# The Hope Device Team 14

# Final Report

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# DISCLAIMER

# EXECUTIVE SUMMARY

The purpose of the project was to create, a useful product for a person with a disability, so we have decided to make the two crutches one for the left leg and second for the right leg. To start with the project, we found existing designs and generated the requirements from the client description. After that, we generated the engineering requirements, which will present in our design. The black box model and the functional model are also developed as well in this report. The report also includes the development of the system level and the sub-system level designs. In system level, a few existing designs were found which were related to our project. These existing designs helped us in the designing phase of the project. In the sub-system level of a project, all the main sub-parts of the project were identified, and their existing designs were found. These existing designs of sub-parts helped us in selecting the material for each sub-part.

Few designs ideas were generated for the design and from these designs, the final design was selected using the Pugh chart and decision matrix. The Pugh chart narrowed down the result from ten designs to top three designs. The decision matrix narrowed down the result from three designs ideas to one final design. The final design selected from the two methods was two crutches, one for the leg movement and second for the support of the body. A CAD model was developed for the defined design and each part was separately developed in CAD model. The design was implemented in SolidWorks, but will not be implemented because of body variations, because for each body, the product has a different dimension. The bill of material was provided to understand the implementation phase and with the help of BOM, this model can implement as well. There was a major change in design that was done at the end of the project. The team decided to make one more component, which was given the name of support. This support was used as a middle part so that the body will not fall over or face any trouble while using the crutches. Two crutches and one middle support were enough for walking for a paralyzed person.

# ACKNOWLEDGEMENTS

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# 1 BACKGROUND

## 1.1 Introduction

Physical challenges and disabilities create complex, influential, dynamic, multidimensional barriers which reduce, limit, and restrict the freedom of movement. An individual that has restricted body movement can walk around with some assistive support. The support could be a wheelchair or a crutch. The project required the team to develop a design that can support the person with a disability to walk around without the use of any wheelchair.

## 1.2 Project Description

There are many disabled people who got injured or they were born with foot paralysis. The team is creating a device that will help the disabled people to walk normally without the wheelchair. The device will be easy to use, affordable and unique.

## 1.3 Original System

There was no original system for the product we were developing.

> “This project involved the design of a completely new hope device system. There was no original system when this project began.”

# 2 REQUIREMENTS

In this section, the requirements of the project described. There were two types of requirements to consider for the project. One was the customer requirements, provided by our client in the form of the project description and the second type was engineering requirements, obtained from the customer requirements.

## 2.1 Customer Requirements (CRs)

The main objective of this project is to create a device that helps the paralyzed person to walk normally by using the hand and getting rid of wheelchair. The customer requirements (CRs) were determined by the client and introduced in the project description and requirements. This device needs to have low cost, light weight, low strain, safe and durable. The following table presents the customer requirements:

Table 1: Customer Requirements

| Customer Requirements | Weightings |
|---|---|
| Low cost | 3 |
| Light weight | 4 |
| Low physical strain | 4 |
| Height accommodates 90% of population | 3 |
| Safe for the user | 5 |
| Comfort and convenience | 4 |
| Appropriate spare parts | 3 |
| Durability | 5 |
| Reliability | 4 |

The customer requirements

## 2.2 Engineering Requirements (ERs)

The engineering requirements were derived from the customer requirements. They comprise the technical requirements of the project and have target values. The following table presents the engineering requirements of this project.

Table 2: Engineering Requirements

| Engineering Requirements | Target Values |
|---|---|
| Cost | $\leq \$1010$ |
| Weight | $\leq 35lb$ |
| Lifting capability of user | $\leq 15lb$ |
| Height of the device | 4ft -5.5ft |
| Safety | $Factor\ of\ safety \geq 1$ |
| Comfortability | Foam |
| Appropriate price for spare parts | $\$25 \leq \$40$ |
| High quality materials | Steel and aluminum |

In the first semester, the team met with the TA for Senior Design 1 class, Mr. Jeremy, and he gave us the recommendation for the type of the materials to be used for this device. Furthermore, he gave us some useful sites to find the information that we were looking for. Table 2 of engineering requirements updated for this semester due to testing analyzed for this device and additional materials added to this device to meet the engineering requirements stated on that table. The estimated cost for this project based on the material that we were using such, as the aluminum, foam and the rubber that suits the project requirements. The testing procedures of each engineering requirement presented in the next section.

## 2.3 Testing Procedures (TPs)

Engineering requirements were the technical requirements which need to be tested and the process of testing for each requirement was present below. The testing procedures were based on the SolidWorks Finite Element Analysis. The force and weight will be added to the design.

### 2.3.1 Cost

Cost of this product was tested when all the items have been purchased. The sum of the cost spent on the implementation of product to identify the total cost

### 2.3.2 Weight

Weight is a physical quantity and was measured through weight scale, so testing of weight can be done by measuring the weight of product at the end.

### 2.3.3 Lifting capability

Capability to lift the product was test when it was implemented, and when the user will lift the product and test it.

### 2.3.4 Appropriate price for spare parts

Spare parts price was determined in the market and see if the part available was lesser $40 or not.

### 2.3.5 Safety

Safety was important because if the device was not safe to use, then it will hurt the user. There must not be any sharp edges on it and must not topple over. Safety was tested using the Finite Element analysis using the ansys software by applying the forces and the weight and checking the factor of safety.

### 2.3.6 Height

This device has the appropriate height for the average person and is adjustable, so the user can easily regulate the crutches to fit the body height.

### 2.3.7 Comfortability for the user

This device includes using some materials that ensures the comfortability of the user. Foam is used for the two handgrips on both crutches and the underarm for the long crutch. Also foam is included inside the harness which makes it feel comfort. However, rubber and sole is used in the leg base, wheel and tire of the device.

### 2.3.8 High quality materials

This device was designed with the use of high quality materials such as aluminum and steel. These types of materials have the high quality of thickness, durability and makes the device reliable. Furthermore, the aluminum meets the engineering requirement of the device weight and can bear the body weight and forces applied.

## 2.4 Design Links (DLs)

Design links, which describe how the proposed design meets each ER, will be described in section 8, Testing.

## 2.5 House of Quality (HoQ)

Information presented in the HOQ illustrates the performance quality and competitiveness of the crutches that we proposed for development under the Senior Design - I with other brands that were currently marketed. This house of quality presents the engineering and customer requirements the team proposed for this project. It clearly shows the importance of each criteria, the weightings of each criteria and technical target values along with the units.

Table 3: House of Quality

| **Customer Requirement** | **Weight (1-5)** | **Engineering Requirement** | Cost | Weight | Lefting capability of user | Height of the Device | Safety | Comfortability | Approbriate price for spare parts | High quality materials |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Low cost | 3 | | 1 | 3 | | | 1 | 1 | 9 | 1 |
| 2. Light weight | 4 | | 3 | 9 | 9 | 1 | 9 | 9 | 1 | 9 |
| 3. Low phisycal strain | 4 | | | 9 | 9 | | 3 | 3 | | 3 |
| 4. Height accomedate 90% of population | 3 | | | | | 9 | | 9 | | |
| 5. Safe for the user | 5 | | 9 | 9 | 3 | 3 | 9 | 3 | | 9 |
| 6. Comfort and conveniece | 4 | | 9 | 9 | 3 | 3 | 9 | 9 | | 3 |
| 7. Spare parts affordable | 3 | | | | | | | | 9 | 3 |
| 8. Durability | 5 | | 9 | 3 | | | 9 | 3 | 3 | 9 |
| 9. Reliablity | 4 | | 3 | | 3 | 1 | 3 | | 3 | 3 |

Based on the results of HOQ, the most important criteria was cost while the weigh and lifting capability of the user came second and have same precentage. In contrast, the least important engineering requirement was radius of leg knobs. Therefore, the HO! Is an important tool that helps propose the engineering and customer requirements in the chronological order which helps the team to focus more on the requirements that have the highest percentages and to reduce the focus on the least important engineering requirement.

# 3 EXISTING DESIGNS

In this section, some of the existing designs will present. Existing designs were those which are implemented already, and this was determined through the research. Existing design does not mean we were not producing the original product. Existing design means similar concepts which currently exist and the reason for searching these designs was to take some help from them while implementing the project. The next thing was searching for existing designs for the subsystem level. There were few sub-system levels of the project, and their existing design will search as well to take the help in our project.

## *3.1 Design Research*

Information and knowledge gained from existing designs and product features of the assistive devices that were marketed under various internal brands were used for making our prototypes more suitable, perfect and satisfactory. The research was done over the internet and few existing designs have been found for the system level designs and the sub-system levels. The research was important in determining the actual requirements for developing the stretcher assistive devices. Also, the data offers a good explanation of the needs of the individuals who have immobility challenges. For example, they require assistive equipment that was flexible, durable, affordable, and comfortable.

## *3.2 System Level*

On a system level, we have determined few concepts which were related to our project and these design concepts helped us implement the project. Existing designs which have found are:

- Underarm Crutches
- Exoskeleton
- Walker Crutches

### 3.2.1 Existing Design #1: Underarm Crutches

Crutches were good for people who like using underarm crutches. This is because they were designed to compensate for the disadvantages of Forearm crutches. The disadvantage to using underarm crutches and crutches, in general, was that they rely on the strength of the user to use them correctly and they can be difficult to use in rainy or snowy weather [2].

Figure 1: Underarm Crutches [2]

### 3.2.2 Existing Design #2: *Exoskeleton*

The Exoskeleton is a work-in-progress device that was being developed at North Carolina State/University of North Carolina-Chapel Hill Department of Biomedical Engineering [3]. The researchers believe that this will help people with paralysis, or trouble walking, overcome their disability. The current version of the device has resulted in an additional benefit of reducing the amount of energy required when using the device by seven percent. Another advantage was the light-weight aspect of the device, as it feels about the same as wearing a loafer on your foot. The biggest disadvantage of this device was that it was not fully tested, and the results were inconclusive for the time being.


Figure 2: Exoskeleton [3]

### 3.2.3 Existing Design #3: Walker Crutches

The Walker Crutches offers the benefits of using crutches base which help the user to aid the balance in walking [4]. This device requires less strength which provide comfortability in usage. The disadvantage of this device was the difficulty to use for some people who stand at full height.

Figure 3: Walker Crutches [4]

## 3.3 Functional Decomposition

The functional decomposition illustrated the effectiveness of the proposed models in enhancing the mobility of the disabled individuals. There were two effective and efficient models which were the Black Box Model and the Functional Model. The Black Box Model presents material, function and flow of the project. It also aimed to enhancing the performance of the device, to enhance the mobility of the individuals with paralysis. The Functional Model illustrates the Black Box Model.

### 3.3.1 Black Box Model

The Black Box model, shown below in Figure 4, was created to imply the fundamental capability of disabled people who can walk normally by our proposed design. In this Black Box, the bold line was defined as the material in this model; a thin line was used to state the energy for this model, and spotted line to identify the signal. The importance of this model was to show the functionalism of this device keeping in mind to reach the goal, which was to help individuals with paralysis walk like normal people. We appropriated the fundamental elements of the hope device by making this model and can be comprehended when having the budget and data sources.

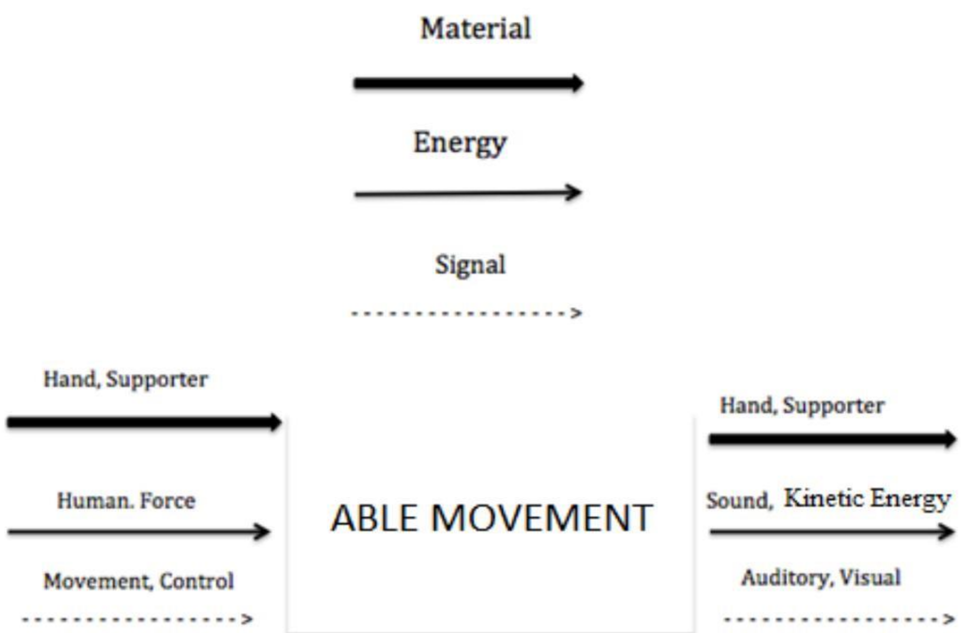


Figure 4: Black Box Model

### 3.3.2 Functional Model

The hypothesized Functional Model shows the complete working of any project, as it has the main function, material, energy, and sound. The functional demonstrates the flows and main functions for the hope device. The Hypothesized Functional Model indicates sub-functions, functions and flows that the hope device contains. The main function used in the Black Box model was Able Movement, which can be designated as the final function of the hope device. This function related to customer needs in one way or another. The functional model was important as the team learned how to divide product into functions and flows that were more accessible to the customer needs. Figure 5 indicates the relationships of various items and concepts in the Functional Model.

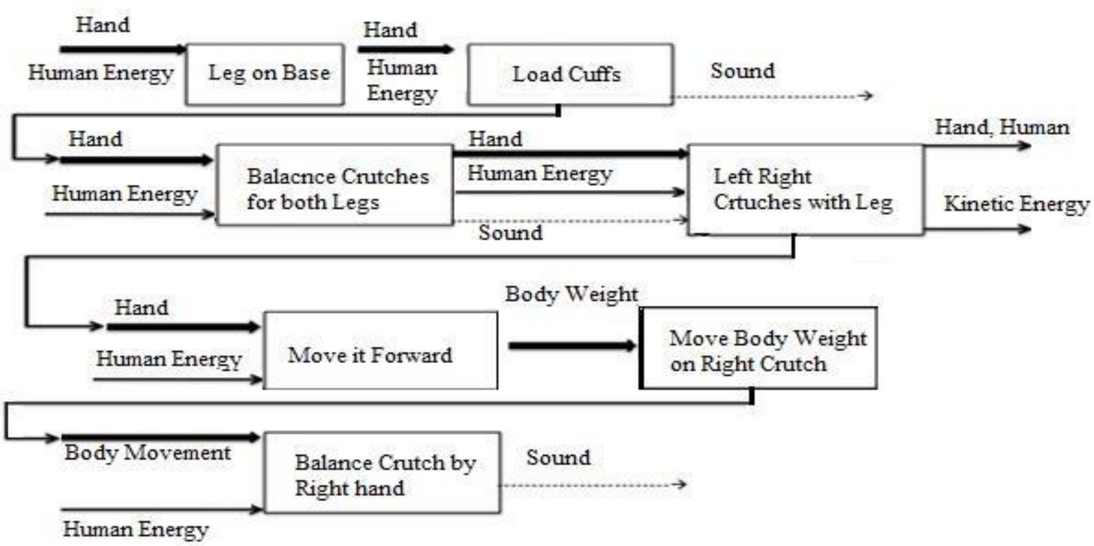


Figure 5: Functional Model

# 4 DESIGNS CONSIDERED

The team came up with 10 designs that was taken into consideration to select the final design for this project. These designs shown in the following sections

## *4.1 Design #1: Two Wheeled Walker*

The two-wheeled walker offers the benefits of using wheels to make walking smoother as well as a seat for the individual to sit on when they become tired. This device makes it easier to go long distances when walking due to the leg base and the smooth of the wheels which is presented by the drawback feature. In addition, it requires less body strength for its use. The disadvantage key of this device was the difficulty to use for some people who stand at full height, the wheels can spin out of control which can cause accidents.

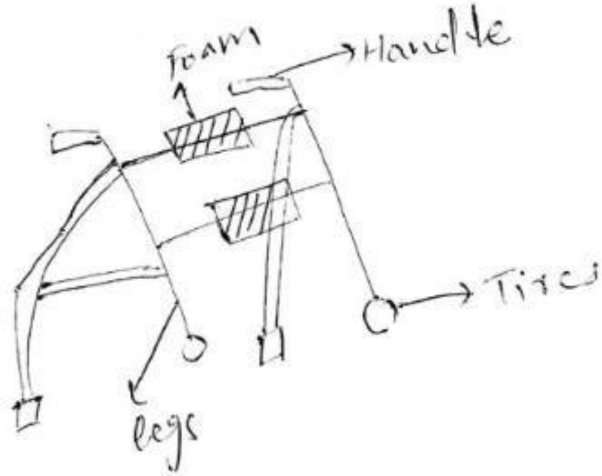


*Figure 6: Two Wheeled Walker*

## *4.2 Design #2: Forearm Walker*

Forearm crutches are a good alternative for people who do not like using underarm crutches. This was because they were designed to compensate for the disadvantages of underarm crutches. They provide a more ergonomic position of the hand and wrist, they allow for improved agility and walking speed, they were easier and safer to use when ascending and descending stairs, and they allow for a variety of walking styles. The forearm crutches rely on the strength as it will be difficult to use in some weather conditions like rain and snow.

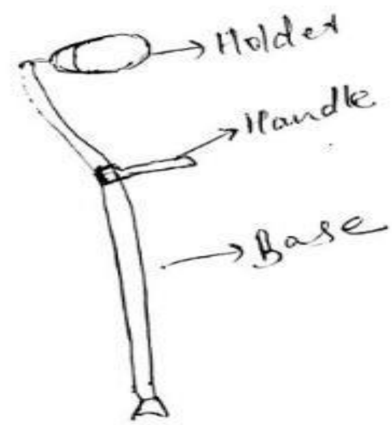


Figure 7: Forearm Walker

### 4.3 Design #3: Quad Cane Walker

The quad cane has been around for a while now. They offer many benefits to walking and those who have a difficult time doing so. Some of the benefits include: reducing knee, ankle, hips and spine stress, they strengthen muscles that support the spine, and it helps the upper body muscles to put off stress in wrists, forearms, hands, shoulders and elbows as well as in the neck. Quad canes do have their disadvantages though. Some of these include: getting stuck in the cracks of the pavement and repetitive strain can become a problem after using the cane too much.

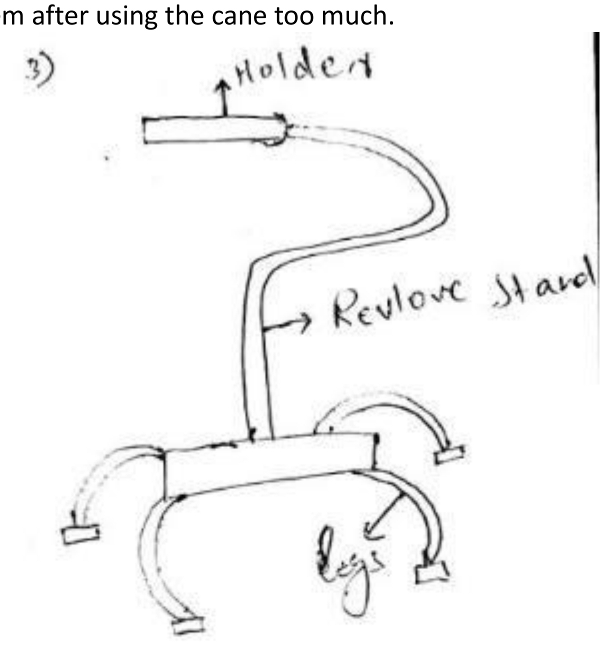


Figure 8: Quad Cane Walker

## 4.4 Rebound Crutch:

Underarm crutches have been around for over a hundred years for the purposes of helping people to walk. However, they have not always provided the best option for walking. The rebound crutch was a design that has many benefits. They are easy to use, provide improved comfort over the traditional crutch design, improve the posture of the user, and allow for a variety of walking styles. The cons of using underarm crutches were that they can cause armpits to be rubbed raw and they can cause major wrist pain.

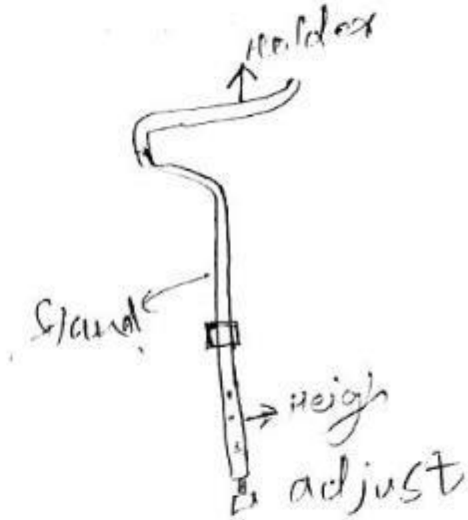


Figure 9: Rebound Crutch

## *4.5 Two-Legged Design*

The idea was that there were two legs support and both supports were different from each other. According to the current design one leg will have three cuffs to hold the leg and second will have the two cuffs to hold the leg. The idea was showing below in Figure 10.


Figure 10: Two-Legged

# 5 DESIGN SELECTED – First Semester

For selection of any design there were difference methods which must use to select the final design. The reason for using these methods was that these methods evaluate the design according to the requirements of clients and without the evaluation of design it was difficult to select the design which fulfill all the requirements. That is why different methods use for selection of final design and in this section these methods will apply to the generated design and select the final design.

## *5.1 Rationale for Design Selection*

To select the final design, we utilized two different methods, from these two methods the final design has obtained. These two methods are:

- Pugh Chart.
- Decision Matrix.

### 5.1.1 Pugh Chart:

The Pugh chart was the tool that analyzes the designs below which were manual method, morph concept and bio inspired design. The Pugh chart was an important tool for designing project as it shows the importance of the sum criteria for each design and analyzes each one. It also gives the team members the insight to analysis the application of the criteria for the three designs in this Pugh chart.

Table 4: Pugh Chart

| 10 Designs | Weight | Design # 1: | Design # 2 | Datum Design | Design # 3 | Design # 4 | Design # 5 | Design # 6 | Design # 7 | Design # 8 | Design # 9 | Design # 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cost | 8 | + | + | D | - | + | - | - | - | + | + | + |
| Durable | 7 | | + | D | + | - | + | | + | + | + | + |
| Aesthetics Design | 6 | - | | D | + | + | - | - | | + | - | + |
| Affordable | 5 | + | + | D | - | + | - | | - | - | - | + |
| Safety | 4 | + | - | D | + | S | - | + | - | + | | + |
| Stable | 3 | + | + | D | + | - | + | - | | + | - | + |
| Low Physical Strain | 2 | - | + | D | + | + | - | - | - | + | | + |
| Light-Weight | 1 | - | - | D | - | - | + | - | - | + | + | + |
| Pluses | | 4 | 5 | - | 5 | 4 | 3 | 1 | 2 | 7 | 2 | 8 |
| Minus | | 3 | 2 | - | 3 | 3 | 5 | 5 | 4 | 1 | 4 | 0 |

The Pugh chart produced the top three designs which were used in the decision matrix. Designs 2, 8 and 10 led to the final design, which was obtained based on the decision matrix calculations and results. The Pugh Chart ensures that the details of the final design adhere to all set criteria and in appropriate levels. For example, the final design had the highest standards of safety and durability. Also, the design was aesthetically appealing and affordable to purchase and maintain.

### 5.1.2 Decision Matrix

The decision matrix was done by taking the top three designs from Pugh chart. In a decision matrix, each design was evaluated on the requirements and each design obtained a mark out of 8 and that marks were multiplied with weightage. The sum up all the values is used to determine which design has obtained maximum marks and that design became the final design.

Table 5: Decision Matrix

| Decision Matrix | Cost | Durable | Aesthetics Design | Affordable | Safety | Stable | Low physical Strain | Light –Weight | Total |
|---|---|---|---|---|---|---|---|---|---|
| Weight | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | |
| Design # 2 | 6x8=48 | 6x7=42 | 2x6=12 | 7x5=35 | 7x4=28 | 5x3=15 | 5x2=10 | 2x1=2 | 192 |
| Design # 8 | 7x8=56 | 6x7=42 | 4x6=24 | 7x5=35 | 7x4=28 | 5x3=15 | 5x2=10 | 3x1=3 | 210 |
| Design # 10 | 8x8=64 | 5x7=35 | 5x6=30 | 7x5=35 | 6x4=24 | 6x3=18 | 7x2=14 | 5x1=5 | 225 |

From the decision matrix, the final design obtained was design #10, which was the two-legged support walker. The design had the highest score, which indicates satisfactory adherence to the important criterion and characteristics of the assistive device.

## 5.2 Design Description

The group decided to design two legs supporters and both supporters were different from each other. According to the current design the long supporter will have four cuffs to hold the leg while the shorter supporter will have the two cuffs to hold the leg.

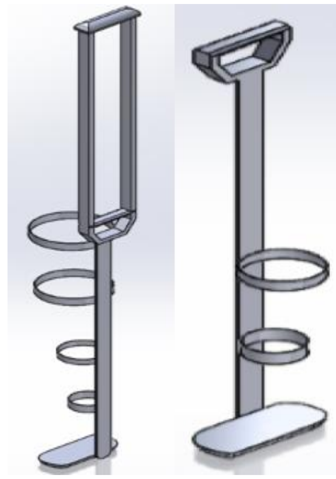

*Figure 11: Final Design*

# 6 PROPOSED DESIGN – First Semester

This design was hard to be manufacturable due to the welding work needed for the most parts of this project specially the joints on the supporters which made it so weak and had lack of safety. The following figure represents the device with having the parts labeled on it.

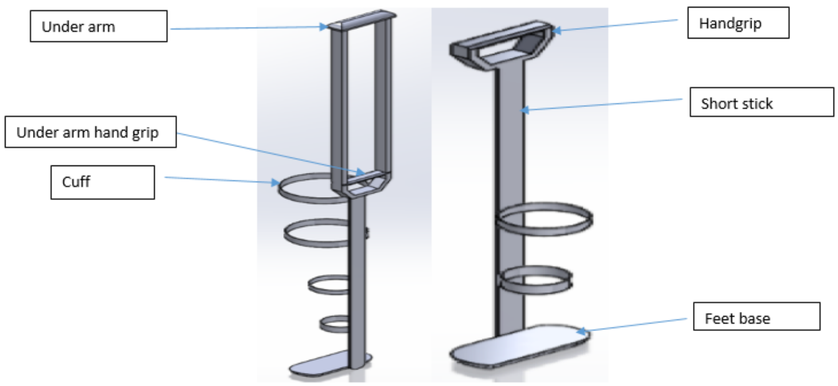


Figure 12: Proposed Design

The work distribution of this semester was divided between the team members equally. All team members attended meetings mostly and worked hard to be on track. The Gantt chart shows that all scheduled tasks for this class have been done 100% which clearly prove that the team is ahead of the schedule. The following figure shows the Gantt chart for this semester and the work progress.

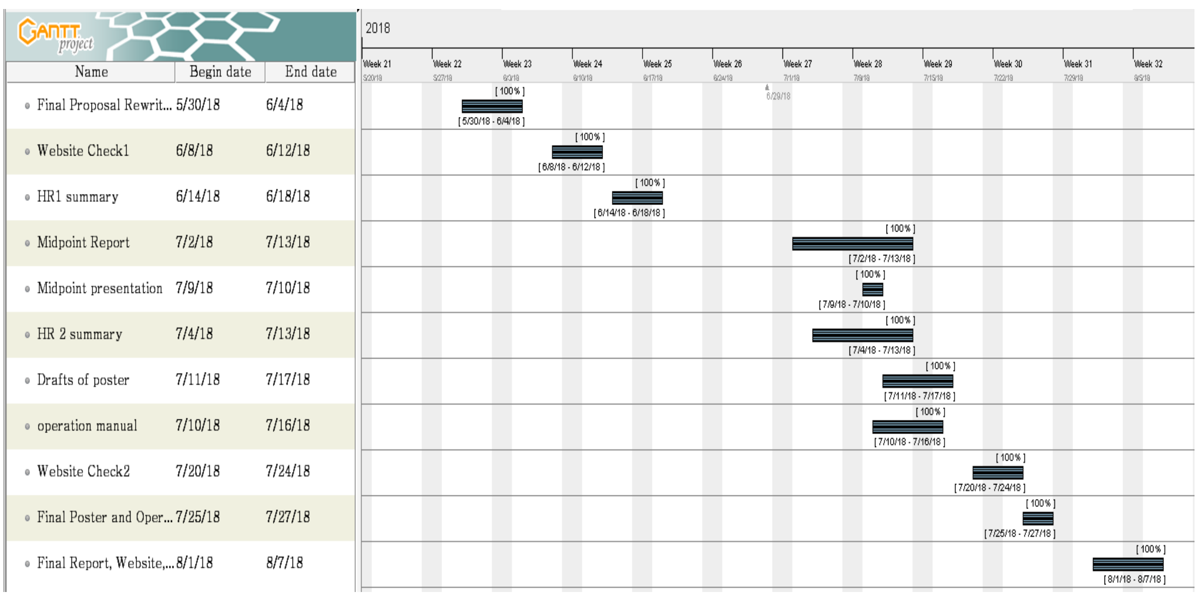


Figure 13: Gantt Chart

# 7 IMPLEMENTATION – Second Semester

For the implementation most of the distribution team's design iterations and testing procedures happened through the hand calculations and by the use of a software such as Finite Element Analysis and CAD modeling in Solidworks. This is due to the difference in the human bodies dimensions which made it hard for the team to manufacture the device and the client totally understood this situation, so the team made the decision of staying with the analytical designing since the first semester of this capstone class. As asked by the client Dr.Oman the team made two ways of testing to examine the device performance which are analytically by Finite Element Analysis and hand calculations. Finite Element Analysis is a software that test the Solidworks drawings by using the ansys. This software helped the team to apply the forces on the device and test the weight applied and checked the factor of safety of each part and finding the place of the weak points which ensured that the engineering requirements were successfully met.

## *7.1 Manufacturing*

For the manufacturing the team made some iterations for this device which will be discussed in this section. Some iterations were made for the rods of the short and long crutches as the height is adjustable so it's up to the user to choose which crutch to be long and to be short. Also the crutches have cuffs on each side and have many different sizes which can be used for both crutches. Furthermore, the handgrip was iterated because it can be used for both crutches and the foam material can fit easily to provide comfortability for the user. Also the brockets was used for both for the two rods connected to the chest along with the two wheels and the brake system to provide the balance and the safety in the falling situations for the user. Moreover, the leg base added to the two crutches along with its sheet that can be folded for the safety purposes and to make it manufacturable. However, the leg base has sole underneath it consist of rubber to prevent slipping which ensures the safety for the user. The manufacturing process will depend weather the parts that we are looking for are found in the market and meet the dimensions requirements then it can be connected together. On the other hand, if the team didn't find the parts on the market that have same dimensions for this device we will have to ask the machine shop to provide us with these parts and then we can manufacture it. Some parts can be connected with the steel screws while other parts such as the cuffs the lower sticks will just go through them. However, some materials like the foam and the rubber needs the high glow. The foam will be glowed up in the handgrip for the long and short crutch, underarm in the long crutch and inside the chest. In contrast, the sole which is made from the rubber will be glowed under the leg base, under the tire and brake pad will be made from rubber. The below table shows the implementations details for this device which will help the team in the manufacturing process.

Table 6: Implementation Tasks

| Part Name | Qty | Material | Manufacturing Process | Time (min) |
|---|---|---|---|---|
| Cuffs | 6 | Rubber | Metal cutting | 30 |
| Short bended rod | 2 | Aluminum | Metal cutting | 60 |
| Long bended rod | 2 | Aluminum | Metal cutting | 60 |
| Upper rod | 2 | Aluminum | Pipe cutting | 60 |
| Lower rod | 2 | Aluminum | Pipe cutting | 60 |
| Hand grip rod | 1 | Aluminum | Pipe cutting | 60 |
| Top rod | 2 | Aluminum | Pipe cutting | 60 |
| Underarm foam | 2 | Foam | Metal cutting | 30 |
| Short crutch handgrip foam | 1 | Foam | Metal cutting | 15 |
| Sole | 2 | Rubber | Metal cutting | 20 |
| feet base | 2 | Aluminum | bending machine | 40 |
| Rods bracket | 2 | Aluminum | Metal cutting | 90 |
| Chest bracket | 1 | Steel | Metal cutting | 70 |
| Tire | 4 | Rubber | Metal cutting | 50 |
| Wheel | 4 | Steel | Metal cutting | 120 |
| Brake pads | 2 | Rubber | Metal cutting | 35 |
| Brake rod | 2 | Aluminum | Pipe cutting | 45 |
| Belts | 3 | Leather | Metal cutting | 20 |
| Belt clip | 6 | Aluminum | Metal cutting | 40 |
| Harness foam | 1 | Foam | Metal cutting | 20 |
| Supporter lower rod | 2 | Aluminum | Pipe cutting | 60 |
| Supporter upper rod | 1 | Aluminum | Pipe cutting | 60 |
| Hand grip foam | 1 | Foam | Metal cutting | 20 |
| Screws | 47 | Steel | Metal cutting | 15 |

The Implementation of this device depends on the availability of the rods with the specific dimensions and thickness that fits the device. If these rods found as the team designed then it can be connected with the screws tightly. If these rods are not found on the market then the team must manufacture it on the machine shop. The manufacturing processes that can be used to implement the device presented on the above tasks schedule. This implementation process needs a total of 19 hours to complete the device. The team can find the best time fits their schedule and distribute the work between the team members equally.

## 7.2 Design Changes

Many design changes occurred this semester which improved the device efficiently. These changes were made by taking the feedback from the client who is the instructor of this class Dr.oman and Dr.Larner who is one of the NAU faculties into consideration. The team worked consecutively to address the problems occurred during the implementation process and this will be discussed in the following sections.

### 7.2.1 Crutches Redesign:

In the previous design the team had two crutches that needs welding process to manufacture the device which is hard to manufacture the device will using the aluminum also the welding points will be weak which will affect the safety of this device. The team decided to use the steel screws to connect the parts without the need of using the welding. Moreover, the previous design had sharp corners which presents weak point and when this device redesigned the team made it curved and that helped to increase the safety by getting rid of the weak points on the crutches. The team changed the thickness of the rods to be stringer and to bare the force and the weight of the human body during the testing procedures.

### 7.2.2 Leg Base Redesign:

The team added the leg base for both crutches. This leg base is constructed of the aluminum and connected by the steel screws. Also it provided with the sole which is made of the rubber to prevent the user from slipping and keep him safe. Furthermore, this leg base needed to have welding work which is really hard to manufacture it, so the team got rid of this problem by adding a leg base sheet that can be connected by the screws.

### 7.2.3 Chest Supporter:

The team met Dr.Larner and he provided us with the idea of adding the supporter to the chest to solve the balance issue for this project. The team improved this idea by adding harness that has foam inside it. This harness can be wearable by the leather belts that can make it unmovable. The team observed a weak point on the chest brocket base and instead the brocket attached to the harness directly. Also the brocket material was changed to the steel to make it strong and safer when using it. For the balancing purpose, the team added one rod and connected them with two brockets and added one wheel to make the device safe in the falling situations.

# 8 TESTING

This section will discuss the analytical testing procedures done to ensure that the proposed design has met all of the engineering requirements. Table 7 below summarizes the engineering requirements and compares them to analytical results.

*Table 7: ERs Testing Results*

| Engineering Requirement | Target | Achieved Value |
|---|---|---|
| 1. Cost | $\leq \$1010$ | $\$775$ |
| 2. Weight | $\leq 35lb$ | 28 lb. |
| 3. Lifting capability of the user. | $\leq 15lb$ | 15 lb. |
| 4. Height of the device | 4 ft – 5.5 ft | 5.5 ft Max height |
| 5. Safety | Factor of safety $\geq 1$ | Min was 2.5 for the chest part |
| 6. Comfortability | Foam | Comfortable |
| 7. Appropriate price for spare parts | $\$25 \leq \$40$ | Max spare part was $25 |
| 8. High quality materials | Steel and aluminum | Thickness increased on each part to achieve the factor of safety requirement and each part has different thickness depending on the dimension of each part. |

## 8.1 Cost Testing

Table 8: Cost Table

| Part Name | Qty | Material | Manufacturing Process | Price |
|---|---|---|---|---|
| Cuffs | 6 | Rubber | Metal cutting | $60 |
| Short bended rod | 2 | Aluminum | Metal cutting | $30 |
| Long bended rod | 2 | Aluminum | Metal cutting | $40 |
| Upper rod | 2 | Aluminum | Pipe cutting | $30 |
| Lower rod | 2 | Aluminum | Pipe cutting | $30 |
| Hand grip rod | 1 | Aluminum | Pipe cutting | $15 |
| Top rod | 2 | Aluminum | Pipe cutting | $30 |
| Underarm foam | 2 | Foam | Metal cutting | $10 |
| Short crutch handgrip foam | 1 | Foam | Metal cutting | $5 |
| Sole | 2 | Rubber | Metal cutting | $20 |
| feet base | 2 | Aluminum | bending machine | $30 |
| Rods bracket | 2 | Aluminum | Metal cutting | $30 |
| Chest bracket | 1 | Steel | Metal cutting | $10 |
| Tire | 4 | Rubber | Metal cutting | $40 |
| Wheel | 4 | Steel | Metal cutting | $40 |
| Brake pads | 2 | Rubber | Metal cutting | $20 |
| Brake rod | 2 | Aluminum | Pipe cutting | $30 |
| Belts | 3 | Leather | Metal cutting | $20 |
| Belt clip | 6 | Aluminum | Metal cutting | $60 |
| Harness foam | 1 | Foam | Metal cutting | $5 |
| Supporter lower rod | 2 | Aluminum | Pipe cutting | $30 |
| Supporter upper rod | 1 | Aluminum | Pipe cutting | $15 |
| Hand grip foam | 1 | Foam | Metal cutting | $5 |
| Screws | 47 | Steel | Metal cutting | $20 |

Total price for the material= $625 [15]
Labor price $20 per hour
The estimation time to manufacture the device 19 hours by showing the CAD to one of the machine shop in Phoenix. So, the labor price will cost the team around $380
Total budget = $1005

## 8.2 Appropriate price for spare parts:

According to the above table the highest value for a spare part is bended underarm stick which is $25. Therefore, the engineering requirement for spare parts has been satisfied.

## 8.3 Safety:

The minimum factor of safety is ≥1 has successfully met. Minimum factor of safety was found on the long crutch by 1.6 while the minimum factor of safety was found in the brocket by 12.144. Therefore, all the device parts have meet the safety requirement

## 8.4 Weight:

As shown on the figure 14 below the weight of the whole device is almost 35 lbs. which meets the weight requirement on the table provided for engineering requirements.

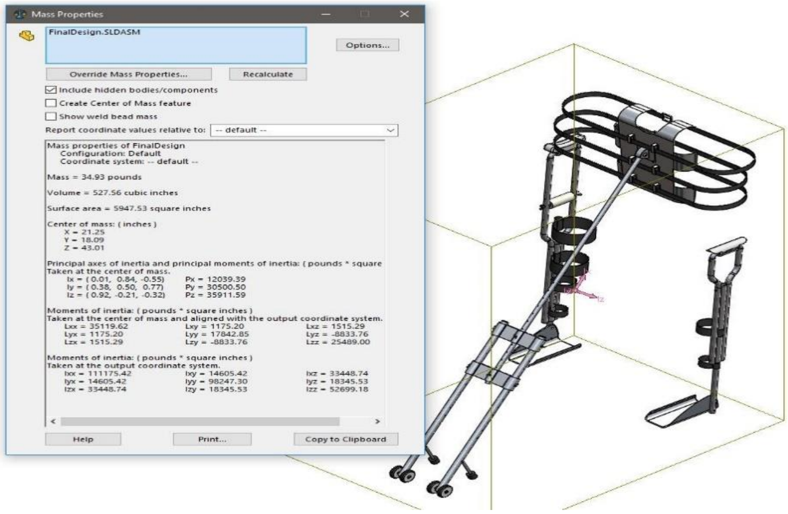


Figure 14: mass properties of the device

## 8.5 Lifting capability of the user:

The whole device weight 35 lbs. The long crutch weigh 5 lb. As the team designed it on the CAD we recommend the lifting capability to be 10 lbs. As the user may use two long crutches instead of one long and one short, which met our engineering requirements.

## 8.6 Height of the device:

The average from the underarm to the top of the head is between 0.7ft to 1ft. Based on this information, the team got the highlighted dimensions as shown on the CAD figure below for the long crutch.

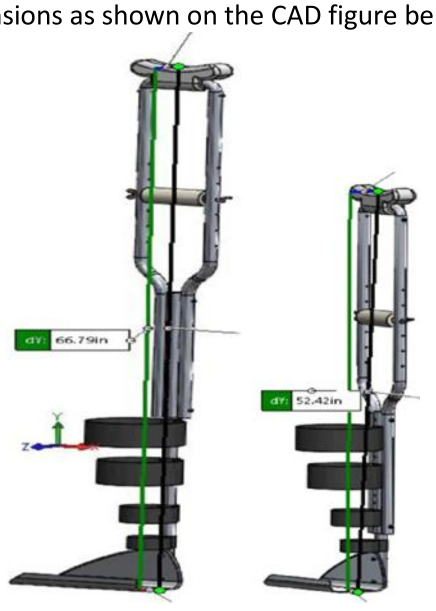


Figure 15: Long crutch height

The short crutch has dimensions of 40.73in when the user wants to make it taller and 31.91in when the user wants to make it shorter as its height flexible.

Figure 16: Short crutch height

- The Supporter rods have flexible angle and flexible length. The approximate maximum length = Middle rod length + side rod length - 2*Brocket length.
- So, the approximate maximum length of the supporter = 39.25 + 40 - 2*3= 73.25in = 6ft
- The approximate minimum length of the supporter = Side rod length + Middle rod length - 2* # of holes of middle rod = 39.25 + 40 - 2* 13 = 53.25in = 4.4ft

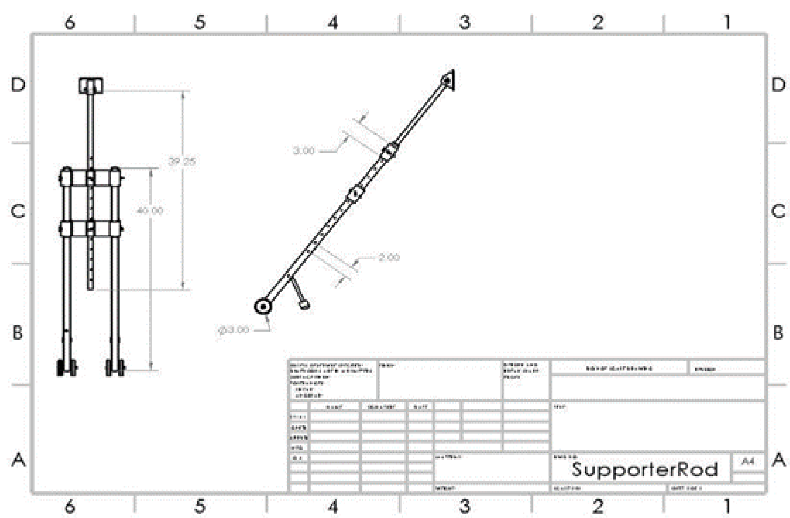


Figure 17: Chest Rod

## 8.7 Comfortability for the user:

The team decided to attach some comfort materials like the foam to the user body. Furthermore, some important areas that the user needs to have comfort are handgrip, underarm and chest. The foam material will help the user in this case to feel comfortably when using the device. Therefore, the engineering requirement of comfortability has been met successfully.

## 8.8 High quality materials:

This device constructed of the alloy aluminum 2011 that has the required thickness for this device. This material  has many characteristics that fits our needs for this design which are poor welding, excellent machinability, can be heat treated, high mechanical strength and high speed automatic screw machine parts [14]. These characteristics helped the team when implementing the device. As most parts of the device needs to be connected with screws this kind of aluminum helped much with the implementation process.

# 9 CONCLUSIONS

The purpose of the following section is to reflect on ME486C and understand how well the team worked. In this semester. It is divided into two sections: Contributors to project success and Opportunities for improvement. Reflecting on teamwork and projects is essential as an engineer because we can become better team contributors and succeed in our chosen fields.

## *9.1 Contributors to Project Success*

The team came up with the idea of a device that can help the disabled people to walk normally. The team had the meaningful feelings toward the disabled people to contribute in giving them aid to get rid of their struggles on this society. Two main factors helped the team toward the success of this project which are hardworking and the bond relation between the team members. The team had successfully improved an existing design in the market to a unique design that can makes the disabled person to walk normally.

During the senior design 1 class, the team faced many issues with the ground rules and cooping strategies. As an example, some of the rules like coming to coming unprepared, coming to meeting late, using cell phones during the mid of the meeting and ignorance of other prospective due to conflict of the opinions. Some of the team members did this few times and the other members talked to him and advise him to go back and read the rules that we agreed on as a team again.

During the senior design 2 class, the team resolved the issues that happened on the senior design 1 class and pledged to follow the rules strictly as the second semester of the capstone class needed much more work than the first semester. The team distributed their time effectively to focus on the analytical designing and using Finite Element Analysis to test the device along with the hand calculations. The team member dedicated themselves to learn new software technology to test the device which is the Ansys software on the Finite Element Analysis. As it is summer class the short time was challenging to the team members as they have to test the device by new tool and they had to learn it independently as no one required to take Finite Element Analysis class. The team faced many struggles to meet the engineering requirements for this project as every part have to bear the weight and force applied. The team members were testing the device by new software which took long time for them to get the desired results required from the client. Beside this, every member has other classes to study for which consumes the time of some meetings. This was one of the many challenges the team faced on the senior design 2 class.

As the senior class approaching, the team gained sufficient experience for manufacturing, using softwares such as SolidWorks and Finite Element Analysis which expand their engineering knowledge. The hope team succeed to design the unique device of the developed crutched that can be the hope of the disabled people to walk normally. Furthermore, the team members bonded the relation and it became stronger with the passage of the time. Since resolving all issues occurred, the group members execuse their teammates if they have exams on same meeting day the work distributed load for that person will be less than the others, so he can focus on his exam. Furthermore, incase if any teammate is facing a struggle on his part, the group gathered and everyone tries to explain to him and help him getting the work done. By this way, everyone feel close to each other and the members will have the motivation between them to get the best work achieved for this project.

## *9.2 Opportunities/areas for improvement*

Some of the aspects that we struggled with was writing. All team members are international students and tend to take longer on the assignments, which means that there is minimal time for editing and feedback. This could have been improved by constantly uploading anything new that we finish, which would give everyone else enough time to look at our progress and edit as we go. This would make sure that we still get done on time, that our work is good, and that we do not have to make a lot of last minute changes. Also, because the writing styles of each person are very different, that means that it took heavy editing to try to ensure that there was a single voice throughout the project.

The team struggled a lot with meetings. Many times we were all busy and therefore meetings were hard to schedule ahead of time. Other times, we did not plan enough time for everything that we needed to discuss and this means that we were not expecting to stay that long and it interfered with other aspects. The team faced a lot of communication problems. There were a few times when a member would text someone from the team because he did not understand something or because he was not sure when the next meeting was. By the time we did reply we would tell him that we already had the meeting and he missed it. There were times when it would take us a few days to text back and this led to a lot of problems with work. Sometimes one of the group member would say that he would do an assignment, but no one would see the text and someone else would do it and that means that he wasted time doing something that was not needed, while he could have been doing something that none of the team members focused on.

The best way to improve our performance is to make sure there is constant interaction. If we cannot get in touch with any of the team members, we need to go to our project advisor and mention that we have been calling, texting, and email the individuals and that no one is getting back to us. Also, when we want to do an assignment it would be best to get it done immediately and share it with the rest of the team. This will ensure that they know someone is working on it and that they do not need to continue with it. We also think that we can do a better job at scheduling meetings. Usually during a meeting we will plan the next one, but sometimes we forget to text the people that did not show up. This means that these people do not know what is going on and are likely to miss the next meeting and this will have a negative impact on how we communicate and the work that we give each other.

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# 11 APPENDICES

[Use Appendices to include lengthy technical details or other content that would otherwise break up the text of the main body of the report. These can contain engineering calculations, engineering drawings, bills of materials, current system analyses, and surveys or questionnaires. Letter the Appendices and provide descriptive titles.  For example: Appendix A-House of Quality, Appendix B- Budget Analysis, etc.]

## *11.1 Appendix A: House of Quality*

*Table A-1: House of Quality*

**House of Quality (HoQ)**

| **Customer Requirement** | **Weight (1-5)** | **Engineering Requirement** | Cost | Weight | Lefting capability of user | Height of the Device | Safety | Comfortability | Approbriate price for spare parts | High quality materials |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Low cost | 3 | | 1 | 3 | | | 1 | 1 | 9 | 1 |
| 2. Light weight | 4 | | 3 | 9 | 9 | 1 | 9 | 9 | 1 | 9 |
| 3. Low phisycal strain | 4 | | | 9 | 9 | | 3 | 3 | | 3 |
| 4. Height accomedate 90% of population | 3 | | | | | 9 | | 9 | | |
| 5. Safe for the user | 5 | | 9 | 9 | 3 | 3 | 9 | 3 | | 9 |
| 6. Comfort and conveniece | 4 | | 9 | 9 | 3 | 3 | 9 | 9 | | 3 |
| 7. Spare parts affordable | 3 | | | | | | | | 9 | 3 |
| 8. Durability | 5 | | 9 | 3 | | | 9 | 3 | 3 | 9 |
| 9. Reliablity | 4 | | 3 | | 3 | 1 | 3 | | 3 | 3 |
| **Absolute Technical Importance (ATI)** | | | 102 | 168 | 108 | 51 | 215 | 148 | 75 | 200 |
| **Relative Technical Importance (RTI)** | | | 6 | 3 | 5 | 8 | 1 | 4 | 7 | 2 |
| **Target ER values** | | | ≤800 | ≤35 | ≤15 | 4-5.5 | ≥1 | | ≤25 | |
| **Tolerances of Ers** | | | 0.97 | 0.8 | 0.6 | 1 | 1 | 1 | 0.9 | 0.8 |
| **Units** | | | $ | lb. | lb. | ft. | | | $ | |

## *11.2 Appendix B: Designs*

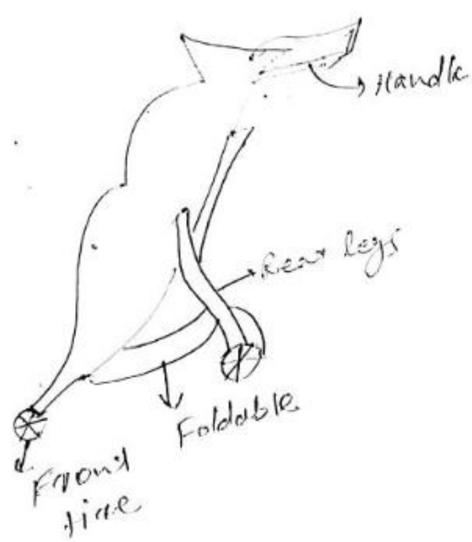



Figure B-1: Walking Frame

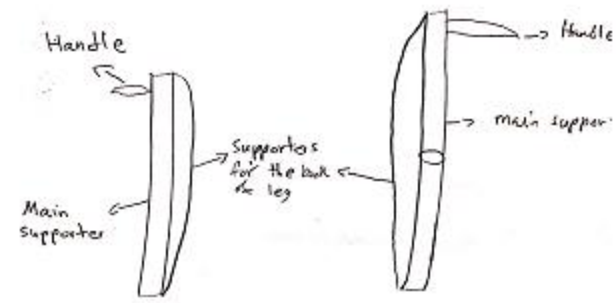



Figure B-2: Swap design

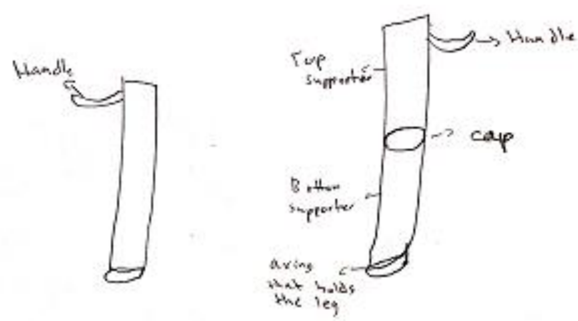



Figure B-3: Handle and cap stand

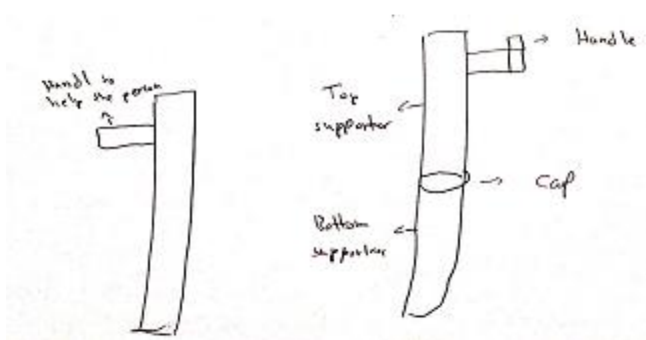
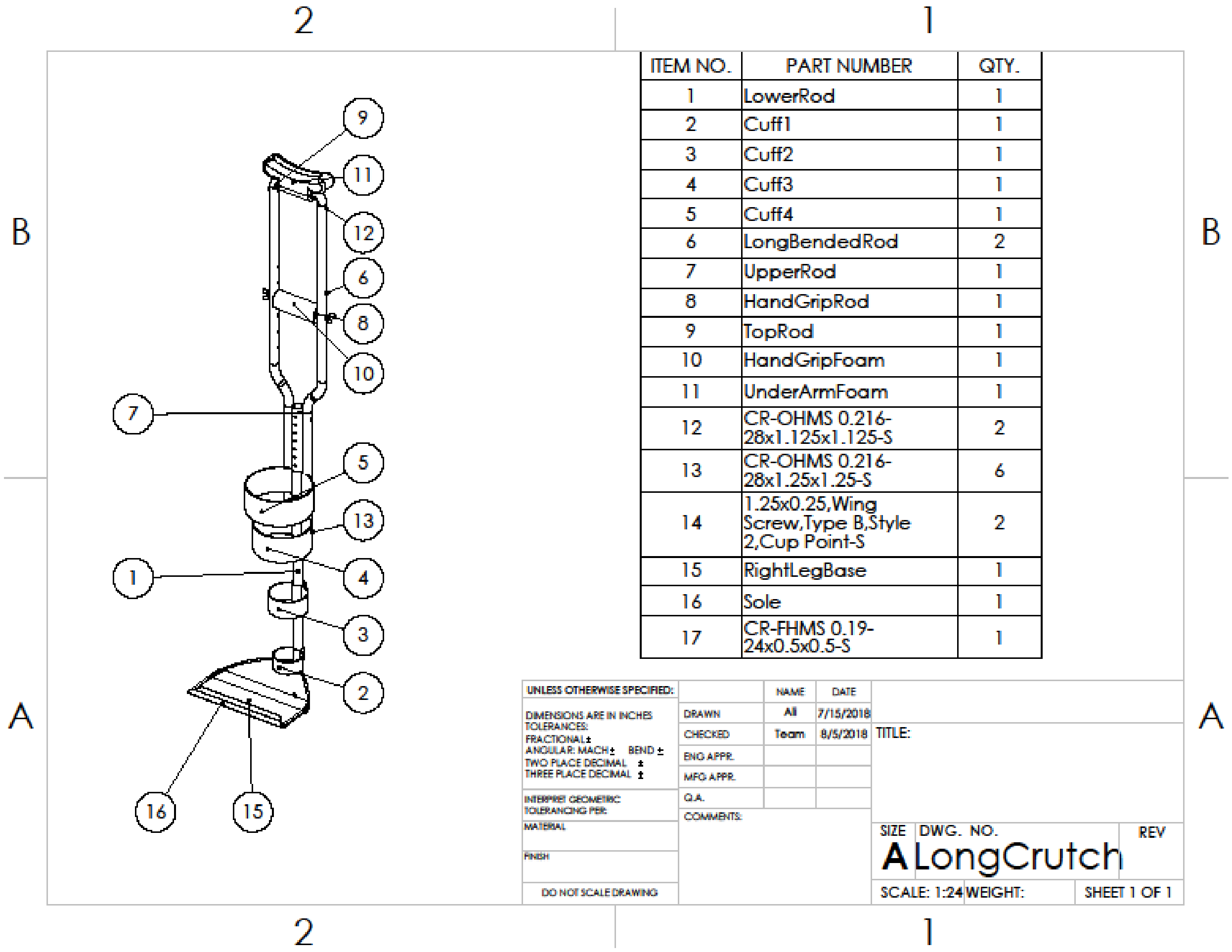


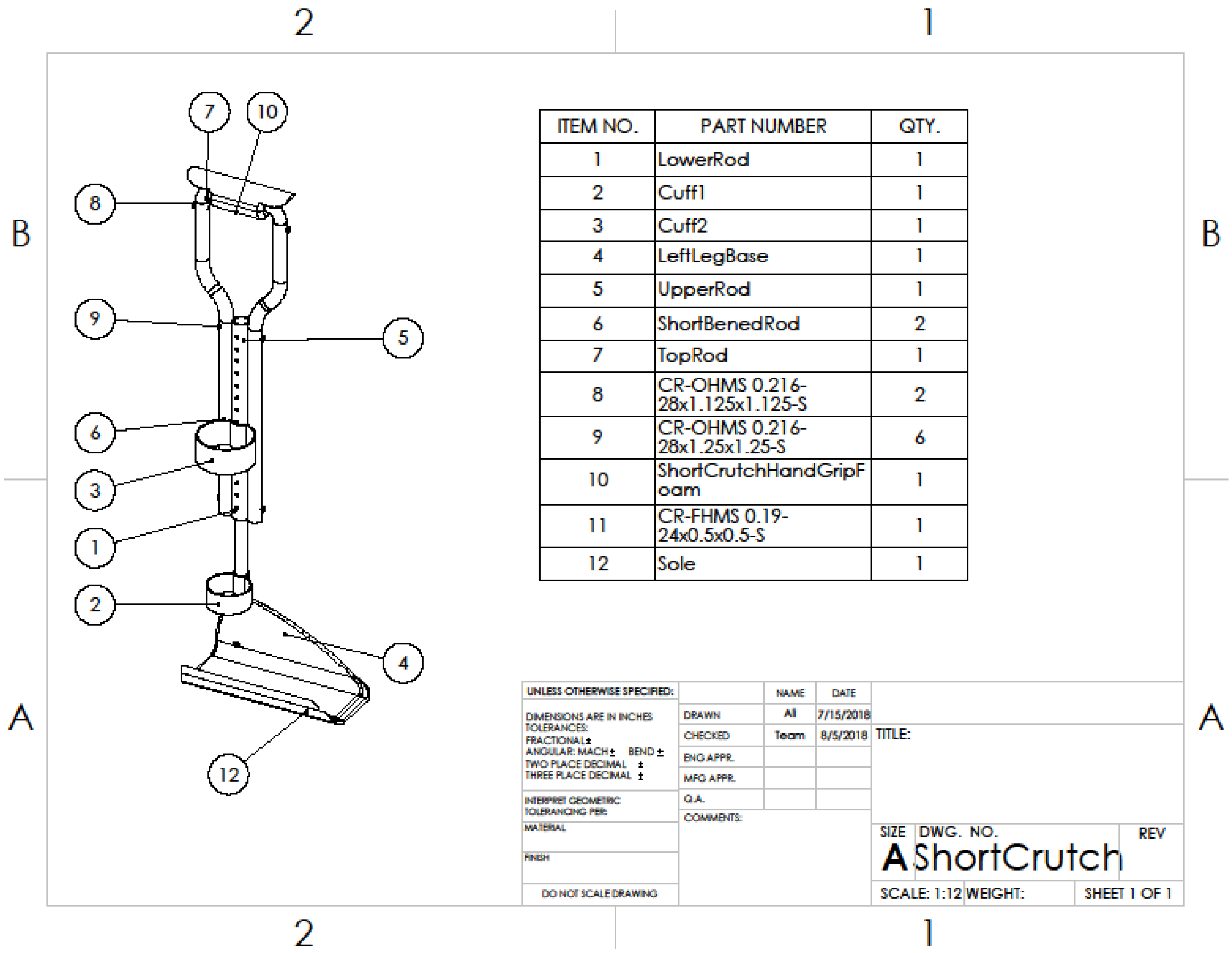

Figure B-4: double cap stand design

## 11.3 Appendix C: CAD drawing package:



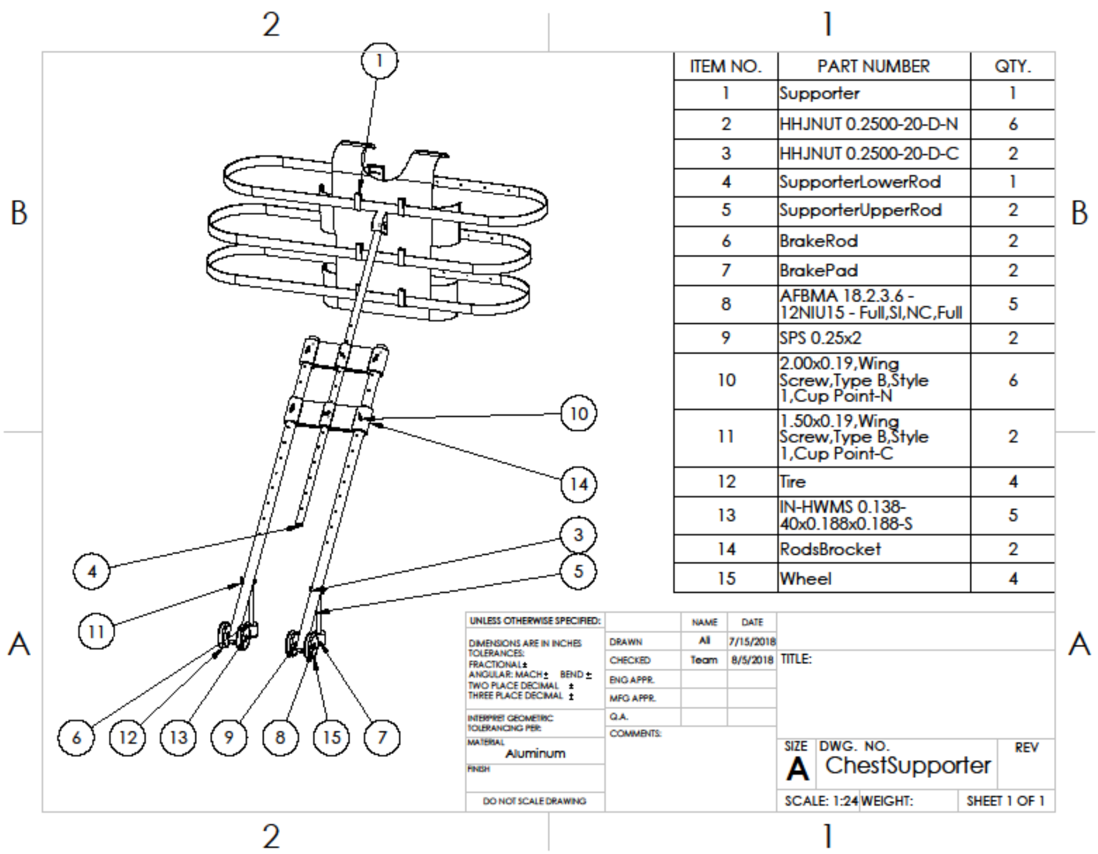

| ITEM NO. | PART NUMBER | QTY. |
|---|---|---|
| 1 | LowerRod | 1 |
| 2 | Cuff1 | 1 |
| 3 | Cuff2 | 1 |
| 4 | Cuff3 | 1 |
| 5 | Cuff4 | 1 |
| 6 | LongBendedRod | 2 |
| 7 | UpperRod | 1 |
| 8 | HandGripRod | 1 |
| 9 | TopRod | 1 |
| 10 | HandGripFoam | 1 |
| 11 | UnderArmFoam | 1 |
| 12 | CR-OHMS 0.216-28x1.125x1.125-S | 2 |
| 13 | CR-OHMS 0.216-28x1.25x1.25-S | 6 |
| 14 | 1.25x0.25,Wing Screw,Type B,Style 2,Cup Point-S | 2 |
| 15 | RightLegBase | 1 |
| 16 | Sole | 1 |
| 17 | CR-FHMS 0.19-24x0.5x0.5-S | 1 |

Figure C-1: CAD drawing for Long crutch



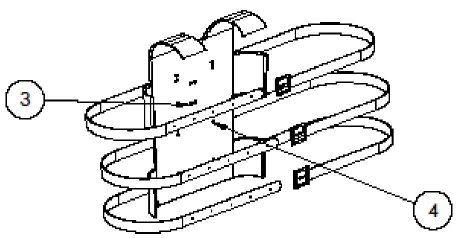

| ITEM NO. | PART NUMBER | QTY. |
|---|---|---|
| 1 | LowerRod | 1 |
| 2 | Cuff1 | 1 |
| 3 | Cuff2 | 1 |
| 4 | LeftLegBase | 1 |
| 5 | UpperRod | 1 |
| 6 | ShortBenedRod | 2 |
| 7 | TopRod | 1 |
| 8 | CR-OHMS 0.216-28x1.125x1.125-S | 2 |
| 9 | CR-OHMS 0.216-28x1.25x1.25-S | 6 |
| 10 | ShortCrutchHandGripFoam | 1 |
| 11 | CR-FHMS 0.19-24x0.5x0.5-S | 1 |
| 12 | Sole | 1 |

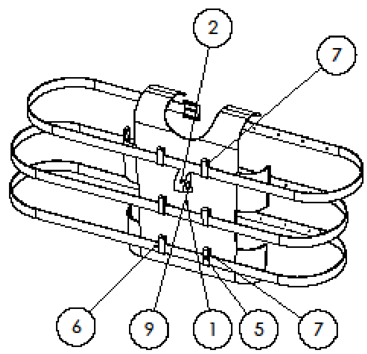
Figure C-2: CAD drawing for short crutch




| ITEM NO. | PART NUMBER | QTY. |
|---|---|---|
| 1 | Supporter | 1 |
| 2 | HHJNUT 0.2500-20-D-N | 6 |
| 3 | HHJNUT 0.2500-20-D-C | 2 |
| 4 | SupporterLowerRod | 1 |
| 5 | SupporterUpperRod | 2 |
| 6 | BrakeRod | 2 |
| 7 | BrakePad | 2 |
| 8 | AFBMA 18.2.3.6 - 12NIU15 - Full,SI,NC,Full | 5 |
| 9 | SPS 0.25x2 | 2 |
| 10 | 2.00x0.19,Wing Screw,Type B,Style 1,Cup Point-N | 6 |
| 11 | 1.50x0.19,Wing Screw,Type B,Style 1,Cup Point-C | 2 |
| 12 | Tire | 4 |
| 13 | IN-HWMS 0.138-40x0.188x0.188-S | 5 |
| 14 | RodsBrocket | 2 |
| 15 | Wheel | 4 |

*Figure C-3: CAD drawing for chest supporter*




| ITEM NO. | PART NUMBER | QTY. |
|---|---|---|
| 1 | Harness | 1 |
| 2 | ChestBrocket | 1 |
| 3 | CR-FHM1 0.19-32x0.4375x0.4375-C | 4 |
| 4 | CR-FHM1 0.19-32x0.5x0.5-C | 12 |
| 5 | BeltClip | 6 |
| 6 | Belt | 3 |
| 7 | HHJNUT 0.2500-20-D-C | 12 |
| 8 | HarnessFoam | 1 |
| 9 | SBHCSCREW 0.5-13x1.625-HX-C | 1 |
| 10 | HJNUT 0.5000-13-D-N | 1 |

| UNLESS OTHERWISE SPECIFIED: | | NAME | DATE |
|---|---|---|---|
| DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL± ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ± | DRAWN | AI | 7/15/2018 |
| | CHECKED | Team | 8/5/2018 |
| | ENG APPR. | | |
| | MFG APPR. | | |
| INTERPRET GEOMETRIC TOLERANCING PER: | Q.A. | | |
| MATERIAL | COMMENTS: | | |
| FINISH | | | |
| DO NOT SCALE DRAWING | | | |

TITLE:

SIZE A DWG. NO. Harness REV

SCALE: 1:12 WEIGHT: SHEET 1 OF 1

Figure C-4: CAD drawing for harness

## 11.4 Appendix D: Bill of Material:

Table D-1: Bill of Material

| **Product Name** | | | The Hope Device | | | | |
|---|---|---|---|---|---|---|---|
| **Team #14** | | | | | | | |
| **Part #** | **Part Name** | **Qty** | **Description** | **Functions** | **ufacturing Proc** | **Price** | **Time (min)** |
| 1 | Cuffs | 6 | Two circles of rubber with different diameter that fits the user's leg | Holdes the user's leg to the crutch | Metal cutting | $60 | 30 |
| 2 | Short bended rod | 2 | Upper sided rods for short crutch with holes on sides | | Metal cutting | $30 | 60 |
| 3 | Long bended rod | 2 | Upper sided rods for long crutch with holes on sides | | Metal cutting | $40 | 60 |
| 4 | Upper rod | 2 | A rod with holes in four sides | To connect bended rods and to adjust the device length | Pipe cutting | $30 | 60 |
| 5 | Lower rod | 2 | A rod with holes in two sides | To attach the leg base and upper rod for adjusting | Pipe cutting | $30 | 60 |
| 6 | Hand grip rod | 1 | A rod with hols in the senter of each circle | To be attached to the long bended rods | Pipe cutting | $15 | 60 |
| 7 | Top rod | 2 | A bended rod with horizontal holes in both ends | To be attached to the top of short and long bended rods | Pipe cutting | $30 | 60 |
| 8 | Underarm foam | 2 | A foam in the top of the long crutch | Attached to the top rod of the long crutch and goes to the user's underarm for comfortability | Metal cutting | $10 | 30 |
| 9 | Short crutch handgrip foam | 1 | A foam in the top of the short crutch | Attached to the top rod of the short crutch and goes to the user's handgrip for comfortability | Metal cutting | $5 | 15 |
| 10 | Sole | 2 | Sole at the bottom of the leg base | Attached to the leg base to give more static friction | Metal cutting | $20 | 20 |
| 11 | feet base | 2 | A bended sheet with two horizontal hole vertically to each other in the long side | To hold the foot from hitting the ground | bending machine | $30 | 40 |
| 12 | Rods bracket | 2 | A bended sheet to three circles | To connect the supporter lower and upper rods together | Metal cutting | $30 | 90 |
| 13 | Chest bracket | 1 | Sheets of steel with two horizontal holes and opened from the bottom side | To connect the supporter upper rod to harness and gives freedom of 42 degree | Metal cutting | $10 | 70 |
| 14 | Tire | 4 | Tire | To roll and give freedom of movement | Metal cutting | $40 | 50 |
| 15 | Wheel | 4 | Wheel | To give strength and to attach the tires | Metal cutting | $40 | 120 |
| 16 | Brake pads | 2 | Pad mades of rubber with a hole at the top it | To stop the ground when the user is falling | Metal cutting | $20 | 35 |
| 17 | Brake rod | 2 | Bended rod with horizontal hole at the top | To connect the supporter lower rods with brake pads | Pipe cutting | $30 | 45 |
| 18 | Belts | 3 | Leather belts | To attach the harness to the user's chest | Metal cutting | $20 | 20 |
| 19 | Belt clip | 6 | A clip | To attach the belt to the harness | Metal cutting | $60 | 40 |
| 20 | Harness foam | 1 | Sheet of foam in front of the user's chest | Attached to inside of the harness and goes to the user's chest for comfortability | Metal cutting | $5 | 20 |
| 21 | Supporter lower rod | 2 | A rod with many holes in four sides | For adjustability and to support the chest supporter at falling | Pipe cutting | $30 | 60 |
| 22 | Supporter upper rod | 1 | A rod with many holes in four sides | For adjustability and to be connected to the rods bracket | Pipe cutting | $15 | 60 |
| 23 | Hand grip foam | 1 | A foam in the middle of the long crutch | Attached to hand grip rod of the long crutch and goes to the user's handgrip for comfortability | Metal cutting | $5 | 20 |
| 24 | Screws | 47 | simple screw | To connect parts together | Metal cutting | $20 | 15 |