (2002); Rosecrance *et al*. (2006); Davis (2007); Osborne *et al*. (2010); Fathallah (2010)
Elbow disorders such as epicondylitis	Forceful exertion Repetition Extreme postures	NIOSH (1997); Davis (2007); Fathallah (2010)
Hand/wrist tendonitis such as carpal tunnel syndrome	Repetition Forceful exertion Awkward posture	NIOSH (1997); Walker-Bone & Palmer (2002); Davis (2007); Osborne *et al*. (2010); Fathallah (2010)
Low back disorders	Heavy physical work Lifting and forceful movements Bending and twisting (awkward postures) such as stooping Whole-body vibration Static work postures	NIOSH (1997); Walker-Bone & Palmer (2002); Rosecrance *et al*. (2006); Osborne *et al*. (2010); Davis (2007); Fathallah (2010); Lee (2012)
Knee pain (including osteoarthritis)	Kneeling Squatting Prolonged standing	Walker-Bone & Palmer (2002); Davis (2007); Osborne *et al*. (2010); Lee (2012)
Ankle / foot pain	Prolonged standing Static posture	Walker-Bone & Palmer (2002); Davis (2007) Osborne *et al*. (2010)

4.5 Social and Political Considerations

Oil palm fruit harvesters in developing countries would benefit from an electromechanical harvesting device; farmers would be able to harvest more fruit for a lower cost and increase profits, because the harvesting process would be efficient, simple, and safe. If the oil palm harvesting process is improved, more individuals in developing countries may wish to purchase the harvesting device. However, since the demand for palm oil is inelastic [17], the demand for palm oil would not necessarily increase.

However, there will end up being a surplus of workers competing for an even smaller number of jobs, which could actually increase the unemployment rate of oil palm harvesters [18]. This may cause social resentment among oil palm workers, because some individuals will inevitably be terminated, while their coworkers will remain employed. This section will be updated in the future with more information regarding additional social and political considerations, once the implementation plan for the final design is completed.

4.6 Sustainability

The sustainability of any oil palm fruit harvesting device is heavily dependent on the materials' strength, durability, and the number of electromechanical components. The strength of the materials used in the device and its durability will affect the product's life cycle. For example, the device must be able to resist oxidation in a moist rainforest environment. Furthermore, minimizing the number of components will result in fewer parts that need to be replaced throughout the product's life cycle. Once a final design is selected, more information regarding the sustainability of the design will be added to this section.

5. Project Progress

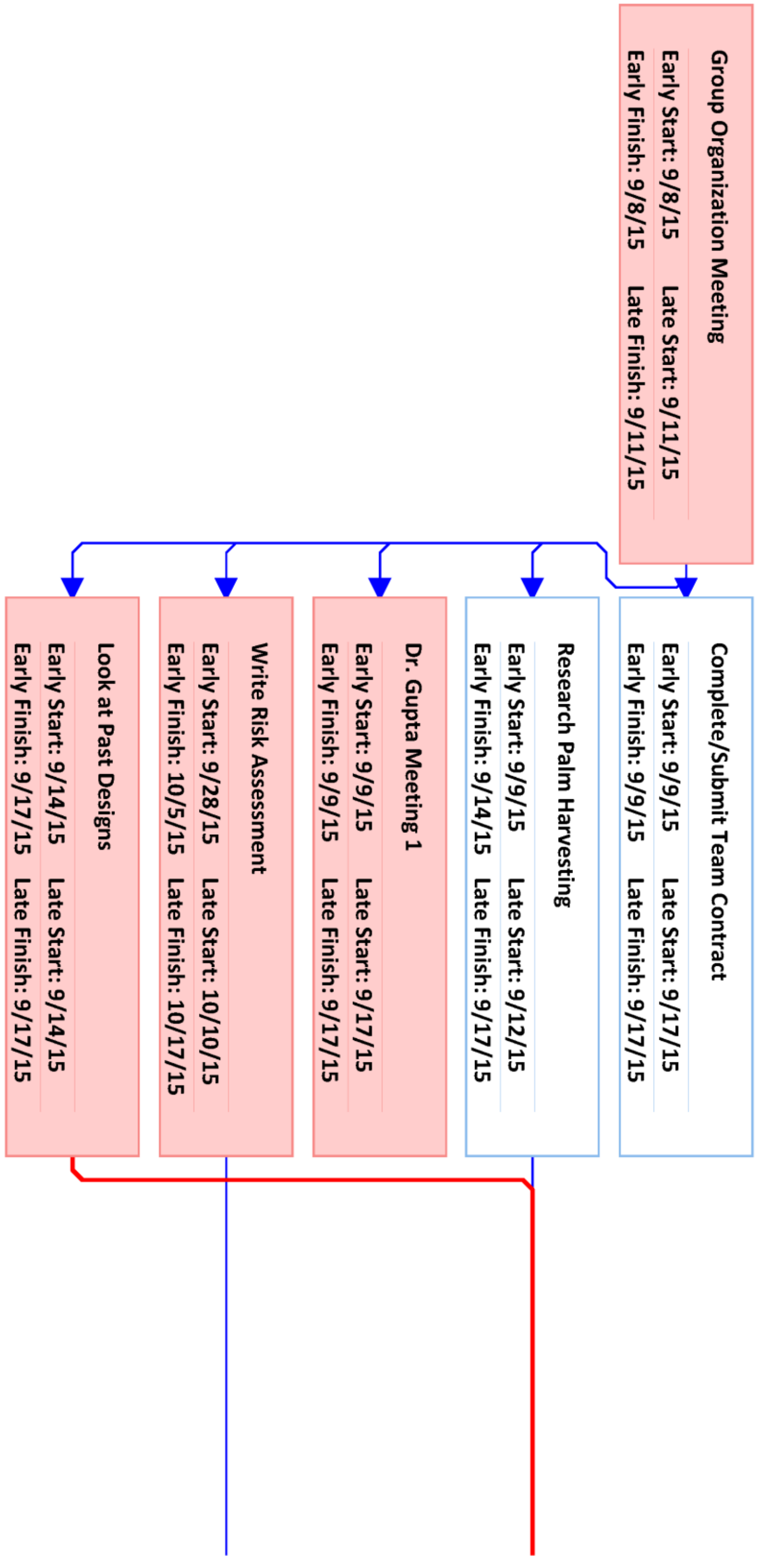
5.1 Milestones and Schedule

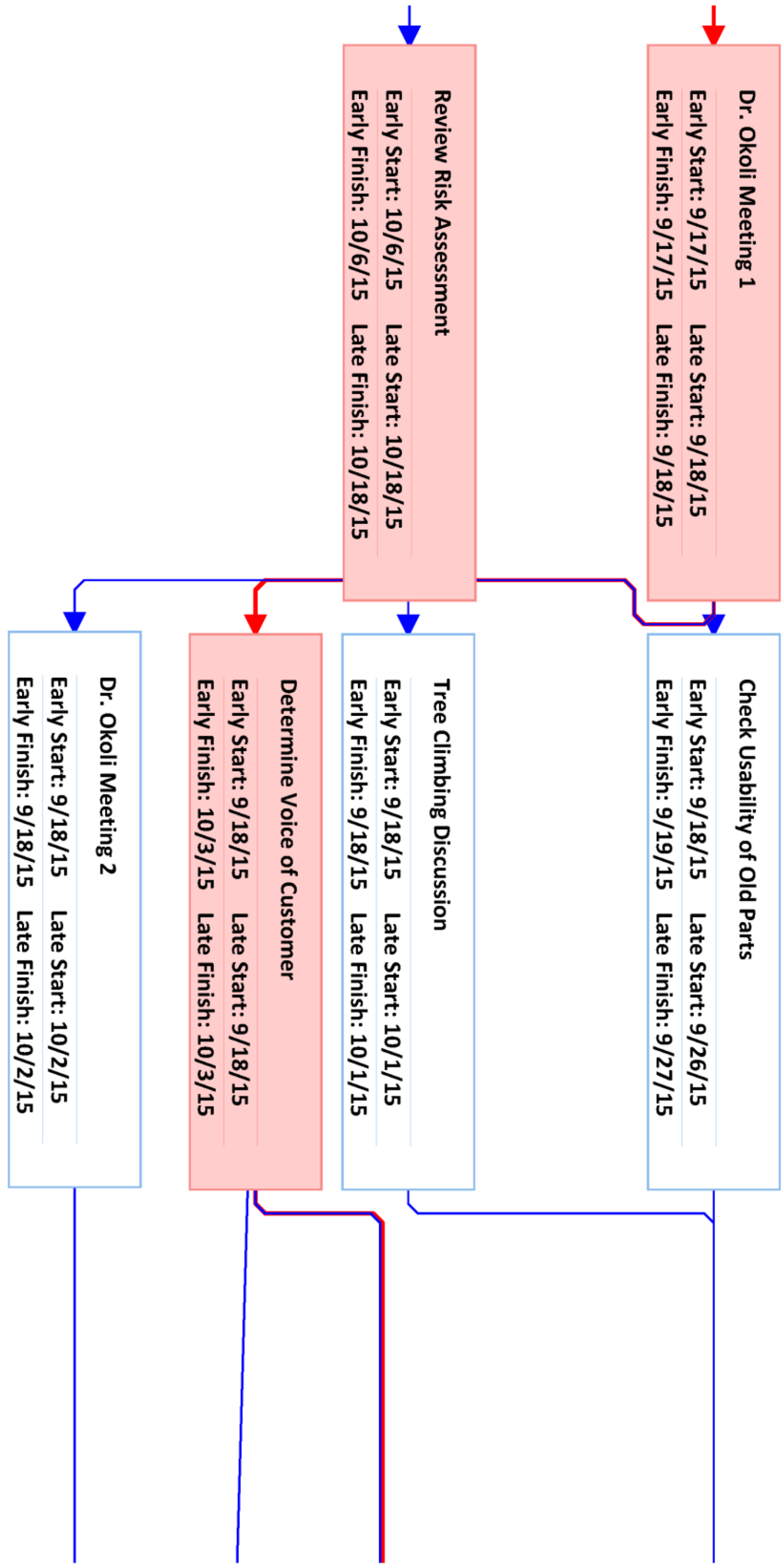
5.1.1 Define Phase Tasks

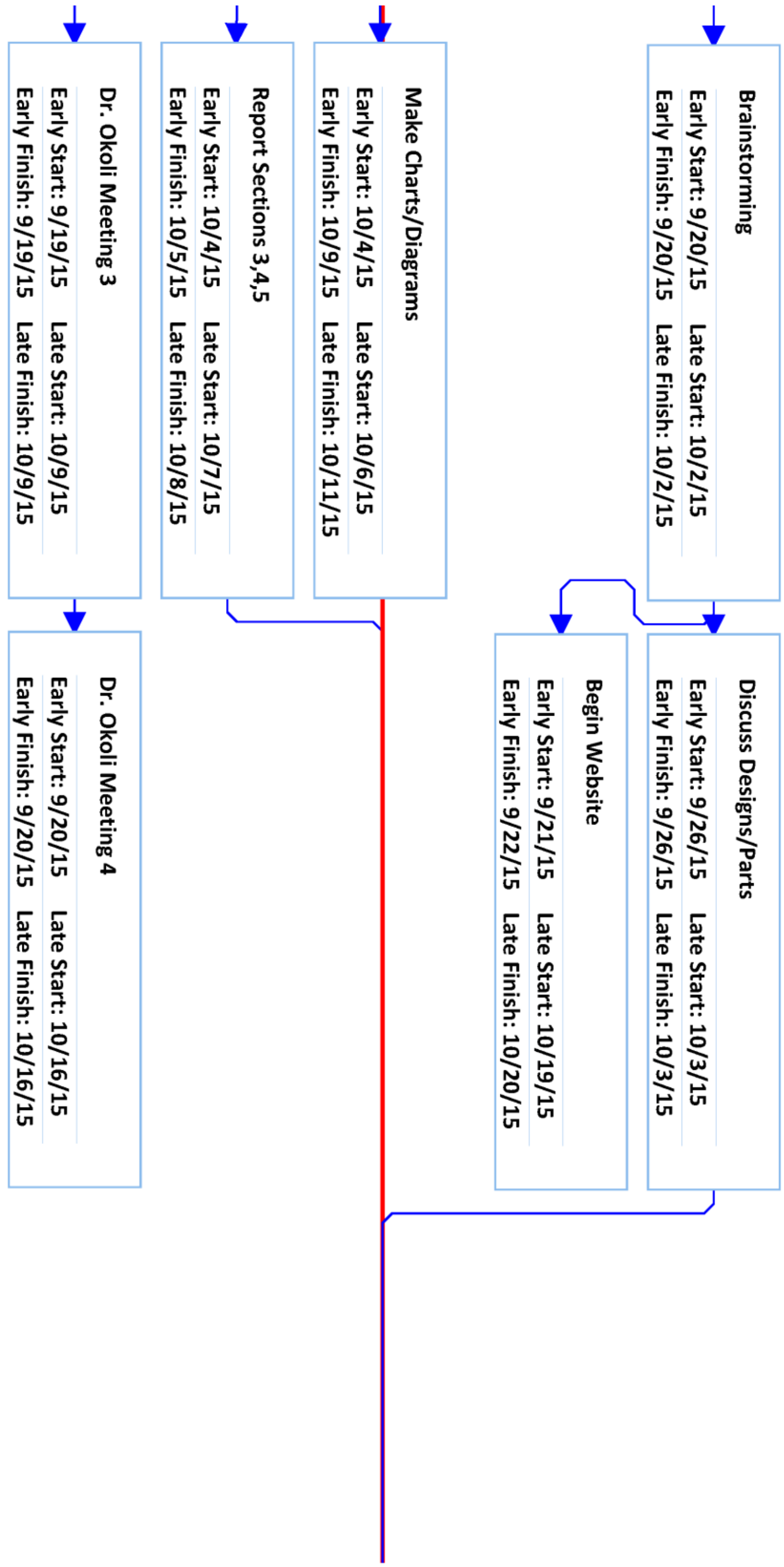
Major tasks that are required to be completed by the end of the Design Phase are discussed in Table 9. Figure 13 depicts the network flow diagram for the Design Phase, which includes the specific tasks necessary to complete the ones given in Table 9. Quantitative information regarding the specific tasks for the Define Phase depicted in Figure 13 is given in Table 10.

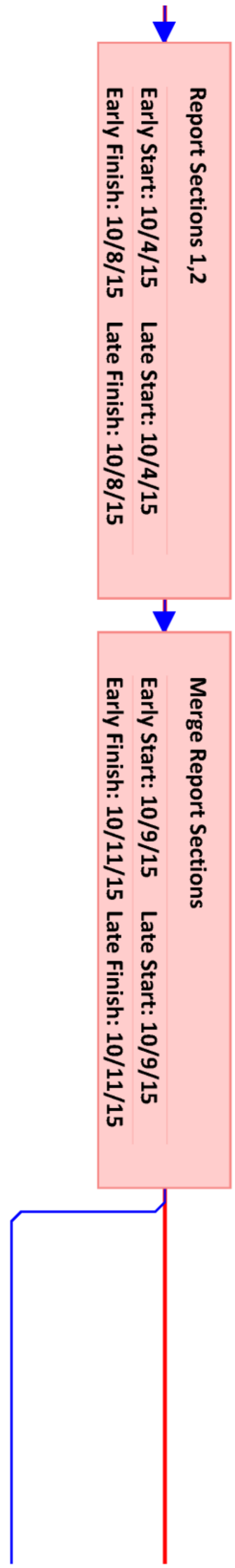
Table 9: Major Tasks for the Define Phase

Task	Explanation
Writing the group's team contract.	This task ensures all team members agree on the policies and procedures that will be used throughout this project.
Contacting and meeting with Dr. Okoli.	This task allows the team to obtain the sponsor's customer requirements and demands for the oil palm fruit harvesting device.
Making a voice of the customer diagram.	This task verifies that all of the customer's requirements were successfully understood.
Constructing the house of quality.	This task converts the customer's requirements into technical requirements and determine the most important elements to consider.
Conducting background research.	This task includes conducting background research into past prototypes and design methodology. It also includes researching current oil palm fruit harvesting methods and the variables involved. This task is significant, because a prototype cannot be designed without knowledge of the current harvesting process.
Writing the group's Risk Assessment.	This task ensures the safety of all group members during the construction and testing of any prototype design.
Brainstorming.	This task allows group members to discuss ideas regarding harvesting device designs.
Choosing a design selection deadline.	This task ensures the team receives the necessary materials by the beginning of the Analyze Phase.
Writing the Define Phase report.	This task allows the group to communicate to the sponsor and stakeholders the team's approach to the project and the current status of any design concepts.
Presenting the group's project status.	This task allows the group to demonstrate a firm understanding of the project to the sponsor and stakeholders, as well as provide a synopsis of the Define Phase report.


Group Organization Meeting
Early Start: 9/8/15
Late Start: 9/11/15
Early Finish: 9/8/15
Late Finish: 9/11/15
Complete/Submit Team Contract
Early Start: 9/9/15
Late Start: 9/17/15
Early Finish: 9/9/15
Late Finish: 9/17/15
Research Palm Harvesting
Early Start: 9/9/15
Late Start: 9/12/15
Early Finish: 9/14/15
Late Finish: 9/17/15
Dr. Gupta Meeting 1
Early Start: 9/9/15
Late Start: 9/17/15
Early Finish: 9/9/15
Late Finish: 9/17/15
Write Risk Assessment
Early Start: 9/28/15
Late Start: 10/10/15
Early Finish: 10/5/15
Late Finish: 10/17/15
Look at Past Designs
Early Start: 9/14/15
Late Start: 9/14/15
Early Finish: 9/17/15
Late Finish: 9/17/15


Dr. Okoli Meeting 1
Early Start: 9/17/15 Late Start: 9/18/15
Early Finish: 9/17/15 Late Finish: 9/18/15
Review Risk Assessment
Early Start: 10/6/15 Late Start: 10/18/15
Early Finish: 10/6/15 Late Finish: 10/18/15
Check Usability of Old Parts
Early Start: 9/18/15 Late Start: 9/26/15
Early Finish: 9/19/15 Late Finish: 9/27/15
Tree Climbing Discussion
Early Start: 9/18/15 Late Start: 10/1/15
Early Finish: 9/18/15 Late Finish: 10/1/15
Determine Voice of Customer
Early Start: 9/18/15 Late Start: 9/18/15
Early Finish: 10/3/15 Late Finish: 10/3/15
Dr. Okoli Meeting 2
Early Start: 9/18/15 Late Start: 10/2/15
Early Finish: 9/18/15 Late Finish: 10/2/15


Brainstorming
Early Start: 9/20/15
Late Start: 10/2/15
Early Finish: 9/20/15
Late Finish: 10/2/15
Discuss Designs/Parts
Early Start: 9/26/15
Late Start: 10/3/15
Early Finish: 9/26/15
Late Finish: 10/3/15
Begin Website
Early Start: 9/21/15
Late Start: 10/19/15
Early Finish: 9/22/15
Late Finish: 10/20/15
Make Charts/Diagrams
Early Start: 10/4/15
Late Start: 10/6/15
Early Finish: 10/9/15
Late Finish: 10/11/15
Report Sections 3,4,5
Early Start: 10/4/15
Late Start: 10/7/15
Early Finish: 10/5/15
Late Finish: 10/8/15
Dr. Okoli Meeting 3
Early Start: 9/19/15
Late Start: 10/9/15
Early Finish: 9/19/15
Late Finish: 10/9/15
Dr. Okoli Meeting 4
Early Start: 9/20/15
Late Start: 10/16/15
Early Finish: 9/20/15
Late Finish: 10/16/15


Report Sections 1,2
Early Start: 10/4/15
Late Start: 10/4/15
Early Finish: 10/8/15
Late Finish: 10/8/15
Merge Report Sections
Early Start: 10/9/15
Late Start: 10/9/15
Early Finish: 10/11/15
Late Finish: 10/11/15

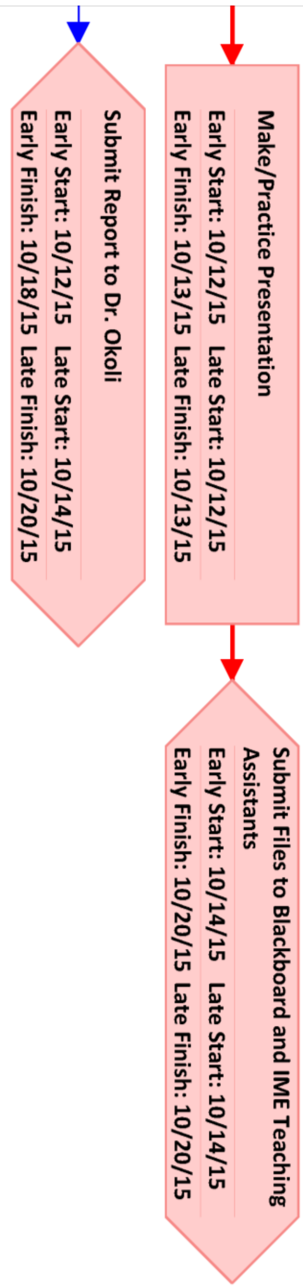


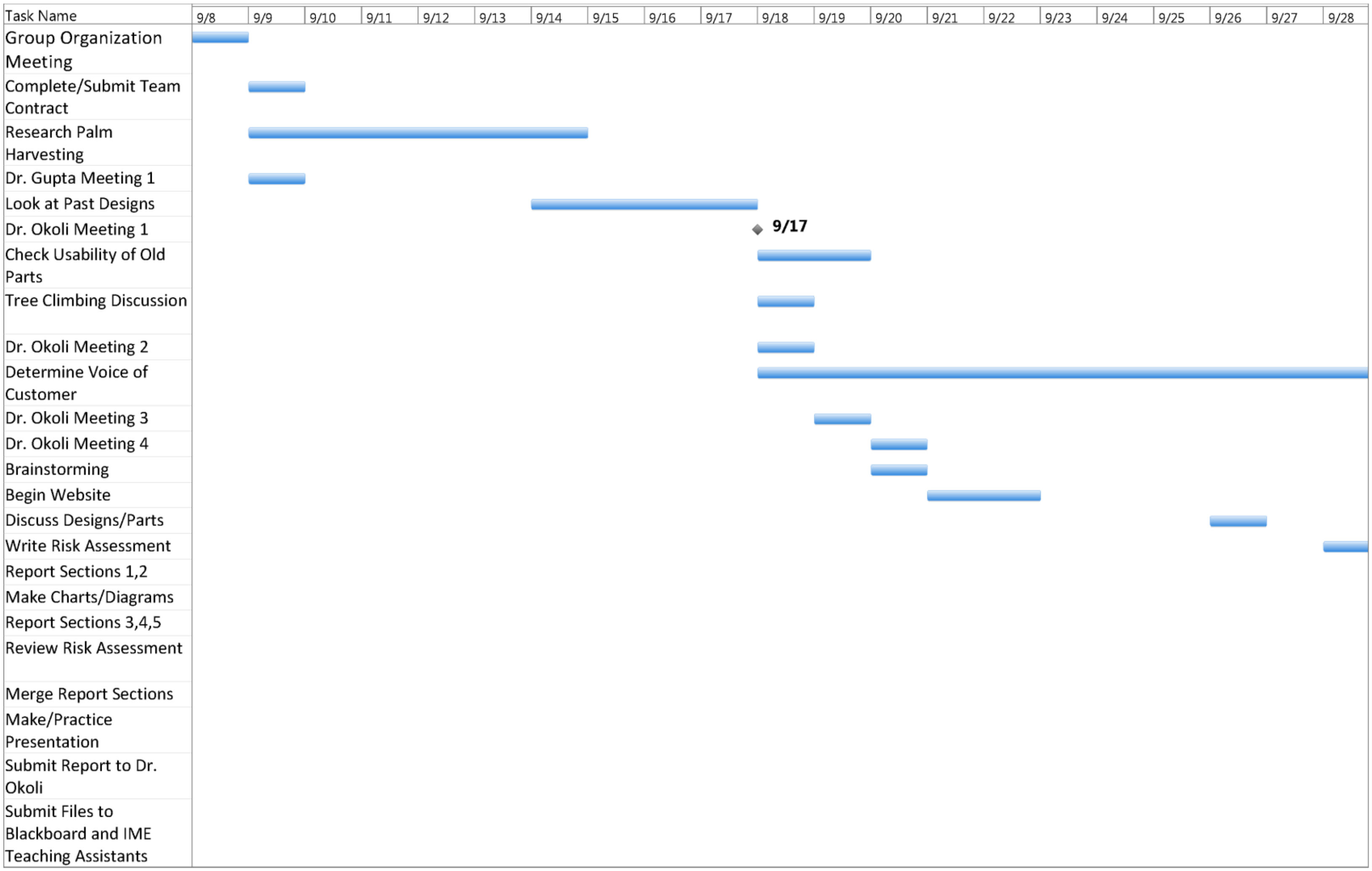
Figure 13: Network Flow Diagram for the Define Phase

Table 10: Detailed Network Flow Diagram Information for Define Phase Tasks

Task Name	Start	Finish	Free Slack	Total Slack	Early Start	Early Finish	Late Start	Late Finish
Group Organization Meeting	9/8/15	9/8/15	0 days	3 days	9/8/15	9/8/15	9/11/15	9/11/15
Complete/Submit Team Contract	9/9/15	9/9/15	8 days	8 days	9/9/15	9/9/15	9/17/15	9/17/15
Research Palm Harvesting	9/9/15	9/14/15	3 days	3 days	9/9/15	9/14/15	9/12/15	9/17/15
Dr. Gupta Meeting 1	9/9/15	9/9/15	8 days	8 days	9/9/15	9/9/15	9/17/15	9/17/15
Look at Past Designs	9/14/15	9/17/15	0 days	0 days	9/14/15	9/17/15	9/14/15	9/17/15
Dr. Okoli Meeting 1	9/17/15	9/17/15	0 days	0 days	9/17/15	9/17/15	9/18/15	9/18/15
Check Usability of Old Parts	9/18/15	9/19/15	0 days	8 days	9/18/15	9/19/15	9/26/15	9/27/15
Tree Climbing Discussion	9/18/15	9/18/15	1 day	13 days	9/18/15	9/18/15	10/1/15	10/1/15
Dr. Okoli Meeting 2	9/18/15	9/18/15	0 days	14 days	9/18/15	9/18/15	10/2/15	10/2/15
Determine Voice of Customer	9/18/15	10/3/15	0 days	0 days	9/18/15	10/3/15	9/18/15	10/3/15
Dr. Okoli Meeting 3	9/19/15	9/19/15	0 days	20 days	9/19/15	9/19/15	10/9/15	10/9/15
Dr. Okoli Meeting 4	9/20/15	9/20/15	26 days	26 days	9/20/15	9/20/15	10/16/15	10/16/15
Brainstorming	9/20/15	9/20/15	0 days	12 days	9/20/15	9/20/15	10/2/15	10/2/15
Begin Website	9/21/15	9/22/15	28 days	28 days	9/21/15	9/22/15	10/19/15	10/20/15
Discuss Designs/Parts	9/26/15	9/26/15	7 days	7 days	9/26/15	9/26/15	10/3/15	10/3/15
Write Risk Assessment	9/28/15	10/5/15	0 days	12 days	9/28/15	10/5/15	10/10/15	10/17/15
Report Sections 1,2	10/4/15	10/8/15	0 days	0 days	10/4/15	10/8/15	10/4/15	10/8/15
Make Charts/Diagrams	10/4/15	10/9/15	2 days	2 days	10/4/15	10/9/15	10/6/15	10/11/15
Report Sections 3,4,5	10/4/15	10/5/15	3 days	3 days	10/4/15	10/5/15	10/7/15	10/8/15
Review Risk Assessment	10/6/15	10/6/15	12 days	12 days	10/6/15	10/6/15	10/18/15	10/18/15
Merge Report Sections	10/9/15	10/11/15	0 days	0 days	10/9/15	10/11/15	10/9/15	10/11/15
Make/Practice Presentation	10/12/15	10/13/15	0 days	0 days	10/12/15	10/13/15	10/12/15	10/13/15
Submit Report to Dr. Okoli	10/12/15	10/18/15	2 days	2 days	10/12/15	10/18/15	10/14/15	10/20/15
Submit Files to Bb and TAs	10/14/15	10/20/15	0 days	0 days	10/14/15	10/20/15	10/14/15	10/20/15

Free slack refers to the number of days an activity can be delayed before it delays any succeeding activities, while total slack (also known as float) denotes the number of days an activity can be delayed before it delays the entire project [19]. All activities with a total slack value of zero (0) in Table 10 are along the Define Phase's critical path, which is denoted by red boxes and arrows in Figure 13. These critical tasks must be completed by the specified deadline, or the Define Phase will be delayed. Table 10 shows that the first part of the Define Phase's critical path starts on 9/14/15 and ends on 10/20/15. Thus, the critical path of the Define Phase is 36 days.

A Gantt chart of the Define Phase's activities was constructed and is depicted in Figure 14. A Gantt chart is a project management tool used to visualize a project from start to finish. This includes, but it not limited to, a list of all project activities, when each activity begins and finishes, the expected duration of each activity, and where any activities may overlap with one another.


Task Name
9/8
9/9
9/10
9/11
9/12
9/13
9/14
9/15
9/16
9/17
9/18
9/19
9/20
9/21
9/22
9/23
9/24
9/25
9/26
9/27
9/28
Group Organization Meeting
Complete/Submit Team Contract
Research Palm Harvesting
Dr. Gupta Meeting 1
Look at Past Designs
Dr. Okoli Meeting 1
9/17
Check Usability of Old Parts
Tree Climbing Discussion
Dr. Okoli Meeting 2
Determine Voice of Customer
Dr. Okoli Meeting 3
Dr. Okoli Meeting 4
Brainstorming
Begin Website
Discuss Designs/Parts
Write Risk Assessment
Report Sections 1,2
Make Charts/Diagrams
Report Sections 3,4,5
Review Risk Assessment
Merge Report Sections
Make/Practice Presentation
Submit Report to Dr. Okoli
Submit Files to Blackboard and IME Teaching Assistants

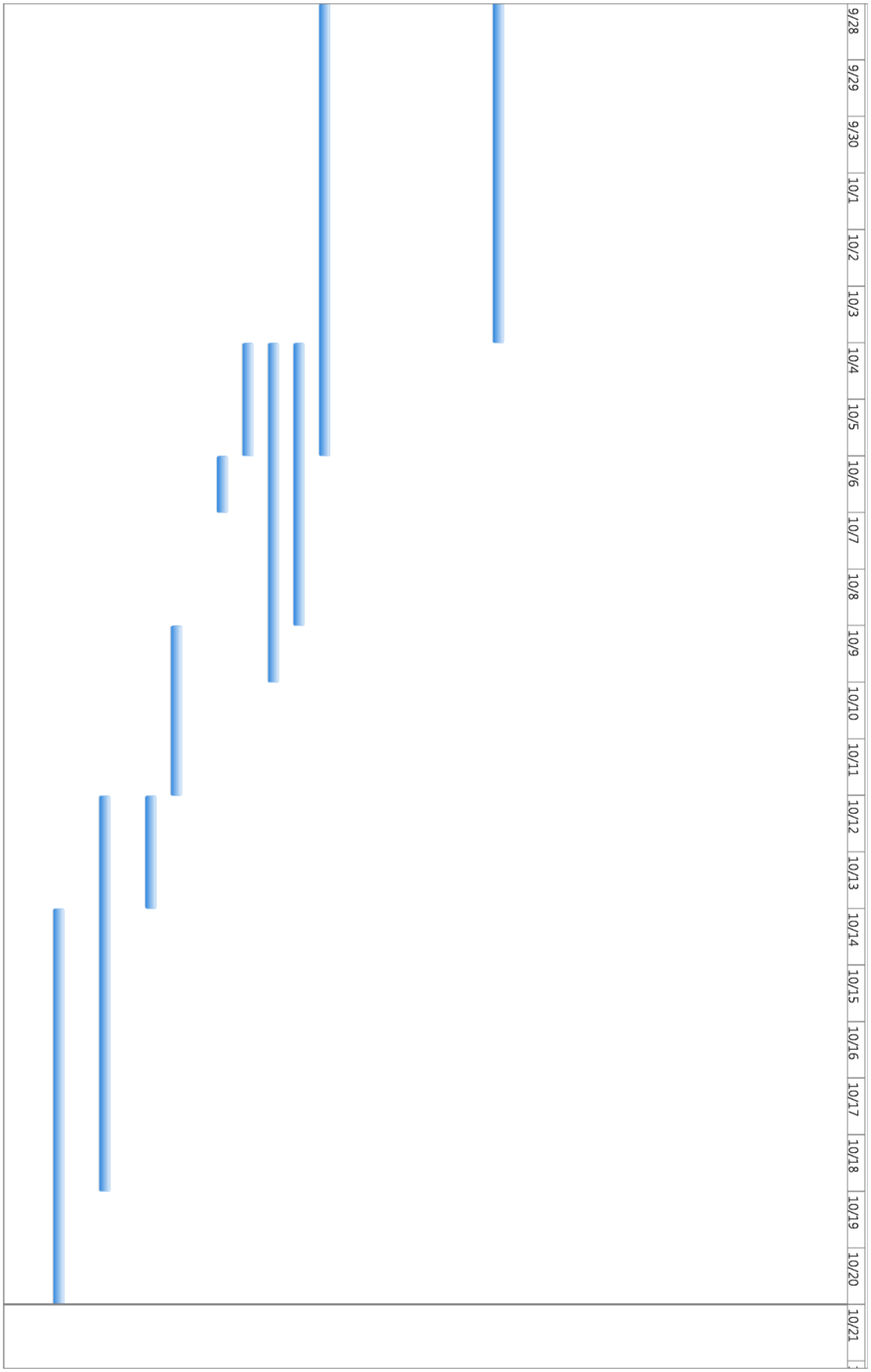


Figure 14: Gantt Chart for the Define Phase

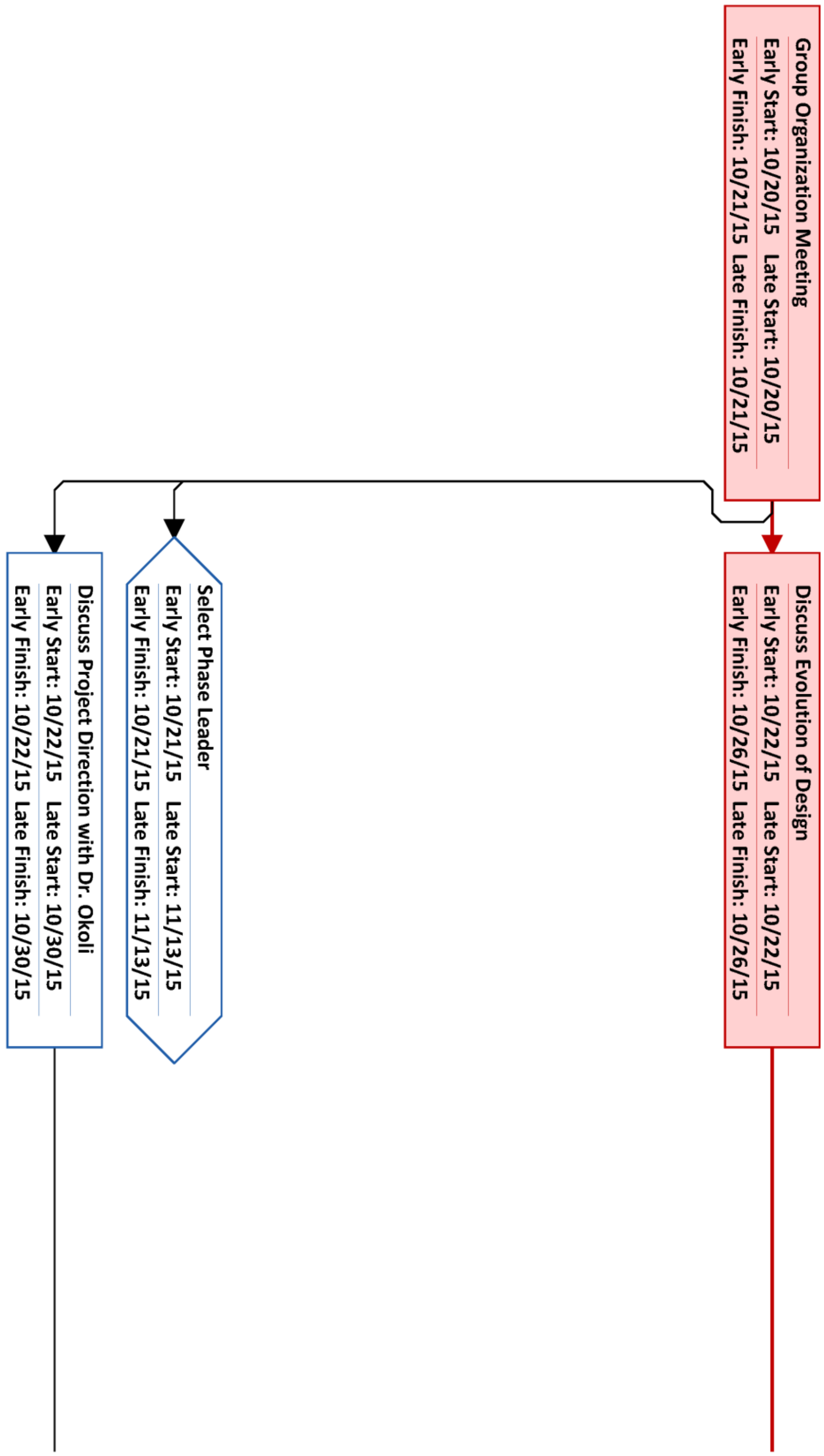
Using Figure 13 and Figure 14, the earliest the Define Phase can end is 10/20/15. The latest the Define Phase can end is also 10/20/15. The reason the early and late finish dates are the same is due to the aforementioned critical path and total slack times, as well as the fact that the Define Phase requires a significant amount of time to ensure all customer requirements are defined properly. In Figure 13 and Figure 14, four days were allotted to submitting the report to the project's stakeholders. If critical tasks are not completed by their late finish deadlines, then the amount of time needed to submit the report at the end of the Define Phase must be reduced. In order to accomplish this task, the team would be required to work in time that was previously not designated for the project. Since this is the beginning of the project and the team is defining customer requirements, the team has not yet faced any delays in the project.

5.1.2 Measure Phase Tasks

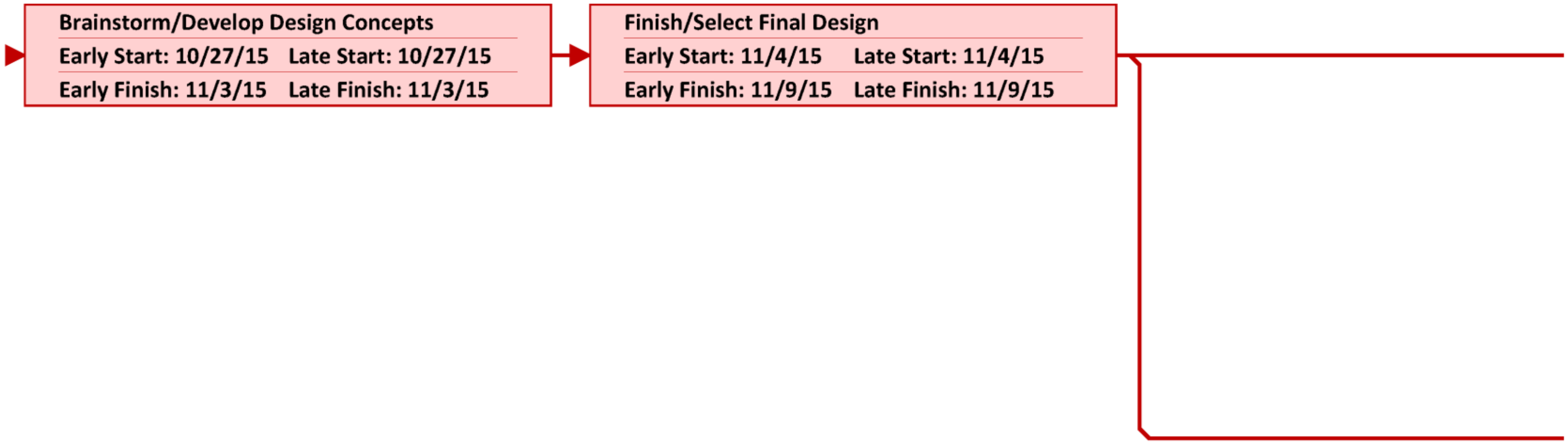
Since the Measure Phase has not yet begun, all tasks listed in this subsection are subject to change in the future, based on the team's design process or new instructions from the sponsor. Major tasks that are required to be completed by the end of the Measure Phase are discussed in Table 11. Figure 15 depicts the network flow diagram for the Measure Phase, which includes the tentative planning of the beginning of the Measure Phase in detail, along with a broader plan of the end of the phase. Quantitative information regarding the specific tasks depicted in Figure 15 is given in Table 12.

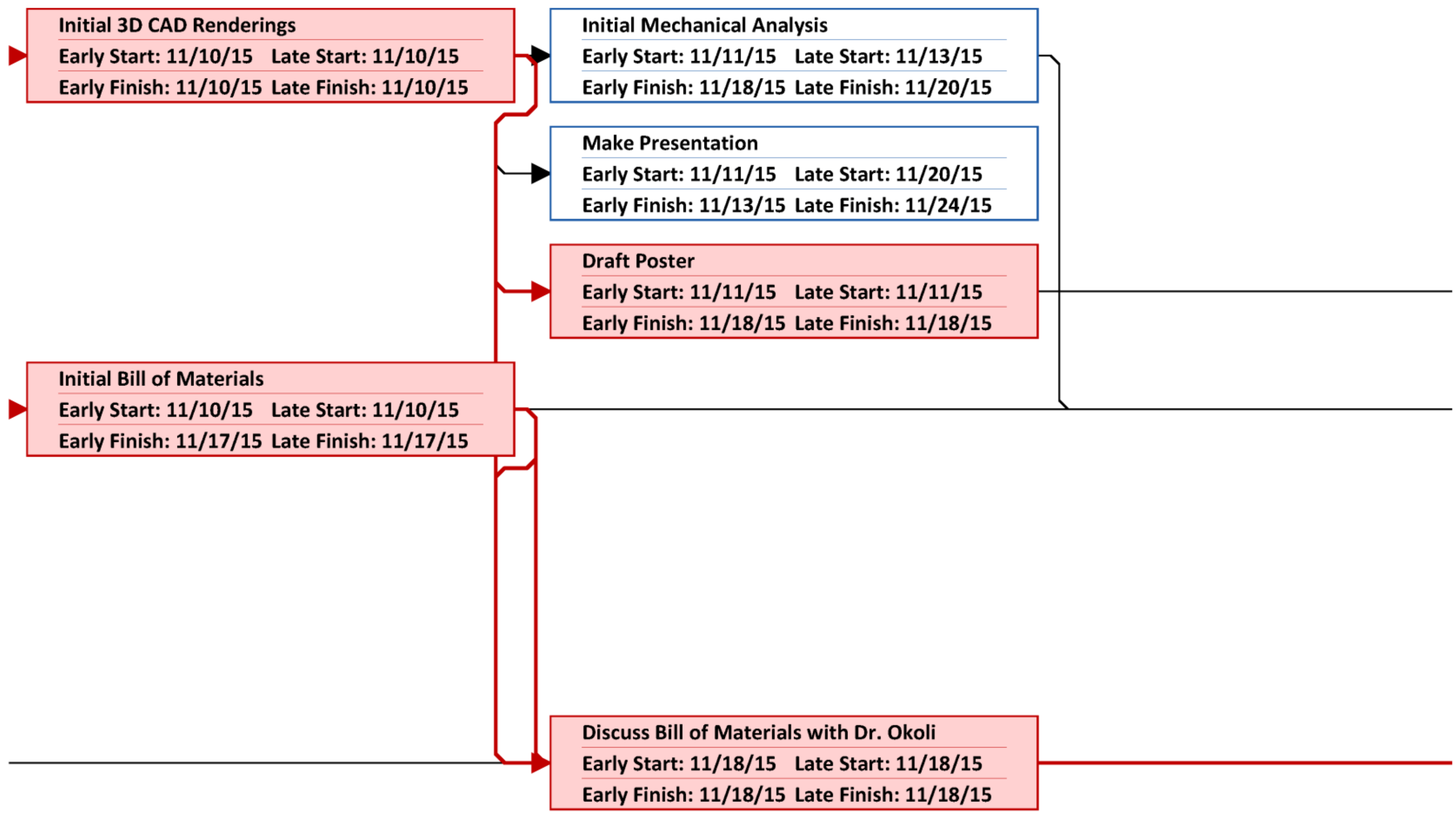
Table 11: Major Tasks for the Measure Phase

Task	Explanation
Contacting and meeting with Dr. Okoli.	This ensures that any designs developed by the group are desirable by the sponsor.
Brainstorming.	Group members discuss ideas regarding harvesting device designs.
Discuss the evolution of the team's designs.	Team members discuss which palm harvesting ideas are feasible, given the time constraints of the project.
Final design selection.	A design that meets the sponsor's requirements must be selected.
Generate three-dimensional design renderings.	This visualizes how the palm harvesting prototype will appear after it is built and allows for any design issues to be identified before construction begins.
Writing the Measure Phase report.	This communicates to the sponsor and stakeholders the team's design selection and the steps that must be taken before it is constructed.
Presenting the group's project status.	This demonstrates that a design was selected and materials were ordered to the sponsor and stakeholders, as well as provide a synopsis of the Measure report.
Ordering the materials needed for the selected palm harvesting device design.	Makes sure materials arrive before the beginning of the Analyze Phase.



Group Organization Meeting
Early Start: 10/20/15 Late Start: 10/20/15
Early Finish: 10/21/15 Late Finish: 10/21/15
Discuss Evolution of Design
Early Start: 10/22/15 Late Start: 10/22/15
Early Finish: 10/26/15 Late Finish: 10/26/15
Select Phase Leader
Early Start: 10/21/15 Late Start: 11/13/15
Early Finish: 10/21/15 Late Finish: 11/13/15
Discuss Project Direction with Dr. Okoli
Early Start: 10/22/15 Late Start: 10/30/15
Early Finish: 10/22/15 Late Finish: 10/30/15


Brainstorm/Develop Design Concepts
Early Start: 10/27/15 Late Start: 10/27/15
Early Finish: 11/3/15 Late Finish: 11/3/15
Finish/Select Final Design
Early Start: 11/4/15 Late Start: 11/4/15
Early Finish: 11/9/15 Late Finish: 11/9/15


Initial 3D CAD Renderings
Early Start: 11/10/15 Late Start: 11/10/15
Early Finish: 11/10/15 Late Finish: 11/10/15
Initial Mechanical Analysis
Early Start: 11/11/15 Late Start: 11/13/15
Early Finish: 11/18/15 Late Finish: 11/20/15
Make Presentation
Early Start: 11/11/15 Late Start: 11/20/15
Early Finish: 11/13/15 Late Finish: 11/24/15
Draft Poster
Early Start: 11/11/15 Late Start: 11/11/15
Early Finish: 11/18/15 Late Finish: 11/18/15
Initial Bill of Materials
Early Start: 11/10/15 Late Start: 11/10/15
Early Finish: 11/17/15 Late Finish: 11/17/15
Discuss Bill of Materials with Dr. Okoli
Early Start: 11/18/15 Late Start: 11/18/15
Early Finish: 11/18/15 Late Finish: 11/18/15

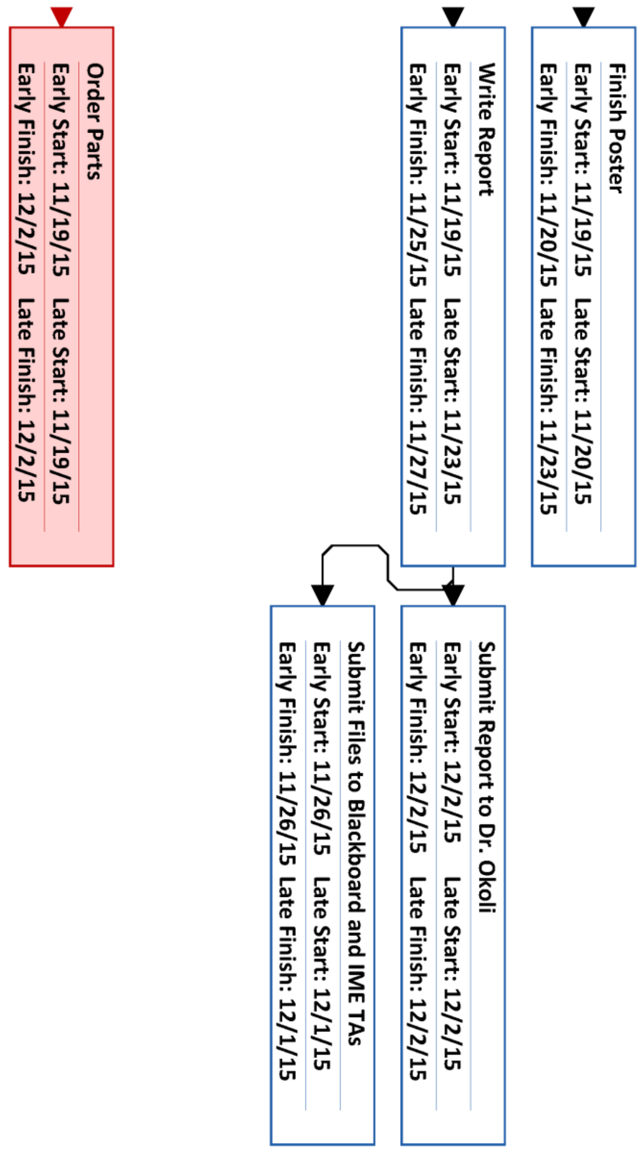


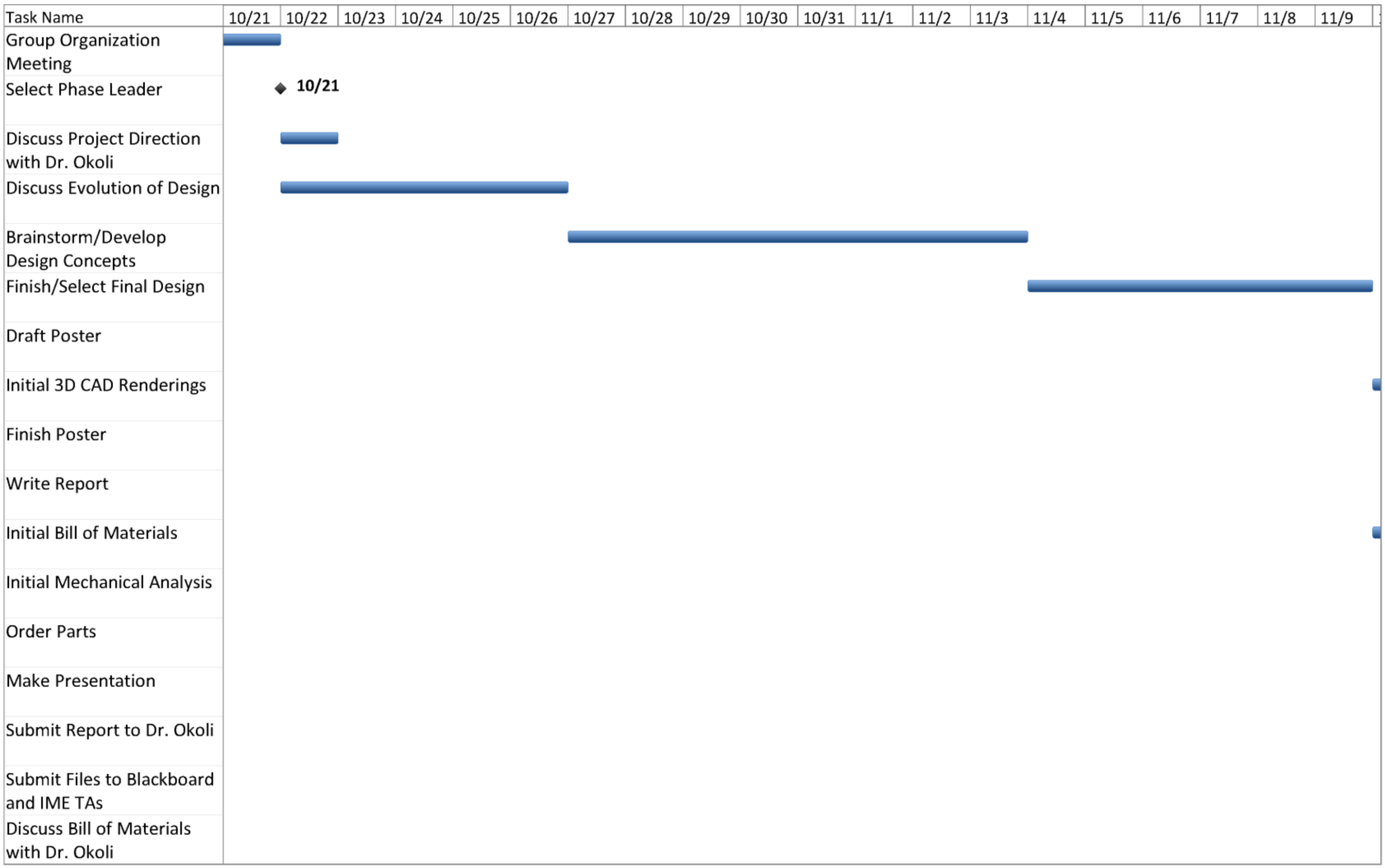
Figure 15: Network Flow Diagram for the Measure Phase

Table 12: Detailed Network Flow Diagram Information for Measure Phase Tasks

Task Name	Start	Finish	Free Slack	Total Slack	Early Start	Early Finish	Late Start	Late Finish
Group Organization Meeting	10/20/15	10/21/15	0 days	0 days	10/20/15	10/21/15	10/20/15	10/21/15
Select Phase Leader	10/21/15	10/21/15	17 days	17 days	10/21/15	10/21/15	11/13/15	11/13/15
Discuss Project Direction with Dr. Okoli	10/22/15	10/22/15	6 days	6 days	10/22/15	10/22/15	10/30/15	10/30/15
Discuss Evolution of Design	10/22/15	10/26/15	0 days	0 days	10/22/15	10/26/15	10/22/15	10/26/15
Brainstorm/Develop Design Concepts	10/27/15	11/3/15	0 days	0 days	10/27/15	11/3/15	10/27/15	11/3/15
Finish/Select Final Design	11/4/15	11/9/15	0 days	0 days	11/4/15	11/9/15	11/4/15	11/9/15
Initial 3D CAD Renderings	11/10/15	11/10/15	0 days	0 days	11/10/15	11/10/15	11/10/15	11/10/15
Initial Bill of Materials	11/10/15	11/17/15	0 days	0 days	11/10/15	11/17/15	11/10/15	11/17/15
Draft Poster	11/11/15	11/18/15	0 days	0 days	11/11/15	11/18/15	11/11/15	11/18/15
Initial Mechanical Analysis	11/11/15	11/18/15	0 days	2 days	11/11/15	11/18/15	11/13/15	11/20/15
Make Presentation	11/11/15	11/13/15	7 days	7 days	11/11/15	11/13/15	11/20/15	11/24/15
Discuss Bill of Materials with Dr. Okoli	11/18/15	11/18/15	0 days	0 days	11/18/15	11/18/15	11/18/15	11/18/15
Finish Poster	11/19/15	11/20/15	1 day	1 day	11/19/15	11/20/15	11/20/15	11/23/15
Write Report	11/19/15	11/25/15	0 days	2 days	11/19/15	11/25/15	11/23/15	11/27/15
Order Parts	11/19/15	12/2/15	0 days	0 days	11/19/15	12/2/15	11/19/15	12/2/15
Submit Files to Blackboard and IME TAs	11/26/15	11/26/15	3 days	3 days	11/26/15	11/26/15	12/1/15	12/1/15
Submit Report to Dr. Okoli	12/2/15	12/2/15	0 days	0 days	12/2/15	12/2/15	12/2/15	12/2/15

Free slack and total slack (float) were discussed in Section 5.1.1. All activities with a total slack value of zero (0) in Table 12 are along the Measure Phase's critical path, which is denoted by red boxes and arrows in Figure 15. These critical tasks must be completed by the specified deadline, or the Measure Phase will be delayed. Table 10 shows that the first part of the Measure Phase's critical path starts on 10/20/15 and ends on 12/2/15. Thus, the critical path of the Measure Phase is 43 days.

Gantt charts were discussed in Section 5.1.1. A Gantt chart of the Measure Phase's planned activities was constructed and is depicted in Figure 16.


Task Name
10/21
10/22
10/23
10/24
10/25
10/26
10/27
10/28
10/29
10/30
10/31
11/1
11/2
11/3
11/4
11/5
11/6
11/7
11/8
11/9
Group Organization Meeting
Select Phase Leader
10/21
Discuss Project Direction with Dr. Okoli
Discuss Evolution of Design
Brainstorm/Develop Design Concepts
Finish/Select Final Design
Draft Poster
Initial 3D CAD Renderings
Finish Poster
Write Report
Initial Bill of Materials
Initial Mechanical Analysis
Order Parts
Make Presentation
Submit Report to Dr. Okoli
Submit Files to Blackboard and IME TAs
Discuss Bill of Materials with Dr. Okoli

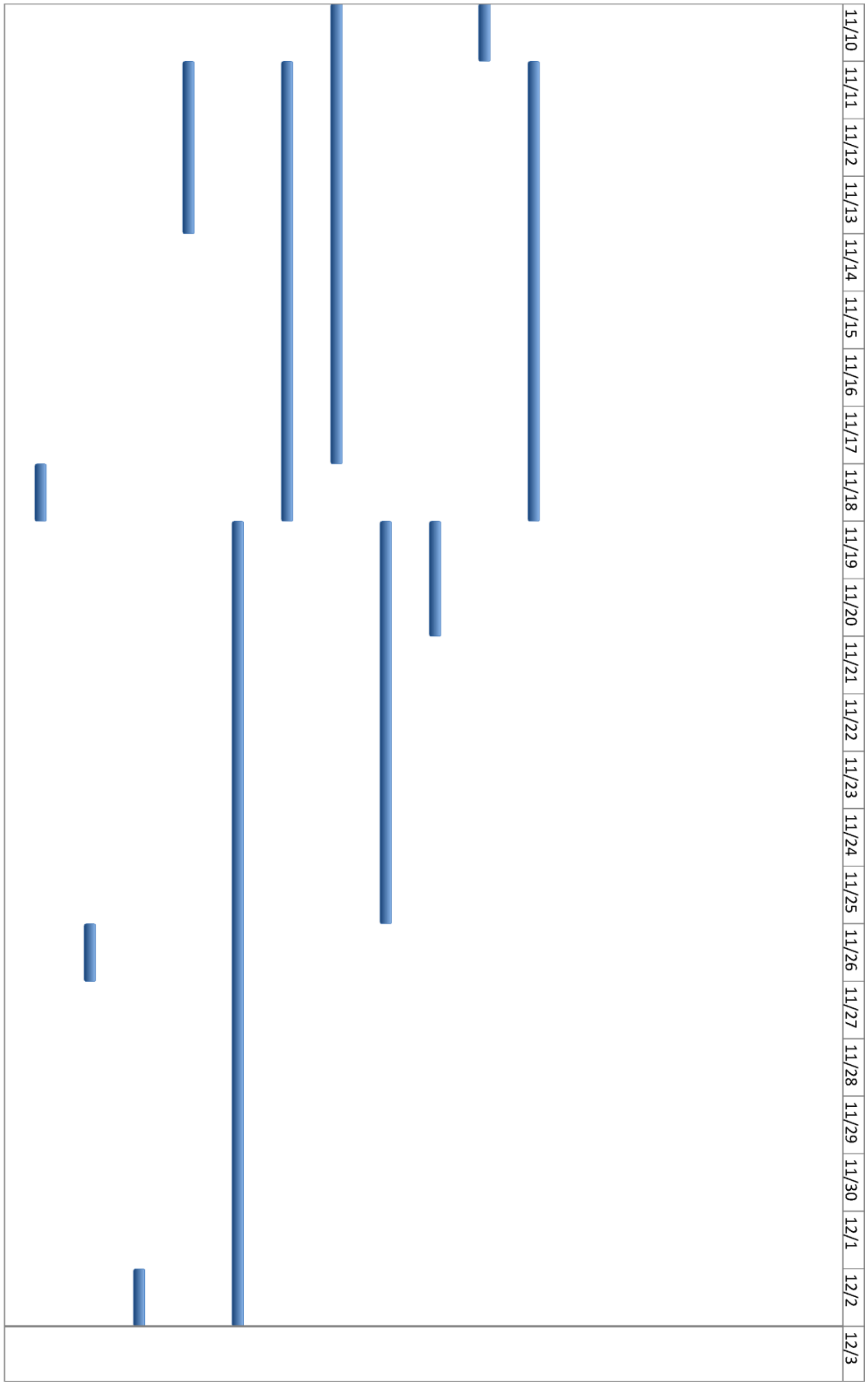


Figure 16: Gantt Chart for the Measure Phase

Using Figure 15 and Figure 16, the earliest the Measure Phase can end is 12/2/15. The latest the Measure Phase can end is also 12/2/15. However, these planned tasks are subject to change at the conclusion of the Define Phase or at the beginning of the Measure Phase.

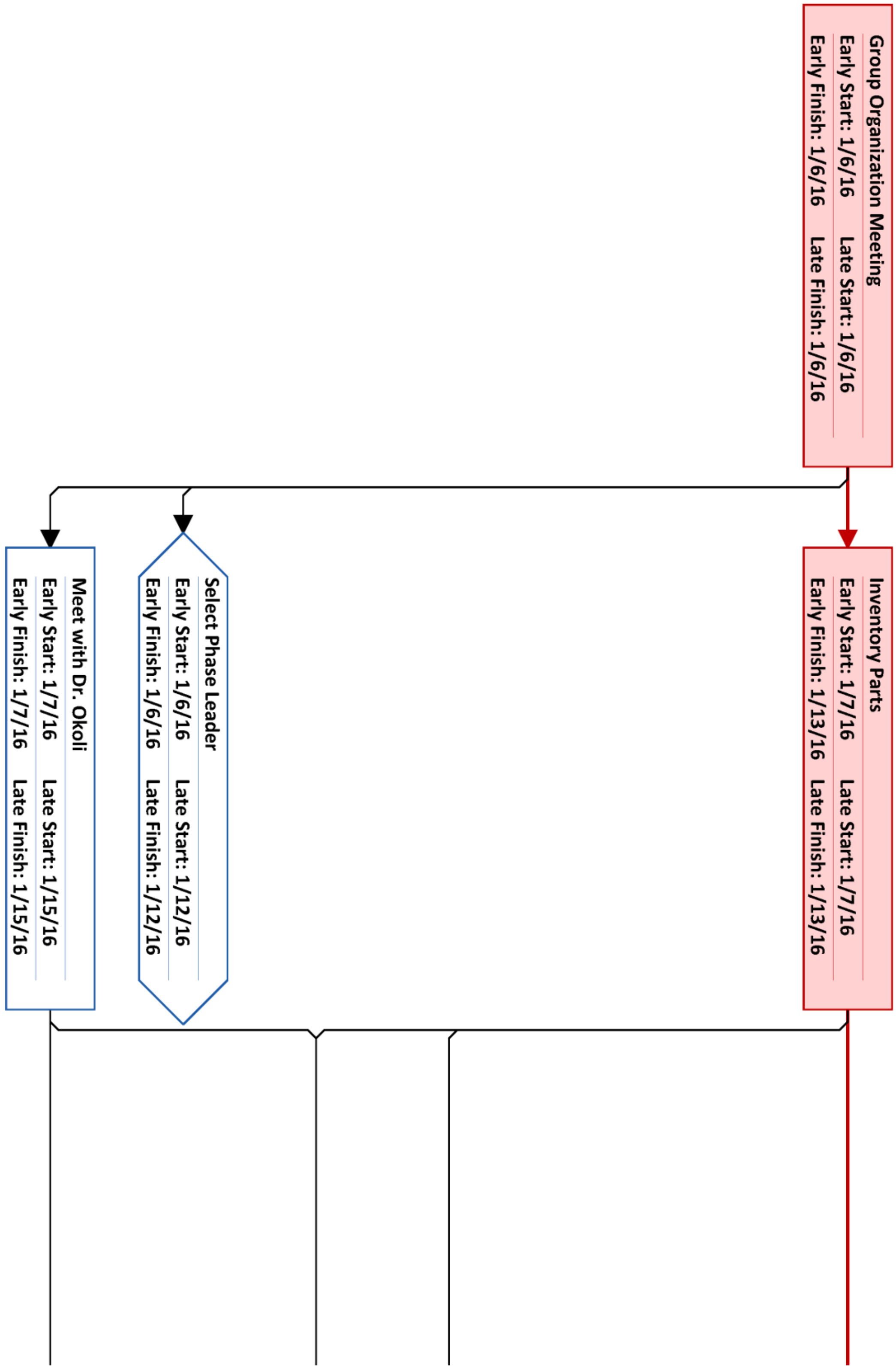
5.1.3 Analyze Phase Tasks

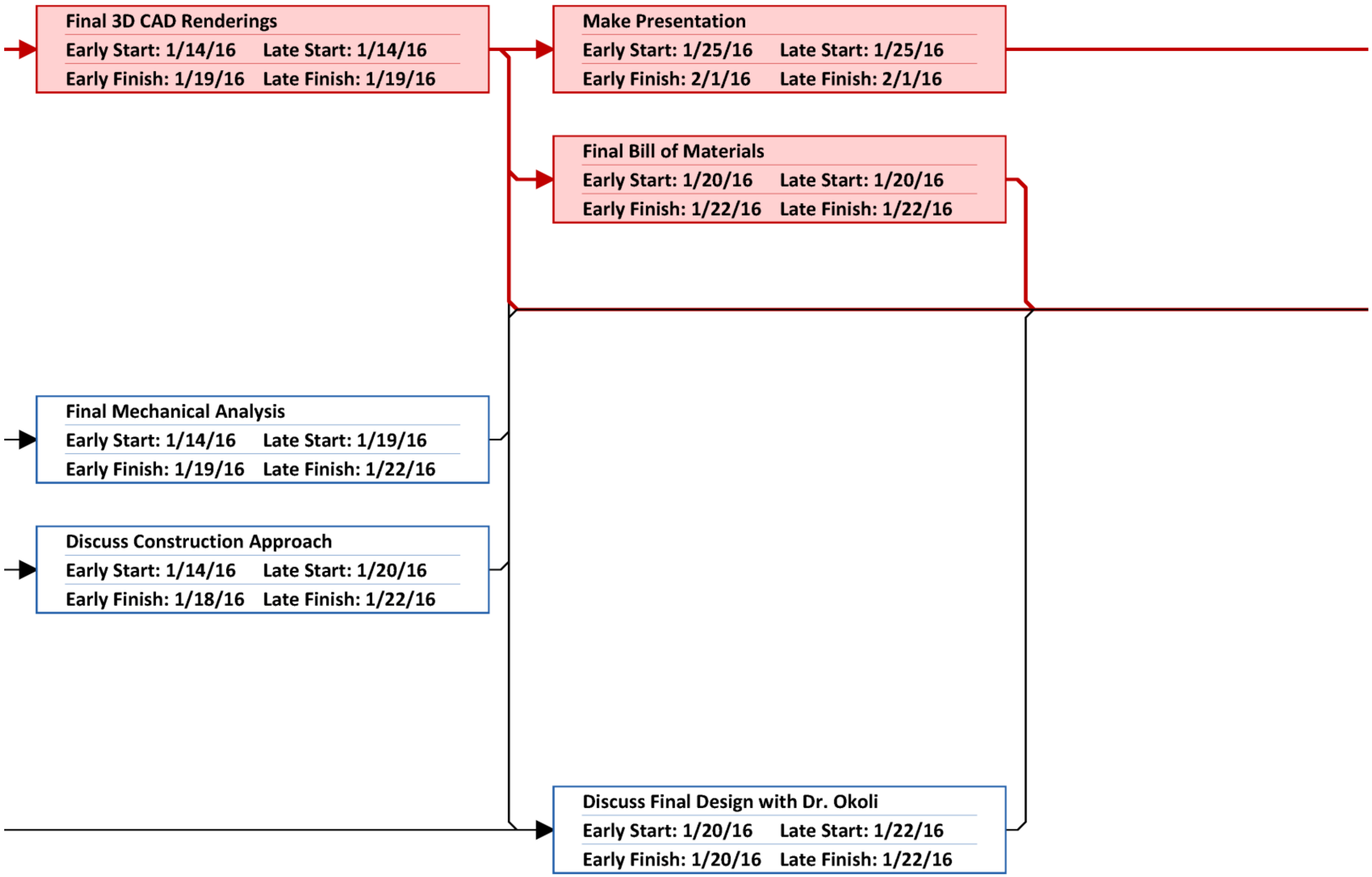
Since the Analyze Phase has not yet begun, all tasks listed in this subsection are subject to change in the future, based on the team's design process or new instructions from the sponsor. Major tasks that are required to be completed by the end of the Analyze Phase are discussed in Table 13.

Figure 17 depicts the network flow diagram for the Analyze Phase, which includes a broad outline of the tasks that need to be completed. Quantitative information regarding the specific tasks depicted in Figure 17 is given in Table 14.

Table 13: Major Tasks for the Analyze Phase

Task	Explanation
Contacting and meeting with Dr. Okoli.	This ensures that any designs developed by the group do not need any final adjustments before being constructed.
Begin construction of the palm harvesting device prototype.	The prototype cannot be tested if it is not built.
Test the prototype.	The group analyzes the effectiveness of the palm harvesting device prototype and begins to study any changes that may be required to the device.
Writing the Analyze Phase report.	This allows the group to communicate to the sponsor and stakeholders the team's prototypes results and any future plans of action.
Presenting the group's project status.	This allows the group to demonstrate that a prototype was built and analyzed, as well as provide a synopsis of the Analyze Phase report.


Group Organization Meeting
Early Start: 1/6/16 Late Start: 1/6/16
Early Finish: 1/6/16 Late Finish: 1/6/16
Inventory Parts
Early Start: 1/7/16 Late Start: 1/7/16
Early Finish: 1/13/16 Late Finish: 1/13/16
Select Phase Leader
Early Start: 1/6/16 Late Start: 1/12/16
Early Finish: 1/6/16 Late Finish: 1/12/16
Meet with Dr. Okoli
Early Start: 1/7/16 Late Start: 1/15/16
Early Finish: 1/7/16 Late Finish: 1/15/16


Final 3D CAD Renderings
Early Start: 1/14/16 Late Start: 1/14/16
Early Finish: 1/19/16 Late Finish: 1/19/16
Make Presentation
Early Start: 1/25/16 Late Start: 1/25/16
Early Finish: 2/1/16 Late Finish: 2/1/16
Final Bill of Materials
Early Start: 1/20/16 Late Start: 1/20/16
Early Finish: 1/22/16 Late Finish: 1/22/16
Final Mechanical Analysis
Early Start: 1/14/16 Late Start: 1/19/16
Early Finish: 1/19/16 Late Finish: 1/22/16
Discuss Construction Approach
Early Start: 1/14/16 Late Start: 1/20/16
Early Finish: 1/18/16 Late Finish: 1/22/16
Discuss Final Design with Dr. Okoli
Early Start: 1/20/16 Late Start: 1/22/16
Early Finish: 1/20/16 Late Finish: 1/22/16

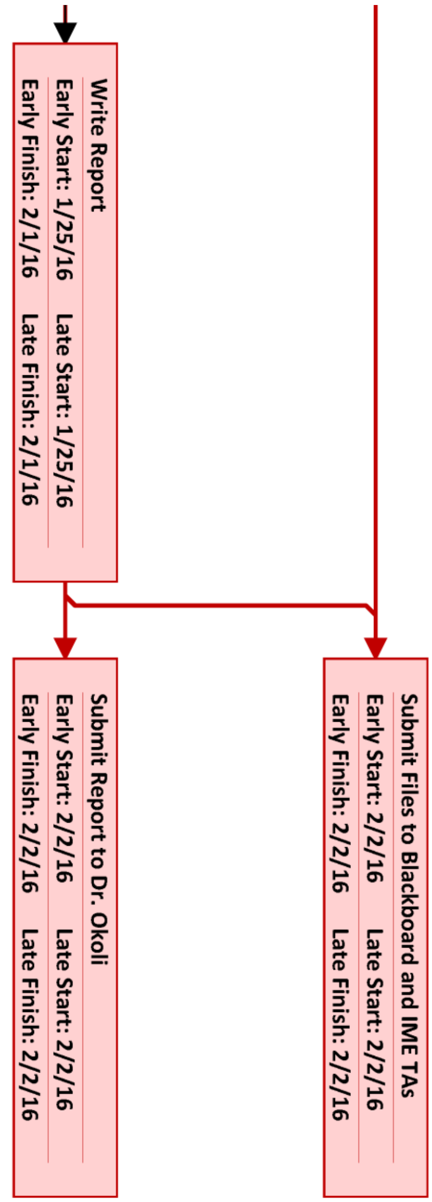


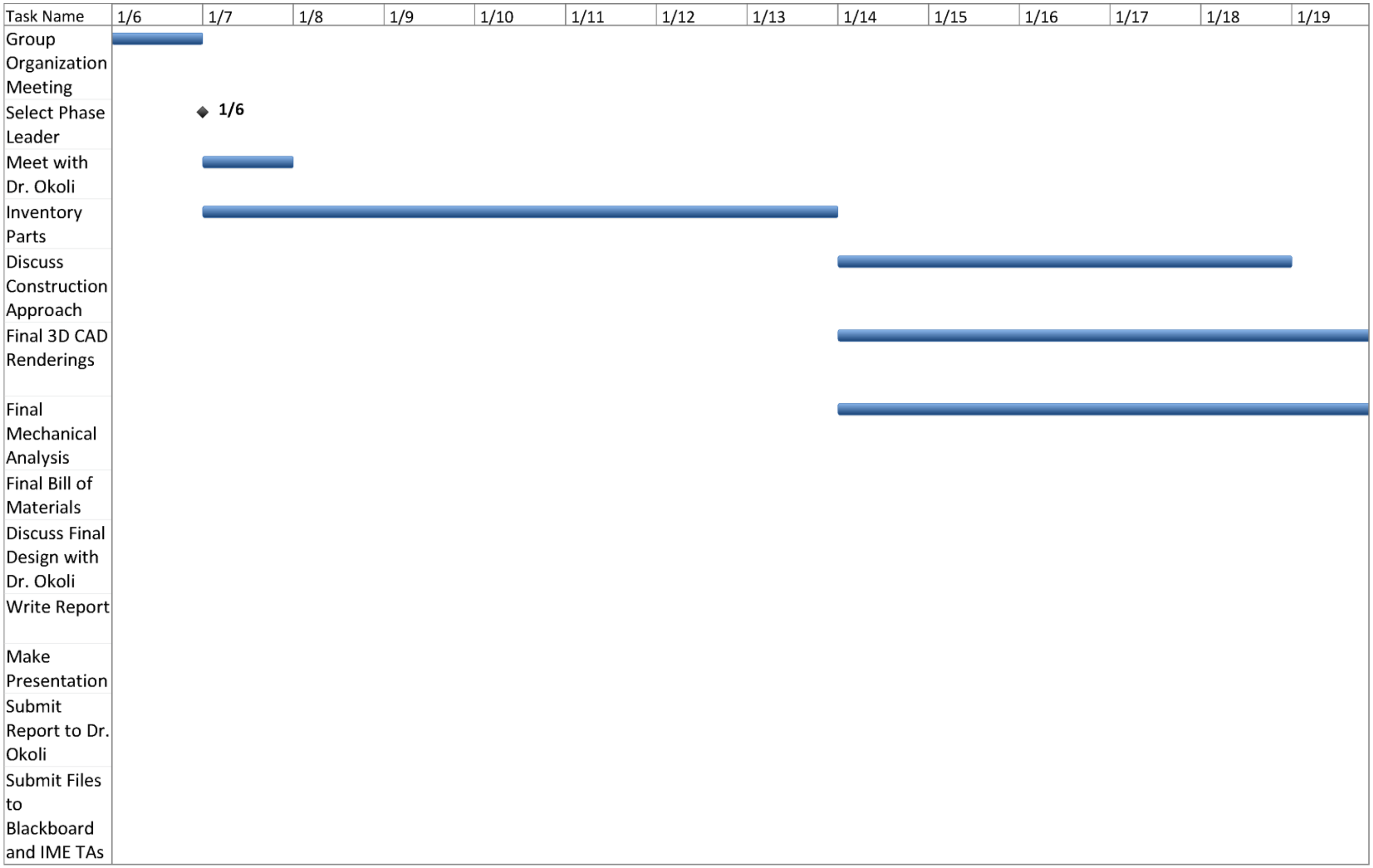
Figure 17: Network Flow Diagram for the Analyze Phase

Table 14: Detailed Network Flow Diagram Information for Analyze Phase Tasks

Task Name	Start	Finish	Free Slack	Total Slack	Early Start	Early Finish	Late Start	Late Finish
Group Organization Meeting	1/6/16	1/6/16	0 days	0 days	1/6/16	1/6/16	1/6/16	1/6/16
Select Phase Leader	1/6/16	1/6/16	4 days	4 days	1/6/16	1/6/16	1/12/16	1/12/16
Meet with Dr. Okoli	1/7/16	1/7/16	4 days	6 days	1/7/16	1/7/16	1/15/16	1/15/16
Inventory Parts	1/7/16	1/13/16	0 days	0 days	1/7/16	1/13/16	1/7/16	1/13/16
Discuss Construction Approach	1/14/16	1/18/16	4 days	4 days	1/14/16	1/18/16	1/20/16	1/22/16
Final 3D CAD Renderings	1/14/16	1/19/16	0 days	0 days	1/14/16	1/19/16	1/14/16	1/19/16
Final Mechanical Analysis	1/14/16	1/19/16	3 days	3 days	1/14/16	1/19/16	1/19/16	1/22/16
Final Bill of Materials	1/20/16	1/22/16	0 days	0 days	1/20/16	1/22/16	1/20/16	1/22/16
Discuss Final Design with Dr. Okoli	1/20/16	1/20/16	2 days	2 days	1/20/16	1/20/16	1/22/16	1/22/16
Write Report	1/25/16	2/1/16	0 days	0 days	1/25/16	2/1/16	1/25/16	2/1/16
Make Presentation	1/25/16	2/1/16	0 days	0 days	1/25/16	2/1/16	1/25/16	2/1/16
Submit Report to Dr. Okoli	2/2/16	2/2/16	0 days	0 days	2/2/16	2/2/16	2/2/16	2/2/16
Submit Files to Blackboard and IME TAs	2/2/16	2/2/16	0 days	0 days	2/2/16	2/2/16	2/2/16	2/2/16

Free slack and total slack (float) were discussed in Section 5.1.1. All activities with a total slack value of zero (0) in Table 14 are along the Analyze Phase's critical path, which is denoted by red boxes and arrows in Figure 17. These critical tasks must be completed by the specified deadline, or the Analyze Phase will be delayed. Table 14 illustrates that the first part of the Analyze Phase's critical path starts on 1/6/16 and ends on 2/2/16. Thus, the critical path of the Analyze Phase is 27 days. However, this duration is subject to change in the future, depending on the results of the Measure Phase.

Gantt charts were discussed in Section 5.1.1. A Gantt chart of the Measure Phase's planned activities was constructed and is depicted in Figure 18.


Task Name
1/6
1/7
1/8
1/9
1/10
1/11
1/12
1/13
1/14
1/15
1/16
1/17
1/18
1/19
Group Organization Meeting
Select Phase Leader
1/6
Meet with Dr. Okoli
Inventory Parts
Discuss Construction Approach
Final 3D CAD Renderings
Final Mechanical Analysis
Final Bill of Materials
Discuss Final Design with Dr. Okoli
Write Report
Make Presentation
Submit Report to Dr. Okoli
Submit Files to Blackboard and IME TAs

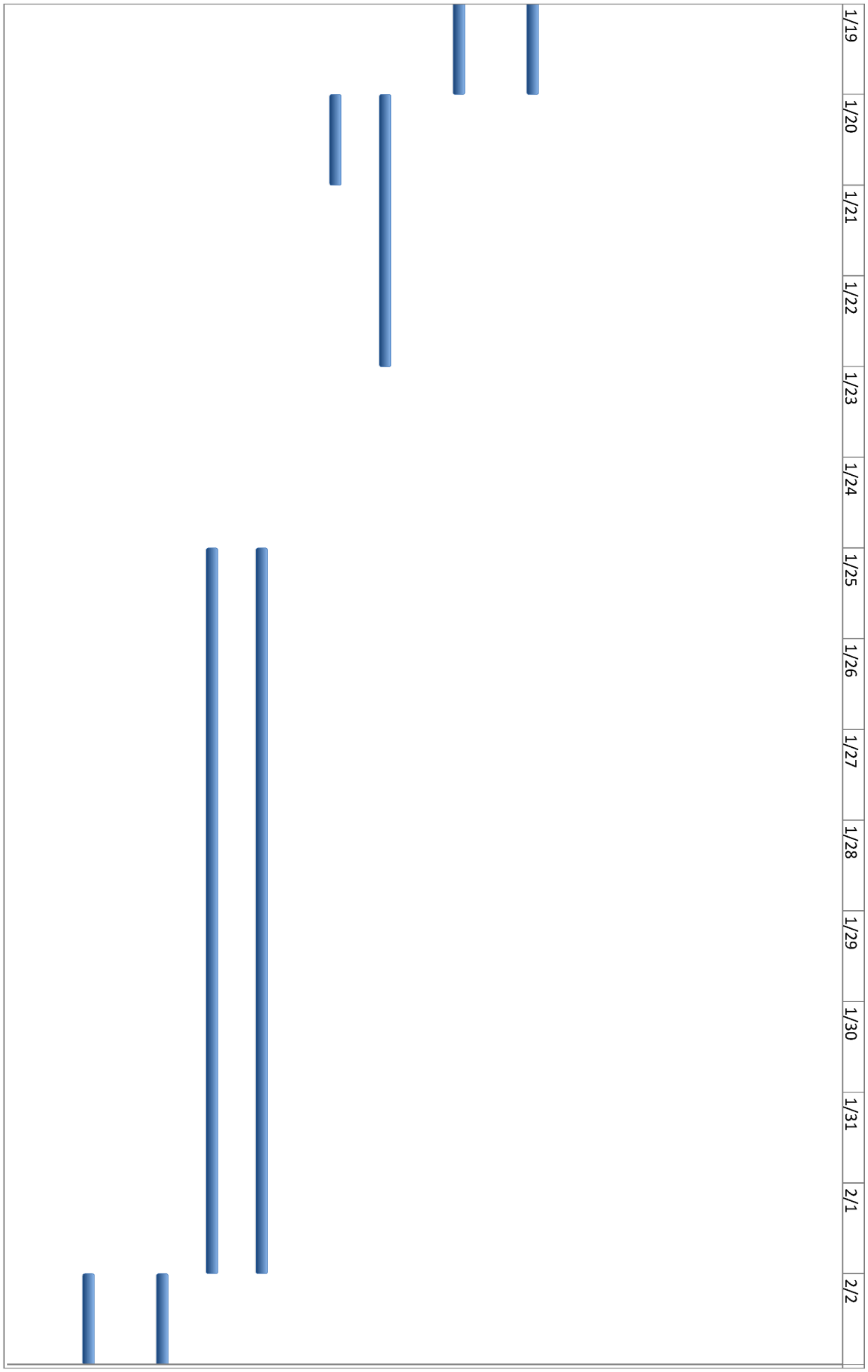


Figure 18: Gantt Chart for the Analyze Phase

Using Figure 17 and Figure 18, the earliest the Analyze Phase can end is 2/2/16. The latest the Analyze Phase can end is also 2/2/16. However, these planned tasks are subject to change at the conclusion of the Measure Phase, when the beginning of the Analyze Phase will be planned further. While the Analyze Phase cannot be completed any later than 2/2/16, it is possible that the phase might be completed earlier than that date when more tasks are scheduled.

5.1.4 Improve Phase Tasks

Since the Improve Phase has not yet begun, all tasks listed in this subsection are subject to change in the future, based on the team's design process or new instructions from the sponsor. Major tasks that are required to be completed by the end of the Improve Phase are discussed in Table 15.

Figure 19 depicts the network flow diagram for the Improve Phase, which includes a broad outline of the tasks that need to be completed. Quantitative information regarding the specific tasks depicted in Figure 19 is given in Table 16.

Table 15: Major Tasks for the Improve Phase

Task	Explanation
Contacting and meeting with Dr. Okoli.	The sponsor can inform the group of any changes that are desired to the constructed prototype.
Brainstorm solutions.	This allows the group to discuss improvements to the prototype that would be beneficial to the sponsor's requirements.
Implement and test solutions.	This allows the group to test any solutions that are conceived and implemented to meet the sponsor's approval criteria.
Writing the Improve Phase report.	This allows the group to communicate to the sponsor and stakeholders the team's improvements to the constructed prototype and how the improvements will be controlled.
Presenting the group's project status.	This allows the group to demonstrate that solutions to any problems with the prototype were devised and implemented to the sponsor and stakeholders, as well as give a synopsis of the Improve Phase report.

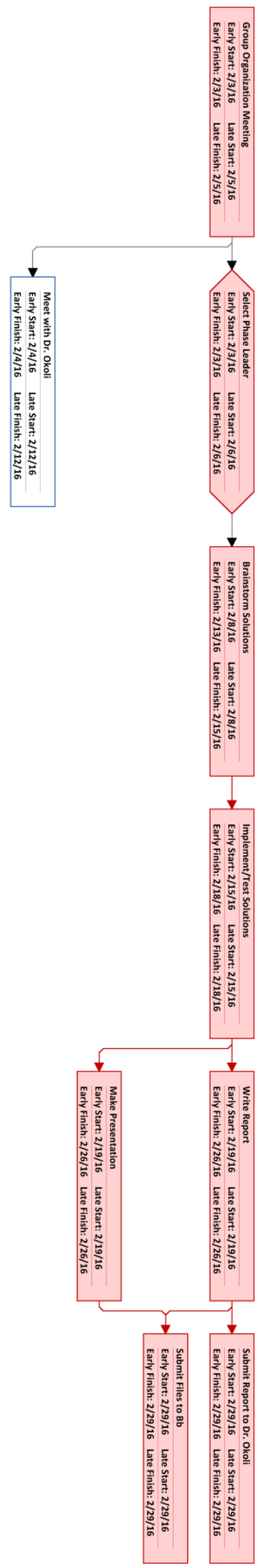


Figure 19: Network Flow Diagram for the Improve Phase

Table 16: Detailed Network Flow Diagram Information for Improve Phase Tasks

Task Name	Start	Finish	Free Slack	Total Slack	Early Start	Early Finish	Late Start	Late Finish
Group Organization Meeting	2/3/16	2/3/16	0 days	2 days	2/3/16	2/3/16	2/5/16	2/5/16
Select Phase Leader	2/3/16	2/3/16	2 days	2 days	2/3/16	2/3/16	2/6/16	2/6/16
Meet with Dr. Okoli	2/4/16	2/4/16	6 days	6 days	2/4/16	2/4/16	2/12/16	2/12/16
Brainstorm Solutions	2/8/16	2/13/16	0 days	0 days	2/8/16	2/13/16	2/8/16	2/15/16
Implement/Test Solutions	2/15/16	2/18/16	0 days	0 days	2/15/16	2/18/16	2/15/16	2/18/16
Write Report	2/19/16	2/26/16	0 days	0 days	2/19/16	2/26/16	2/19/16	2/26/16
Make Presentation	2/19/16	2/26/16	0 days	0 days	2/19/16	2/26/16	2/19/16	2/26/16
Submit Report to Dr. Okoli	2/29/16	2/29/16	0 days	0 days	2/29/16	2/29/16	2/29/16	2/29/16
Submit Files to Bb	2/29/16	2/29/16	0 days	0 days	2/29/16	2/29/16	2/29/16	2/29/16

Free slack and total slack (float) were discussed in Section 5.1.1. All activities with a total slack value of zero (0) in Table 16 are along the Improve Phase's critical path, which is denoted by red boxes and arrows in Figure 19. These critical tasks must be completed by the specified deadline, or the Improve Phase will be delayed. Table 16 illustrates that the first part of the Improve Phase's critical path starts on 2/8/16 and ends on 2/29/16. Thus, the critical path of the Improve Phase is 21 days. However, this duration is subject to change in the future, depending on the results of the Analyze Phase.

Gantt charts were discussed in Section 5.1.1. A Gantt chart of the Improve Phase's planned activities was constructed and is depicted in Figure 20.

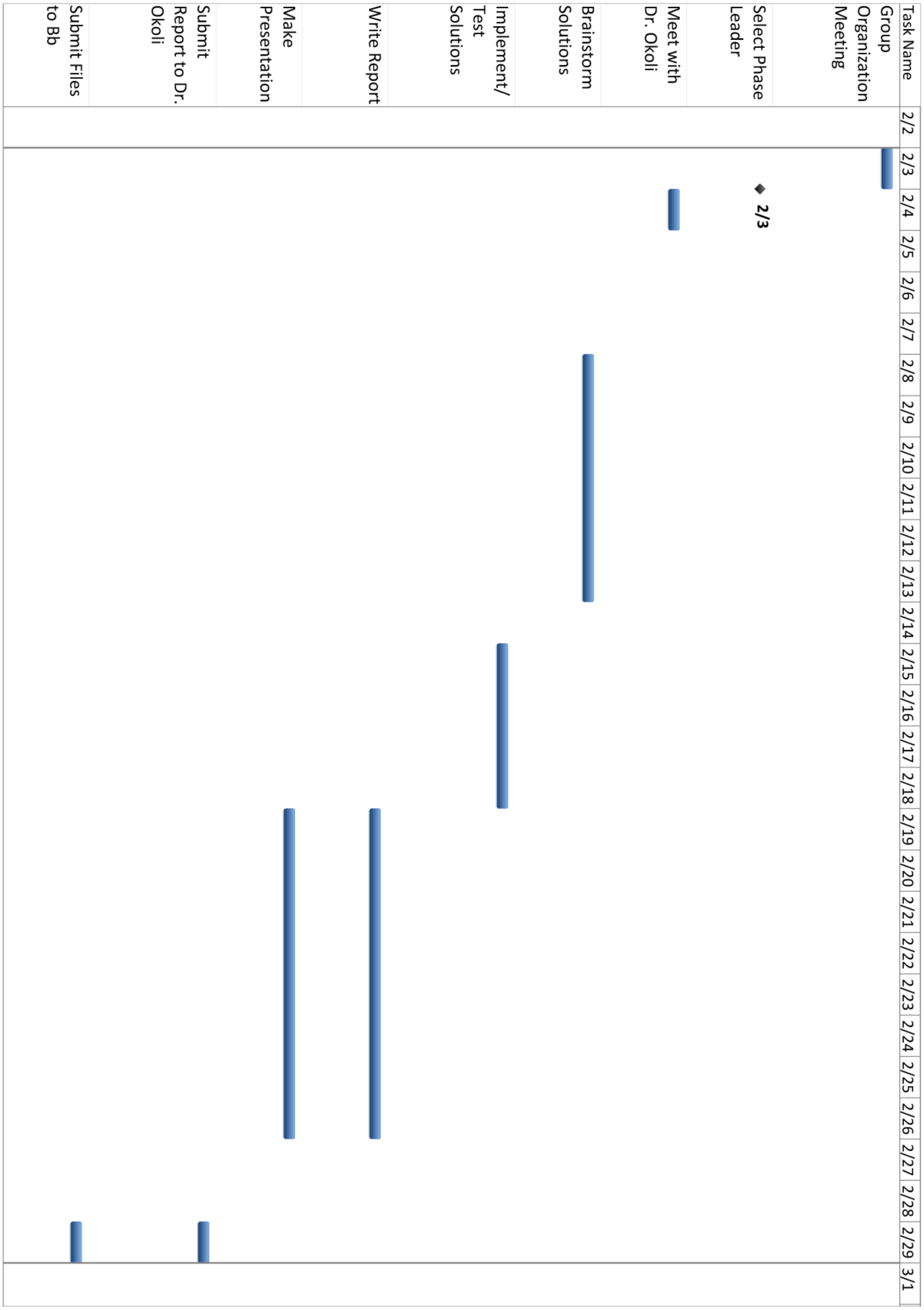


Figure 20: Gantt Chart for the Improve Phase

Using Figure 19 and Figure 20, the earliest the Improve Phase can end is 2/29/15. The latest the Improve Phase can end is also 2/29/16. However, these planned tasks are subject to change at the conclusion of the Analyze Phase, when the beginning of the Improve Phase will be planned further. While the Improve Phase cannot be completed any later than 2/29/19, it is possible that the phase might be completed earlier than that date when more tasks are scheduled.

5.1.5 Control Phase Tasks

Since the Control Phase has not yet begun, all tasks listed in this subsection are subject to change in the future, based on the team's design process or new instructions from the sponsor. Major tasks that are required to be completed by the end of the Control Phase are discussed in Table 17.

Figure 21 depicts the network flow diagram for the Control Phase, which includes a broad outline of the tasks that need to be completed. Quantitative information regarding the tasks in Figure 21 is given in Table 18.

Table 17: Major Tasks for the Control Phase

Task	Explanation
Contacting and meeting with Dr. Okoli.	The sponsor can inform the group of any prototype benchmarks that must be met.
Check efficiency and consistency of prototype.	This allows the group to examine if the prototype is consistent in its harvesting ability, as well as measures the harvesting efficiency.
Write prototype manual.	This allows someone that was not a part of the project to be able to learn how to operate the prototype.
Writing the Control Phase report.	This allows the group to communicate to the sponsor and stakeholders the team's final prototype design and specifications.
Presenting the group's project status.	This allows the group to demonstrate that a successful prototype was built to the sponsor and stakeholders, as well as give a synopsis of the Control Phase report.
Write business analysis report.	This allows the group to analyze the business significance of the final prototype design.
Present the final status of the project.	This allows the team to give a final update to the sponsor and stakeholders.

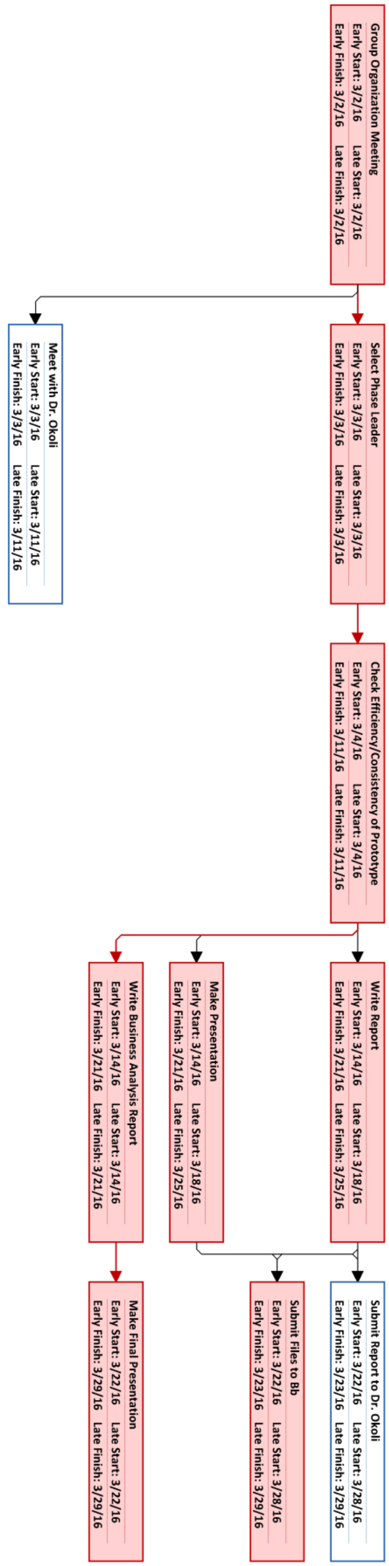


Figure 21: Network Flow Diagram for the Control Phase

Table 18: Detailed Network Flow Diagram Information for Control Phase Tasks

Task Name	Start	Finish	Free Slack	Total Slack	Early Start	Early Finish	Late Start	Late Finish
Group Organization Meeting	3/2/16	3/2/16	0 days	0 days	3/2/16	3/2/16	3/2/16	3/2/16
Select Phase Leader	3/3/16	3/3/16	0 days	0 days	3/3/16	3/3/16	3/3/16	3/3/16
Meet with Dr. Okoli	3/3/16	3/3/16	6 days	6 days	3/3/16	3/3/16	3/11/16	3/11/16
Check Efficiency/Consistency of Prototype	3/4/16	3/11/16	0 days	0 days	3/4/16	3/11/16	3/4/16	3/11/16
Write Report	3/14/16	3/21/16	0 days	4 days	3/14/16	3/21/16	3/18/16	3/25/16
Make Presentation	3/14/16	3/21/16	0 days	4 days	3/14/16	3/21/16	3/18/16	3/25/16
Submit Report to Dr. Okoli	3/22/16	3/23/16	4 days	4 days	3/22/16	3/23/16	3/28/16	3/29/16
Submit Files to Bb	3/22/16	3/23/16	4 days	4 days	3/22/16	3/23/16	3/28/16	3/29/16
Write Business Analysis Report	3/14/16	3/21/16	0 days	0 days	3/14/16	3/21/16	3/14/16	3/21/16
Make Final Presentation	3/22/16	3/29/16	0 days	0 days	3/22/16	3/29/16	3/22/16	3/29/16

Free slack and total slack (float) were discussed in Section 5.1.1. All activities with a total slack value of zero (0) in Table 18 are along the Control Phase's critical path, which is denoted by red boxes and arrows in Figure 21. These critical tasks must be completed by the specified deadline, or the Control Phase will be delayed. Table 18 illustrates that the first part of the Control Phase's critical path starts on 3/2/16 and ends on 3/29/16. Thus, the critical path of the Control Phase is 27 days. However, this duration is subject to change in the future, depending on the results of the Improve Phase.

Gantt charts were discussed in Section 5.1.1. A Gantt chart of the Control Phase's planned activities was constructed and is depicted in Figure 22.

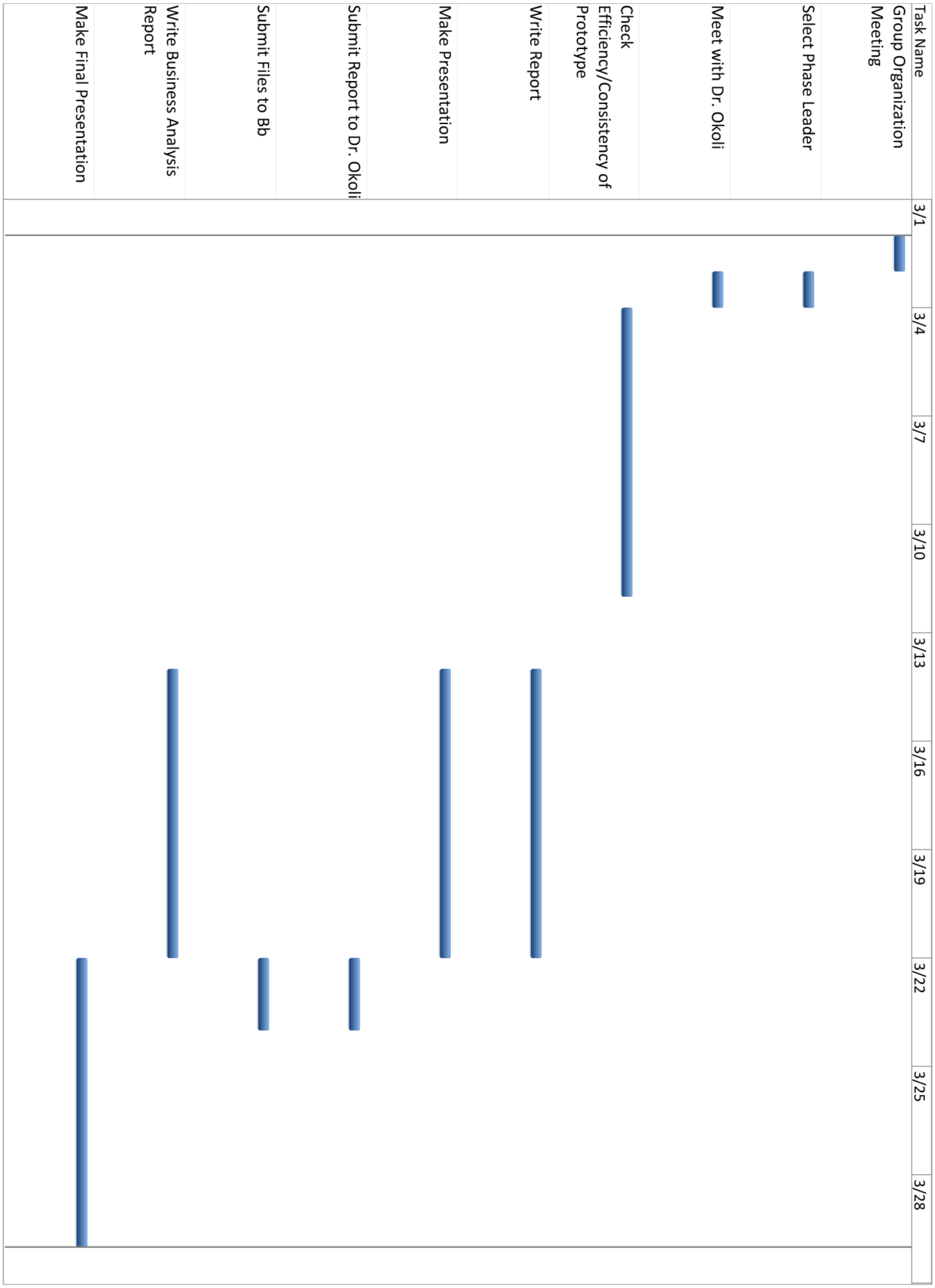


Figure 22: Gantt Chart for the Control Phase

Using Figure 21 and Figure 22, the earliest the Control Phase can end is 3/29/16. The latest the Control Phase can end is also 3/29/16. However, these planned tasks are subject to change at the conclusion of the Improve Phase, when the beginning of the Control Phase will be planned further. While the Control Phase cannot be completed any later than 3/29/16, it is possible that the phase might be completed earlier than that date when more tasks are scheduled.

5.2 Risk Management

To help identify risks for this project, a Strengths/Weaknesses/Threats/Opportunities (SWOT) matrix was constructed and is depicted in Figure 23. The information in this section is subject to change in future phases, once a design is selected.

Figure 23: SWOT Matrix

Since the team consists of students in three different disciplines, there are a variety of perspectives that will inevitably arise during the development of any device. However, having a large team may cause issues scheduling meeting times. Furthermore, while it may be helpful to discuss many different ideas throughout the project, it may also cause conflict and may delay the development of the harvesting device. However, each discipline's assigned faculty advisor should be able to help resolve team disputes and help direct the team in the proper direction.

Although the team has a variety of skills, no members have experience working with oil palm trees. Since there are no oil palm trees located in the Tallahassee area, the device will have to be tested on a structure similar to a 40-foot tall oil palm tree.

The projected demand increase for palm oil [5] means that new techniques to improve the efficiency of current harvesting methods are needed. Since humans become fatigued after climbing several trees throughout the day [2], there is a limit to a human workers efficiency. An electromechanical harvesting device would allow workers to remain on the ground and decrease the amount of physical labor during the harvesting process. This will allow laborers to harvest more oil palm fruit in a safer and more efficient manner.

The petiole, depicted in [19], can become a potential threat for the device during the harvesting process. Petioles are sharp, thus this can make our device unable to descend the tree. Exceeding the budget is another potential threat, because the project would not be completed within the sponsor's requirements. Since the final design has yet been selected, it is difficult to determine how much (if any) damage may occur when operating prototype. The operator, machine, or tree could be at risk while cutting oil palm fruit. The probability and impact of each of these risks is depicted in Figure 25. As the impact and probability increase, the color changes from green to yellow to red and finally to dark red.

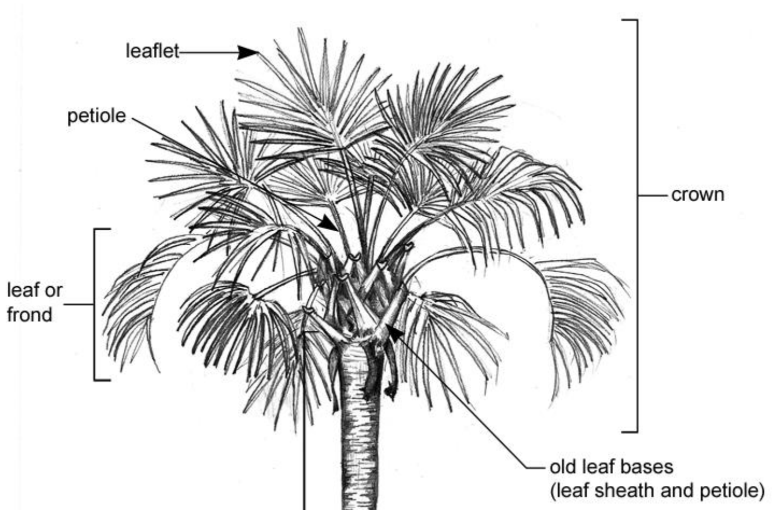


Figure 24: Upper Portion of a Generic Palm Tree [20]

		Impact		
		Low	Moderate	High
Probability	Low		Damaging the environment while operating the palm harvester	Exceeding the $2,500 budget
	Moderate			Cutting oil palm fruit could damage the operator, machine, or tree
	High			Trees have petioles that make descending difficult

Color	Meaning	Result
Green	Low Risk	Acceptable/safe
Yellow	Moderate Risk	Acceptable with proper safety precautions
Red	High Risk	Unacceptable/dangerous
Dark red	Extreme Risk	

Figure 25: Risk Matrix

5.3 Budget and Bill of Materials

The sponsor has set a budget of $2,500 for the entire project. Since any design selected will most likely contain several mechanical components and some electrical components, the mechanical parts and materials used in construction of the prototype will most likely utilize most of the budget. In order to ensure the project does not exceed its budget, 8% of the budget ($200) is set as the management reserve amount.

The "most likely" cost of this project assumes that most parts used in the prototype will be constructed from lightweight aluminum that can easily be machined by team members. Some additional mechanical parts, such as actuators, may also be required. Since most the electrical components will simply involve the mechanical devices communicating among themselves and to the operator, the cost is not expected to be as significant. Based on the Class of 2015's expenditures [9], the most likely cost of this project is described in Table 19.

Table 19: Budget Based on the Most Likely Cost of the Components

Item	**Most Likely Cost**
Mechanical Components	$500.00
Materials	$1,500.00
Electrical Components	$300.00
Total Cost	**$2,300.00**
Remaining Management Reserve	**$200.00**

Table 19 illustrates that the project would be completed within the most likely cost budget, with the entire management reserve still available. Table 20 shows a more optimistic scenario assumes that a minimum number of mechanical and electrical parts will be required and that most of the mechanical parts can be fabricated from existing stock material.

Table 20: Budget Based on the Optimistic Cost of the Components

Item	**Optimistic Cost**
Mechanical Components	$200.00
Materials	$1,200.00
Electrical Components	$100.00
Total	**$1,500.00**
Remaining Management Reserve	**$200.00**
Budget Surplus	**$800.00**

Table 20 demonstrates that the optimistic cost budget would result in the project being completed with the entire management reserve still available, as well as a budget surplus of $800. However, a more pessimistic scenario would likely involve some combination of the budgets given in Table 19 and Table 20. This scenario could result from the team members improperly machining parts, which would result in new materials that would need to be ordered and fabricated quickly, in order to not delay the project. The pessimistic cost budget is given in Table 21.

Table 21: Budget Based on the Pessimistic Cost of the Components

Item	**Cost**
Mechanical Components	$600.00
Materials	$1,700.00
Electrical Components	$300.00
Total	**$2,600.00**
Remaining Management Reserve	**−$100.00**

Table 21 illustrates the in the most pessimistic scenario, the entire management reserve would be used, yet the project would still exceed the budget by $100. The team would either have to petition the sponsor for a slight increase in the budget to complete the project or fund the overage using donations from team members.

In order to determine the most plausible budget, a weighted average of the budgets given in Table 19, Table 20, and Table 21 must be computed, using the formula $C_e = (C_o + 4C_m + C_p)/6$, where C_o represents the optimistic budget given in Table 20, C_m represents the most likely budget given in Table 19, and C_p represents the pessimistic budget given in Table 21. This calculation yielded the final budget given in Table 22.

Table 22: Final Budget Based on a Weighted Average of Three Budgets

Item	Cost
Mechanical Components	$466.67
Materials	$1,483.33
Electrical Components	$267.67
Total	**$2,217.67**
Remaining Management Reserve	**$200.00**
Budget Surplus	**$82.33**

Table 22 demonstrates that the project would be completed within the budget and result in a budget surplus of $82.33. The budgets given in Table 19, Table 20, Table 21, and Table 22. will be updated in the future, once a final design is chosen. Since the team's design has not yet been finalized, the bill of materials (BOM) is not yet available. The BOM will be added to this section in future phases, once the final design is selected. Information regarding the vendors that will be used to purchase parts will also be added at that time.

Figure 26 depicts an S-curve that shows the target expenditures of the project budget over time. A monetary resource histogram will also be added in future reports, once a final design is selected and each component's price is obtained. Figure 26 will also be updated in the future, once a final design is selected and the final budget is calculated.

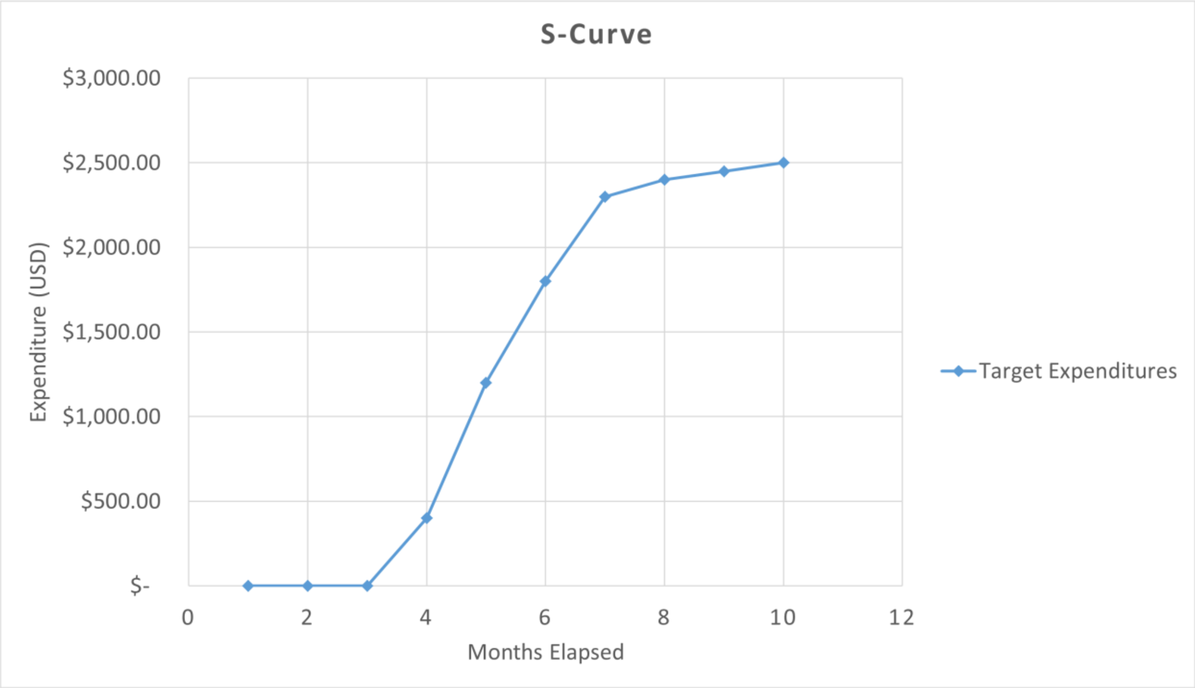


Figure 26: S-Curve

Figure 26 depicts an S-curve that shows the target expenditures of the project budget over time. Most expenditures will occur midway through the project due to the process for ordering parts. Additional expenditures occurring after the initial order will be for tools and extra materials.

5.4 Current Design Ideas

5.4.1 Improving the Class of 2015's Design

The Class of 2015's design utilized telescoping poles comprised of Aluminum 6061 with a saw attached at the top of the pole and is depicted in Figure 27 [9].

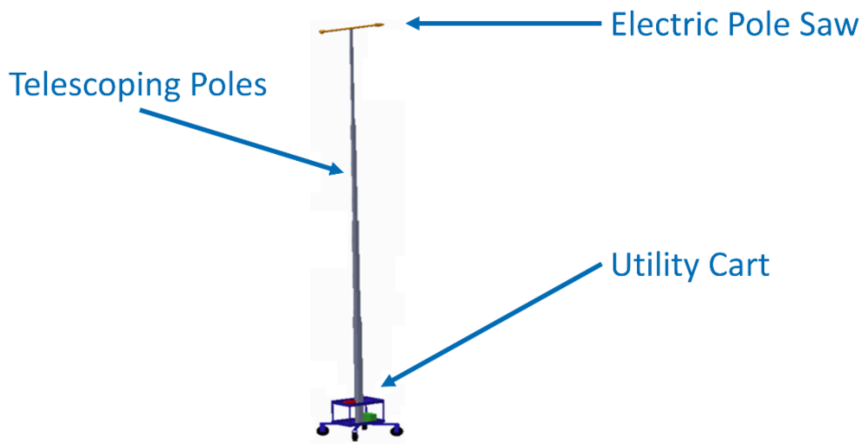


Figure 27: Previous Group's Design [9]

The design depicted in Figure 27 consisted of a pole that was mounted on a manually operated cart with four rugged never-flat wheels protruding from the sides. An electric motor was used to drive a pulley mechanism to extend the pole approximately 40-feet upward. The saw was controlled from the ground by several ropes. While this design proved capable of extending to the required height to harvest the fruit bunches, there were several aspects that prevented it from being an ideal solution. The 40-foot telescoping pole had to be thick enough to resist bending forces. The poles were too heavy to be moved using a small cart and were not able to remain stable when they were extended. Finally, the saw was not securely attached to the poles and the chainsaw blade was dangerously left uncovered [9].

In order to improve this design, a new chassis to hold the pole would need to be designed. The chassis would need to be large enough to ensure the pole remains stable, while also being lightweight enough to be moved by one person. This support structure must also be capable of operating in rough terrain, which may require the construction of a suspension system. Furthermore, the saw located at the top of the pole must be covered when it is not in use, to decrease the risk of injury to the operator. This means that the rope system used to control the saw should be converted to an electronic system, because it is less likely to injure a worker using the device.

5.4.2 Extended Pole Pruner

The extended pole pruner concept utilizes an existing device from the landscaping industry—an extendable gas-powered pole saw. This current device is depicted in Figure 28 [21].

Figure 28: Extendable Gas-Powered Saw [21]

Currently, the device depicted in Figure 28 is used to trim palm trees that are a maximum of 17-feet tall from the ground. Patrick Howard conceived this concept, because he has used the device in the field. This design concept would modify the device's shaft to reach a height of 40 feet. However, since a worker on the ground would not be able to see the top of the pole, a high-definition video camera would be mounted at the top of the device. This camera would connect via Bluetooth to a tablet mounted on the device to allow the operator to see the top of the palm tree and determine which fruit bunches to cut. This design concept is depicted in Figure 29.

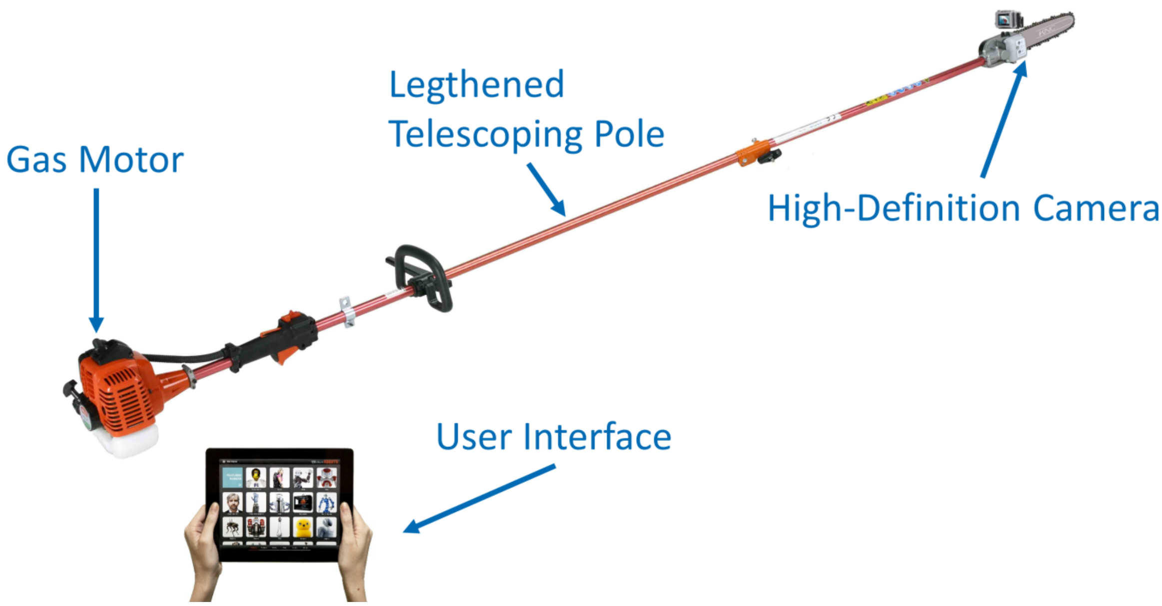


Figure 29: Modified Pole Pruner Framework

This design would meet all of the sponsor's requirements discussed in Section 3.1.1 and Section 3.1.4. However, the extended length of the pole saw would make it difficult for an operator to hold the device without it moving in undesired directions. Therefore, a telescoping tripod stand could be designed and built that would be able to be setup by one operator. This stand would help the user keep the device steady and act as a pivot point.

5.4.3 *Tree Crawler*

The tree clawer concept involves designing a mechanism that can ascend an oil palm tree, cut ripe fruit bunches, and then descend the tree safely. The mechanism consists of two claws, one at the top of the device and one at the bottom, which would wrap around the palm tree's trunk. A body will connect these two claws, which will be designed to retract and extend. The process by which this design would operate is depicted in Figure 30.

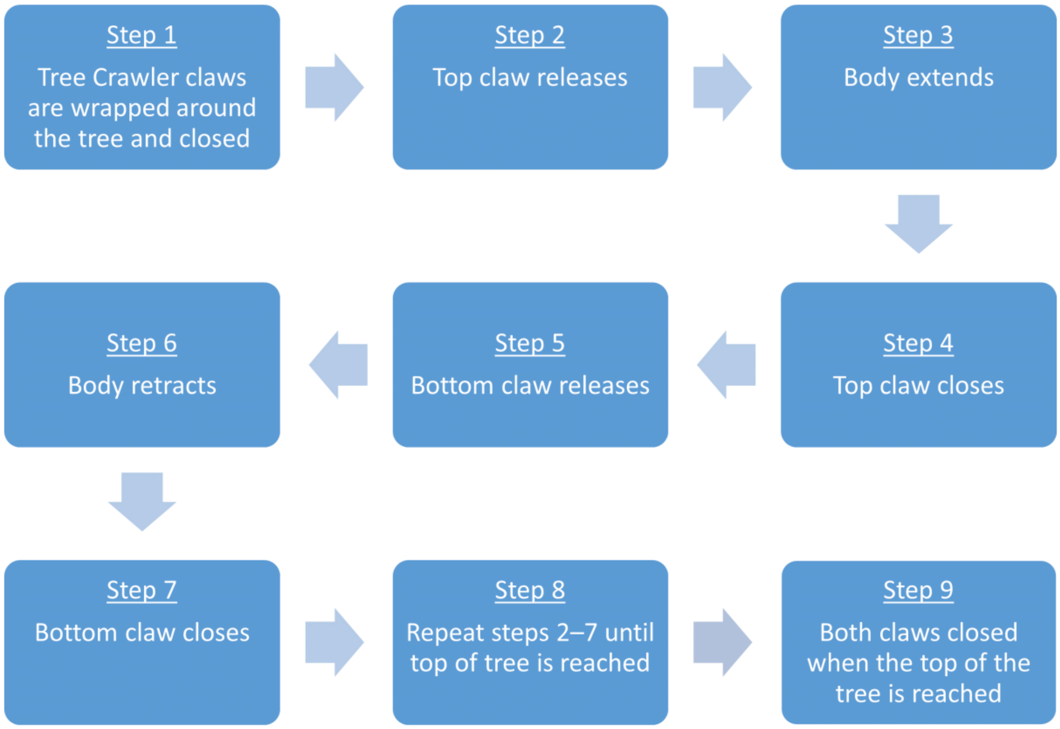


Figure 30: Tree Crawler Operation Process

As illustrated in Figure 30, both claws will need to close once the device has reached the top of the tree. To ensure the device stops at the proper location, the prototype will have a video camera that will be connected via Bluetooth to a display on the user's controller. This controller will allow the user to start and stop the device from ascending and descending the tree. Once the device is in the proper position at the top of the tree, the user will operate an extendable saw at the top of the device to cut ripe fruit bunches, using the video camera's output. Once all desired fruit bunches have been harvested, the user will instruct the robot to descend the tree. The process depicted in Figure 30 operates in reverse when the device descends the tree. Finally, the user will transport the device to the next tree and repeat the process illustrated in Figure 30.

This design would meet all of the sponsor's requirements discussed in Section 3.1.1 and Section 3.1.4. However, this concept would require a large number of electromechanical components and an extensive amount of programming to operate efficiently. Adding more electromechanical components also increases the cost and weight of the device. Furthermore, as the number of components increases, the durability of the system decreases. The claw connectors would also have to withstand a large moment to support the weight of the machine and would also need to be resistant against the vibration that would occur when cutting fruit bunches. If this design is selected in future phases, this section will be updated with a detailed plan on how this device would be constructed, programmed, and tested.

6. Conclusion

There is a large demand for palm oil, all over the world; unfortunately, the current methods used to harvest oil palm fruit are inefficient [2]. Developing a device to improve the efficiency of oil palm fruit harvesting would increase production and improve workers' safety. The current method requires humans to climb 40-foot tall palm trees and manually cut fruit bunches; this is extremely dangerous because a worker has a high probability of falling off the tree [10]. Creating an electromechanical system would eliminate this risky human involvement. To design such a device, the team met with Dr. Okoli, the project's sponsor, researched basic information on oil palm fruit harvesting methods, proposed several design concepts, and became familiar with the limitations that the final design must satisfy.

The group discussed two main approaches to designing a harvesting device. The first approach involved improving one of the previous groups' designs, while the second was to create a new system. The team proposed three distinct design concepts to the project's sponsor. The first design discussed making the previous year's existing telescopic poles more portable and improving the cart design's mobility and safety. The second design involved modifying an existing gas-powered pole pruner with an extendable fiberglass shaft to reach a height of 40 feet. This also includes mounting a camera at the end of the saw to allow the operator to see the oil palm fruit bunches at the top of the tree; this camera will be connected via Bluetooth to a screen used by a worker on the ground. The final design proposed constructing a semi-autonomous, tree-climbing robot. The robot will ascend and descend the tree autonomously, but the user must instruct the robot to begin climbing and stop the robot at the top of the tree. Once the robot is at the top of the tree, the user must manually operate the cutting mechanism to harvest the desired oil palm fruit bunches.

The group analyzed all of the design concepts in discussed Section 5.4 and presented the advantages and disadvantages of each concept to the sponsor. After the most recent meeting with Dr. Okoli, the team decided to begin developing a more tangible concept of the tree climber, including creating CAD renderings of the design concept. Once the CAD renderings are completed, the team will discuss the plausibility and efficiency of the device, given the time constraints of this project. Finally, a financial analysis will be conducted to see if the all of the parts needed for the device can be purchased within the $2,500 budget. If the robot is not able to be constructed within the budget, then the team will meet with the sponsor to discuss utilizing a different design concept or potentially increasing the budget.

7. References

[1] Soyatech, "Palm Oil Facts," 2015. [Online]. Available: http://www.soyatech.com/Palm_Oil_Facts.htm. [Accessed 6 October 2015].

[2] K. Jusoff and M. F. Zainuddin, "Musculoskeletal Disorders in Oil Palm Fruit Bunches in Malaysia," *Journal of Environmental Science & Engineering,* vol. 3, no. 7, pp. 64–67, 2009.

[3] L. Gooch, "Malaysia Enacts Minimum Wage: The New York Times," 1 May 2012. [Online]. Available: http://www.nytimes.com/2012/05/02/business/global/malaysia-enacts-minimum-wage.html. [Accessed 12 October 2015].

[4] E. B. Skinner, "Bloomberg," 18 July 2013. [Online]. Available: http://www.bloomberg.com/bw/articles/2013-07-18/indonesias-palm-oil-industry-rife-with-human-rights-abuses. [Accessed 6 October 2015].

[5] B. Carpenter, C. X. Smith, J. A. Rojas, W. Craig, O. Abakporo and S. Trayner, "Define Phase Report for IE Senior Design Class," FAMU-FSU College of Engineering, Tallahassee, 2011.

[6] A. Smith, C. Chiros, M. Derius, T. Levin, T. Baker and S. Gates, "Control Phase – Palm Harvester Project," FAMU-FSU College of Engineering, Tallahassee, 2015.

[7] R. Aleman, G. Alessandra, D. Boswell, Y. Liu, B. Lobo, B. Newan and L.-O. Verrer, "Define Phase Deliverable - Oil Palm Pruning Device," FAMU-FSU College of Engineering, Tallahassee, 2013.

[8] World Wide Fund for Nature, "Creating Ripples for Positive Change," 10 February 2014. [Online]. Available: http://www.worldwildlife.org/stories/creating-ripples-for-positive-change. [Accessed 6 October 2015].

[9] SayNotoPalmOil.com, "Palm Oil," 2015. [Online]. Available: http://www.saynotopalmoil.com/Whats_the_issue.php. [Accessed 6 October 2015].

[10] CommodityBasis, "Palm Oil Prices," 2014. [Online]. Available: https://www.commoditybasis.com/palmoil_prices. [Accessed 6 October 2015].

[11] E. Dayal, "HitDocs," 23 December 2013. [Online]. Available: http://www.hitdocs.com/sipoc-diagram-xlsx/. [Accessed 14 October 2015].

[12] American Society for Quality, "Building a House of Quality with Technical and Competitive Benchmarking," 2004. [Online]. Available: http://asq.org/learn-about-quality/benchmarking/overview/tutorial-building-house-of-quality.html. [Accessed 14 October 2015].

[13] IDEACore, "QFD Designer User Guide," IDEACore, Birmingham, 2006.

[14] Y. G. Ng, M. T. S. Bahri, M. Y. I. Syah, I. Mori and Z. Hashim, "Ergonomics Observation: Harvesting Tasks at Oil Palm Plantation," *Journal of Occupational Health* , vol. 55, no. 5, pp. 405–414, 2013.

[15] B. A. Talib and Z. Darawi, "An Economic Analysis of the Malaysian Palm Oil Market," *Oil Palm Industry Economic Journal,* vol. 2, no. 1, pp. 19–27, 2002.

[16] K. East, "Global labor imbalance: Some countries see a surplus of jobs while others see higher unemployment," 7 July 2014. [Online]. Available: http://www.washingtontimes.com/news/2014/jul/7/global-labor-imbalance-some-countries-see-a-surplu/?page=all. [Accessed 18 October 2015].

[17] Microsoft TechNet, "Difference between free slack and total slack," 28 June 2012. [Online]. Available: https://social.technet.microsoft.com/Forums/projectserver/en-US/d373c2ae-11b4-4030-a4fb-62bb8a2d73a1/difference-between-free-slack-and-total-slack. [Accessed 6 October 2015].

[18] Gantt.com, "What is a Gantt chart?," 2015. [Online]. Available: http://www.gantt.com/. [Accessed 6 October 2015].

[19] IDTools, "Identifying Commonly Cultivated Palms," May 2014. [Online]. Available: http://idtools.org/id/palms/palmid/images/fs_images/anatomy-fan-palm.png. [Accessed 2015 October 2015].

[20] Stihl, "Pole Pruners," 2015. [Online]. Available: http://www.stihlusa.com/products/pole-pruners/. [Accessed 18 October 2015].

Appendix A

Wage assumptions and return on investment calculations for Malaysian oil palm fruit harvesters.

Assumptions

Malaysian workers earn $297 per month.

Each oil palm plantation contains hundreds of trees.

Oil palms are harvested for eight (8) hours daily.

A worker earns a simple salary of $\$297/\text{month} \times 12\ \text{months} = \$3{,}564/\text{year}$

The return on investment (ROI) formula is:

$$\text{ROI} = \frac{(\text{Gain from Investment} - \text{Cost of Investment}}{\text{Cost of Investment}}$$

Computing the ROI:

$$\text{ROI} = \frac{(\$3{,}564 - \$2{,}000)}{\$2{,}000} = 0.7820$$

$$\text{ROI}_{\text{percent}} = \text{ROI} \times 100\% = 0.7820 \times 100\% = 78.20\%$$