Final Report - Stroke Wheelchair

December 11, 2022

ME 386W Stroke Wheelchair Team 1

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Executive Summary

Our team of engineers were tasked with coming up with a wheelchair design to aid in the everyday life of stroke patients. Strokes are a very common brain injury that often leave their victims paralyzed on one side of their body. This brings forth the problem that people who have suffered from a stroke are not able to walk due to their strength only being on one side of their body. Doctors prefer for patients who have had a stroke to be in a mechanical wheelchair to help aid in the rehabilitation process. Unfortunately there are some instances where the patient is not able to put forth any sort of power on one side of their body, not allowing them to propel a wheelchair. This is why my group has come up with a design that not only serves as a mechanical wheelchair, but helps aid in the rehabilitation process no matter what stage the patient is at. This means that no matter if the patient has no feeling on one side or they are able to function perfectly, our wheelchair has a place in their life until it is no longer needed. We are able to do so because of the final design we have pondered about. With safety as our top priority we have added features such as a stability wheel to prevent tipping, and a speed controller to aid in downhill movements. With rehabilitation as a close second, we have come up with an arm movement system that is battery powered and can be adjusted to every person's needs/wants. This allows the patient to propel themselves while doing a common rehabilitation exercise in their everyday lives. We plan to sell these attachments to hospitals and rehabilitation centers in hopes they will rent the chairs out at a fair price since most patients will not need them for the rest of their lives. In order to keep the hospitals and rehab centers modest, we will also sell and or rent out the chairs to people in need. This helps prevent companies from taking advantage of people who have just suffered an injury such as a stroke. In the rest of this report you will find the steps taken to choose the final design, as well as any calculations, and models created of the design for the wheelchair attachments.

1.0 Introduction

The team chose to take up the task of designing a wheelchair created for individuals who have suffered a stroke. The wheelchair should operate as normal while also including a method of rehabilitation to allow patients to have an easy means of transportation and a form of rehab in one device.

2.0 Problem Statement

The main problem to be solved within the scenario given is the inclusion of rehabilitation within a wheelchair. Understanding how to implement the method of rehabilitation as well as making it safe for the individual using it are the top priorities of the team and will be heavily considered throughout the design process. When weighing different options for the design, there were a few objectives to consider. Each of them were given a unique unit to allow for easy measurement. Important objectives such as safety and cost were weighed heaviest.

	Objective	**Basis for Measurements**	**Units**
1	Inexpensive	Unit production cost for a production run of 50,000 Units	USD
2	Ease of Use	Learning how to use and set up	minutes
3	Durability	Number of cycles	# of cycles
4	Adjustability	Number of Compatible parts	# of parts
5	Mechanically Simple	Number of parts	# of parts
6	Maneuverability	Turning radius	ft
7	Safety	Stability, Lateral Support, anti-tip wheels	# of parts

Table 2.1-1 - *List of Objectives and Measurements*

3.0 QFD

Since the design for the wheelchair modifications require a specific function to allow for the aid of stroke patients, a number of customer requirements were included in *Figure 3.1-1.* to allow for a goal to be visualized for the final design. The product should be easily propelled from one side, allowing users with a loss of motor function to properly use the wheelchair. The modifications made are desired to be adjustable to specific disabilities, being able to accommodate the loss of motor function in a specific area or allow a wide degree of motor function loss to be aided. The wheelchair should be easy to maneuver, giving the patient the ability to get to any area efficiently. The modifications should be durable, portable, and affordable, requiring the team to select a material that is strong enough for the action required, small enough to fit in most places, and be a reasonable cost to allow for the accessibility of patients. The modification will also include a form of rehabilitation, as moving the wheelchair with the modification could be a good inclusion of physical therapy. The materials selected should also allow the modification to be stable and retain form on the wheelchair. The design will be flexible, and be able to connect to any wheelchair. Finally, the device will be lightweight and be easy to move for the patient. There were also engineering characteristics included within *Figure 3.1-1.* The first listed was to decrease the weight of the design which will help patients transport the wheelchair. Another was the addition of universal parts, allowing for the modification to be applicable to as many wheelchairs as possible and accommodate as many disabilities as possible. Increasing the strength of the materials is also important, the modification needs to maintain their strength after continuous use. The parts should also fold with the wheelchair, making the wheelchair less bulky and the modification flexible and able to be added to foldable wheelchairs. The modification will preferably increase the propulsive force of the wheelchair, and help the patients to move it easier. A decrease of cost is also considered, as the design should be affordable to purchase and manufacture. Decreasing the width was the final engineering requirement, coinciding with the portability of the design in mind. As shown in *Figure 3.1-1*, there was a large importance placed on the needs of the patient, with the inclusion of requirements such as “Easy to maneuver” and “Rehabilitation”. These types of values regarding the wellbeing of the patient were the primary focus of the design, and scored higher than other customer requirements. When completing the customer needs and engineering characteristics, the results showed a large connection between engineering characteristics that helped make the design easy to use and portable. Decreasing the width and increasing the propulsion mechanical advantage were the two technical requirements that ranked the highest. This shows that a focus on the propulsion is important, but we cannot lose capabilities that exist in current wheelchairs.

System QFD

Project:	QFD Stroke Wheelchair - 1
Date:	9/18/22

Legend		
A	Boost	https://conne
B	SaeboGlove	https://www.s
C	Arm Peddler	https://www.a

		1	2	3	4	5	6
1	Decrease Weight						
2	Universal Parts	0					
3	Increase strength of Materials	-3	-3				
4	Parts Fold with Wheelchair	0	-9	-3			
5	Increase Propulsion Mechanical Advantage	0	0	0	-3		
6	Decrease Cost	9	9	-9	-3	0	
7	Decrease Width	-3	0	0	3	0	0

	Customer Needs	Customer Weights	Decrease Weight	Universal Parts	Increase strength of Materials	Parts Fold with Wheelchair	Increase Propulsion Mechanical Advantage	Decrease Cost	Decrease Width	1 *Poor*	2	3 *Acceptable*	4	5 *Excellent*
			Technical Requirements							**Customer Opinion Survey**				
1	Easy to Propel with only one side	5	3				9			C		A	B	
2	Adjustable to Specific Disabilities	5		9		3		3		C	AB			
3	Easy to maneuver	4	3				9		9			C	B	A
	Durable	3	3		9			3					AC	B
5	Portable	4	9			9			9		A		BC	
6	Affordable	4	3	9	3	3	1	9				AB		C
7	Rehabilitation	3												ABC
8	Stable	5			3	3	3		9				A	BC
9	Compatible With Variety of Wheelchairs	3		9		9	9	3	3	C		A		B
10	Lightweight	4	9		9				3			A	C	B
	Technical Requirement Units		lb.	# of Compatable Parts	MPa	in (folded width)	N (on a Flat Surface no wind)	$	in (Protruding from Wheelchair Side)					
	Technical Requirement Targets		20	Total Number of Parts	300	15	~5	400	2					
	Absolute Technical Importance		120	108	90	105	127	69	138					
	Relative Technical Importance		3	4	6	5	2	7	1					

Figure 3.1-1 *- QFD*

4.0 SOTA Literature Review

The group constructed a State of the Art Literature Review to allow for a collection of research on rehabilitation. Looking into different methods of rehabilitation and their effectiveness was crucial to understanding how to apply such methods to the design.

1. "Guidelines for Adult Stroke Rehabilitation and Recovery", Journal Article
- Details a variety of treatments for strokes and their effectiveness

2. "Stroke Recovery and Rehabilitation", Textbook
- Explains the different impairments caused by strokes

3. "Management of Adult Stroke Rehabilitation Care", Journal Article
- Focuses and organizes the goals and methods of rehabilitation

4. "Wheel and Spoke Design", Website
- Reviews the different spoke patterns in wheels with larger hubs

5.0 Concept Generation and Final Design

As stated above, our group was tasked with finding a solution to help those who have just suffered a stroke rehabilitate their body while still being able to remain in a wheelchair. Most people who have a stroke are often left with little to no strength in just one side of their body, not allowing them to be able to propel the wheelchair efficiently. Below, you will find a morphological matrix of 25 concept variants that helped aid in the decision of the final design.

5.1 Concept Variants

In order to efficiently and effectively create a design that would help a stroke patient more so than hurt them, the team divided up the design into five different sub functions in which were the most important. Once the five sub functions were decided, each person was responsible for creating a sketch for each of the sub functions. This allowed everybody to express their best ideas for the design while being able to have a discussion about it. The Five sub functions that were added to the morphological matrix (**Figure 5.1.1)** were as follows; Safety and Stability, Portability, Rehabilitation, Increased Mobility, and Propulsion. Every concept variant below has both columns are rows numbered and will be referenced as those numbers for example, the first square would be **1.1**.

Sub-Function	Concept Variant 1	Concept Variant 2	Concept Variant 3	Concept Variant 4	Concept Variant 5 (Bio Inspired)
Stability/Safety	Swappable Modifications that are Stable	Stability Wheel to Prevent Tipping	Forward Assist & Anti Roll Back	Thick Wheels	Retracting Stability Arms Designed After Roots of a Tree
Portability	Wheelchair Folds Into Backpack	Keep Attachments Thin to Maintain Foldability	Bendable Axle	Foldable Parts	Retractable Wheel with Removeable Tire (Folds Like a Leaf)
Rehabilitation	As Wheels Move Footrest Oscillates Up and Down	Cable Feature to Help Move Wheelchair and Aid in Rehabilitation	Detachable Spinner Rim for Stationary Mode	Hand Grip Arm Extension Rehabilitation	Shell Attachable Turtle Shell for Protection
Increased Mobility	Notched Wheels for Better Mobility	Pedal Pedal to Control Steering	Adjustable Steering Pinion Left / Right Arm	Removable Parts to Decrease Weight	Add a Solar Panel to Help Power the Wheelchair (Photosynthesis)
Propulsion	Bicycle Pedals to Propel Forward	Disk Brake Engages an Axle to the Wheels Allowing for One Side Propulsion	In Hub E Assist Motor E Assist Motor to Help Propel	Crank Crank for Propulsion and Rehab	Piston Piston Motion (Cheetah)

Figure 5.1.1- *Morphological Matrix*

5.2 Design Alternatives

Using ***Figure 5.1.1*** the group came up with six different design alternatives which will eventually lead to the final design. Each design alternative consists of many different concept variants within the design allowing the team to factor in every option to create the best design possible.

Design 1

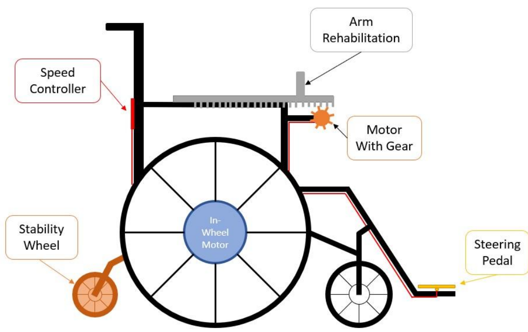


Figure 5.2.1- *Design Alternative One*

Components: 1.2,1.3,3.4,4.2,5.3
Description:
Stability Wheel: Design one features the stability wheel which helps prevent tipping while the patient is in the wheelchair. The team feels the stability wheel is crucial to the wheelchair design because it adds another layer of safety to the chair. This wheel will prevent the patient from tipping over if they are leaning too far back in the chair and or are having trouble going up a steep incline and lose their balance while trying to do so. This safety feature is crucial to this particular design because it does feature an in wheel motor which may offer enough torque to potentially tip the wheelchair over from the start.
Speed Controller: In ***Figure 5.2.1*** you will see it has a speed controller attached to the back of the chair. This speed controller has a number of functions such as aiding in propelling the chair forward on a steep incline. As far as rehabilitation goes, the speed controller will be able to help the patient propel the chair forward as they are only using one arm. The speed controller will have an encoder that will match the speeds of both wheels based upon how much power the patient puts into the wheelchair themselves. The speed controller is also a crucial part to the rehabilitation process because it allows more adjustability than other designs in a sense that the patient can decide how much effort they are wanting to put into the chair. The stronger the patient gets, the more power they will be able to put under their free will and the less power the wheelchair will put in.
Arm Rehabilitation: As stated above, the speed controller will be able to aid in rehabilitation by being able to adjust how much effort both the patient and the chair put into propelling the chair. The speed controller is able to do this because of the rehabilitation device that is attached to the chair. This arm device allows the patient to rehab their arm while still moving the wheelchair forward, this way they can increase their rehabilitation time and decrease their time in the wheelchair. The rehabilitation device moves out and in to create a full cycle. This is a common exercise for people who have just suffered a stroke therefore this will allow them to gain strength back into their arm while still doing their daily activities.
Steering Pedal: The steering pedal is a very important part of the wheelchair and could prevent a serious injury if the event were to occur. The pedal allows the user to steer using only their foot. If the user wants to go left, they need to push their heel down. If the user wants to go right, they will need to push their toes down. If the pedal is flat, it is in a neutral position and is allowing them to go straight. The pedal uses disk brakes to help slow down one side of the chair which then allows them to steer the chair.
Motor with Gear: As previously mentioned, and also seen in ***Figure 5.2.1*** the motor with gear will aid in rehabilitation, propulsion, and safety. The motor will help the user get up a steep incline by providing more power to the wheels if it feels any hesitation at all. The motor also ties into the speed controller which is the main power source to make the speed controller work along with the batteries. The motor will provide power to the wheels while the user is providing their own power to the wheelchair.

Design 2

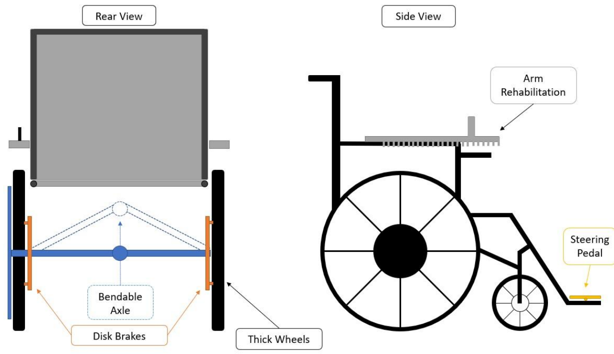


Figure 5.2.2- *Design Alternative Two*

Components: 1.4,2.3,3.4,4.2,5.2
Description:
Thick Wheels: As shown in ***Figure 5.2.2*** this wheelchair design features thick wheels that are able to be mounted onto a standard wheelchair. The thick wheels will allow the user to go over rough terrain. Being able to go over any obstacle that is presented is huge for somebody who has just had a stroke because the thick wheels will allow them to tackle those obstacles with less force required. It is not expected the thick wheels will add more that 2 pounds to the overall design of the wheelchair. This makes thicker wheels a good investment for any wheelchair.
Bendable Axle: Portability plays a large role in a wheelchair user's everyday life. Being in a wheelchair is a very unfortunate event and it does not need to be even harder if the user cannot fit their wheelchair into a storage place like a trunk of a car. The bendable axle is designed to allow the wheelchair to fold easily while still having all of the attachments to the chair. The axle will not be able to break under immense pressure and should have a relatively sturdy design. The axle bends like a folding table, there are clamps that go around the joint and can be removed to help fold the wheelchair into a more compact size.
Arm Rehabilitation: As stated above, This arm device allows the patient to rehab their arm while still moving the wheelchair forward, this way they can increase their rehabilitation time and decrease their time in the wheelchair. The rehabilitation device moves out and in to create a full cycle. This is a common exercise for people who have just suffered a stroke therefore this will allow them to gain strength back into their arm while still doing their daily activities. This design differs from ***Figure 5.2.1*** because it does not consist of the speed controller. The speed controller was used to help propel the wheelchair. This design does not have the speed controller, making this wheelchair fully mechanical and 100% under the user's power.
Steering Pedal: The steering pedal is a very important part of the wheelchair and could prevent a serious injury if the event were to occur. The pedal allows the user to steer using only their foot. If the user wants to go left, they need to push their heel down. If the user wants to go right, they will need to push their toes down. If the pedal is flat, it is in a neutral position and is allowing them to go straight. The pedal uses disk brakes to help slow down one side of the chair which then allows them to steer the chair.
Disk Brakes: While being able to propel yourself with one arm is great, it is even more important you are able to stop. Disk brakes will be attached to this chair as the overall braking system. Disk brakes are one of the lightest forms of braking systems made, making it the best option in this case because it will not add much more weight to the already heavy wheelchair. The disk brake will also aid in steering. If the pedal is pushed in any direction, the proper brake will slow down one side of the wheelchair, allowing the user to turn in the opposite direction. Disk brakes seem to be the safest option for this design because it allows ease of use.

Design 3

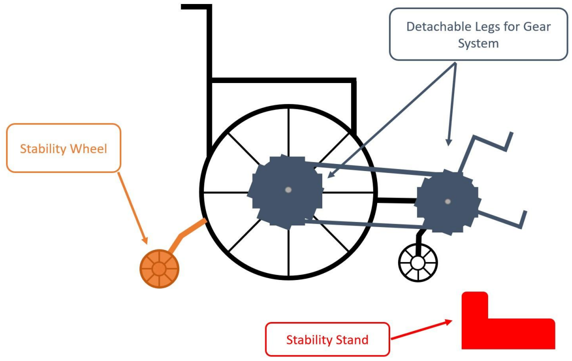


Figure 5.2.3- *Design Alternative Three*

Components: 1.2,2.4,3.3,4.4,5.1
Description:
Stability Wheel: Design three features the stability wheel which helps prevent tipping while the patient is in the wheelchair. The team feels the stability wheel is crucial to the wheelchair design because it adds another layer of safety to the chair. This wheel will prevent the patient from tipping over if they are leaning too far back in the chair and or are having trouble going up a steep incline and lose their balance while trying to do so. This safety feature is crucial to this particular design because it has a bike gear system so the user would not be able to stand up or move from the sitting down, bike position, very easily.
Foldable Parts: ***Figure 5.2.3*** features foldable parts in order to keep the wheelchair portable for the user. The foldable parts will allow the wheelchair to fit into tight spaces with ease. This wheelchair design also features removable parts, which will be talked about later, but that also helps store the wheelchair in tight spaces in which a normal wheelchair would not be able to fit. This wheelchair design would be relatively lightweight and would allow for anybody to be able to use it.
Stability Stand: As previously mentioned, one of the main goals of our team's wheelchair final design is to aid in rehabilitation. We have come up with many ideas that allow the user to rehabilitate while moving the wheelchair to get around but what about when they are sitting stationary. In order to help the user go through rehabilitation exercises, the group has created a stationary mode, which allows the wheelchair to spin freely while staying in the same position. This means the user can use the bike pedals (talked about later) to rehabilitate their legs without having to actually move around. This motivates the user to do their exercises more often since they can be done while simply just watching tv.
Removable Parts: As previously mentioned, **Figure 5.2.3** features removable parts on the wheelchair. The idea behind removable parts is to allow the user to store the wheelchair anywhere and everywhere without a hassle. People who are in a wheelchair, especially those who have suffered from a stroke already have it tough, being able to store their chair should not add to the stress in their life. The wheelchair will feature a quick disconnect like you see on bikes and the part can be removed with one or both hands.
Bike Pedals: In order to add a form of propulsion as well as rehabilitation, the wheelchair features bike pedals. The user will sit and pedal their way across town allowing them to not only get around more efficiently but to rehabilitate their legs as well. We have not come up with a design to do this with only one leg, but for now this will help the wheelchair start to get strength back in either one or both legs. The stationary mode world for this feature like a stationary bike where you pedal away without actually going anywhere.

Design 4

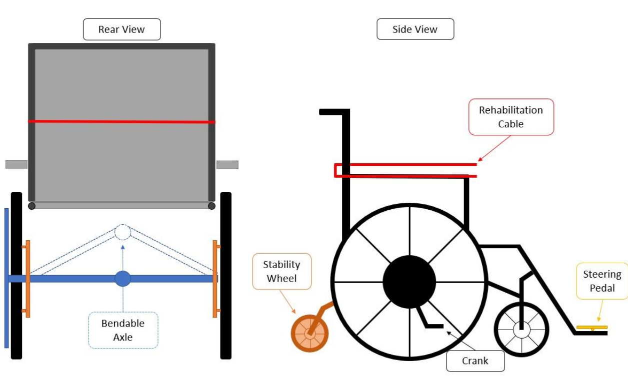


Figure 5.2.4- *Design Alternative Four*

Components: 1.2,1.4,2.3,3.2,4.2,5.4
Description:
Stability Wheel: Design four features the stability wheel which helps prevent tipping while the patient is in the wheelchair. The team feels the stability wheel is crucial to the

wheelchair design because it adds another layer of safety to the chair. This wheel will prevent the patient from tipping over if they are leaning too far back in the chair and or are having trouble going up a steep incline and lose their balance while trying to do so.
Bendable Axle: Portability plays a large role in a wheelchair user's everyday life. Being in a wheelchair is a very unfortunate event and it does not need to be even harder if the user cannot fit their wheelchair into a storage place like a trunk of a car. The bendable axle is designed to allow the wheelchair to fold easily while still having all of the attachments to the chair. The axle will not be able to break under immense pressure and should have a relatively sturdy design. The axle bends like a folding table, there are clamps that go around the joint and can be removed to help fold the wheelchair into a more compact size.
Rehabilitation Cable: Figure 5.2.4 features a rehabilitation cable in order to help propel the wheelchair. The idea behind this design is like an elliptical. One arm moves forward while the other moves back allowing more power to the chair. So long as the user keeps moving, the chair should move with ease and there should be no issues with getting around town. This cable is also a rehabilitation exercise for those who have just had a stroke. It is one of the best ways for the user to propel themselves while still dividing the power to make themselves stronger in the long run. Eventually this cable will no longer be needed for the user and they will be able to propel themselves either using the wheel or the crank which will be talked about later.
Steering Pedal: The steering pedal is a very important part of the wheelchair and could prevent a serious injury if the event were to occur. The pedal allows the user to steer using only their foot. If the user wants to go left, they need to push their heel down. If the user wants to go right, they will need to push their toes down. If the pedal is flat, it is in a neutral position and is allowing them to go straight. The pedal uses disk brakes to help slow down one side of the chair which then allows them to steer the chair.
Crank: The crank on this design is specifically meant for those who have little to no strength in one side of their body. The crank can be used to propel both wheels from just one side. It would be difficult to propel but nonetheless would get the job done. Between the crank and the rehab cable, there should be no reason a stroke patient can't propel this chair on their own.

Design 5

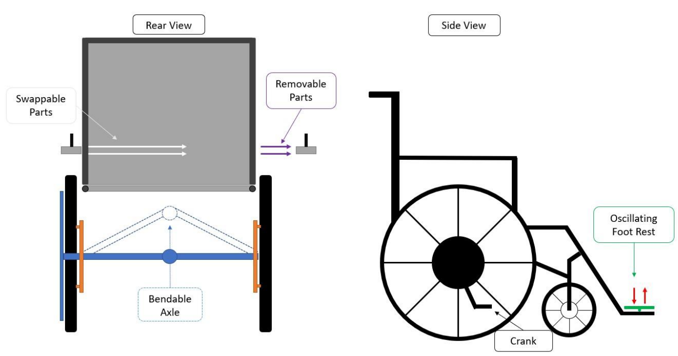


Figure 5.2.5- *Design Alternative Five*

Components: 1.1,2.3,3.1,4.4,5.1
Description:
Swappable Modifications: Being able to create a design that is not only user friendly but also compatible with any wheelchair is very important to the group. While being able to put the attachments on any brand of wheelchair is important, it is more important that whatever chair our attachments end up on are able to go on both sides of the chair accordingly. As Mentioned previously, eighty percent of people who have suffered a stroke are left paralyzed in one side of their body. Since it is not always the same side, our design needs to be able to go onto both sides of the wheelchair which will allow the user to choose which side they want it on based on their injuries.
Bendable Axle: Portability plays a large role in a wheelchair user's everyday life. Being in a wheelchair is a very unfortunate event and it does not need to be even harder if the user cannot fit their wheelchair into a storage place like a trunk of a car. The bendable axle is designed to allow the wheelchair to fold easily while still having all of the attachments to the chair. The axle will not be able to break under immense pressure and should have a relatively sturdy design. The axle bends like a folding table, there are clamps that go around the joint and can be removed to help fold the wheelchair into a more compact size.

Oscillating Foot Rest: The oscillating footrest is meant to aid in rehabilitation. As the wheels of the wheelchair move, the footrest of the wheelchair moves as well. This footrest allows the user to get movement in their legs while still being able to move forward and not get in the way of somebody else. The footrest will aid in rehabilitation because it is most important the user keeps moving throughout the entire rehabilitation process. The last thing we want to do is create more bad than good for the user.
Removable Parts: As previously mentioned, **Figure 5.2.5** features removable parts on the wheelchair. The idea behind removable parts is to allow the user to store the wheelchair anywhere and everywhere without a hassle. People who are in a wheelchair, especially those who have suffered from a stroke already have it tough, being able to store their chair should not add to the stress in their life. The wheelchair will feature a quick disconnect like you see on bikes and the part can be removed with one or both hands
Crank: The crank on this design is specifically meant for those who have little to no strength in one side of their body. The crank can be used to propel both wheels from just one side. It would be difficult to propel but nonetheless would get the job done.

Design 6

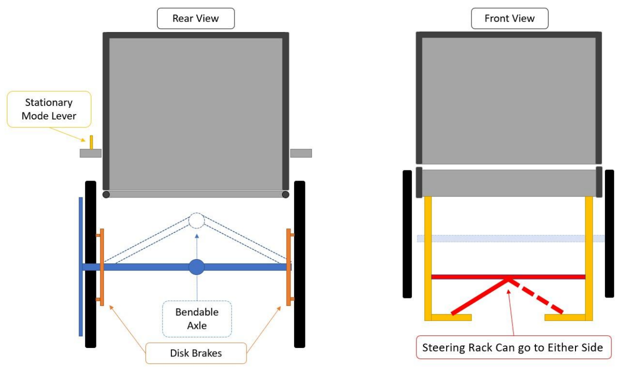


Figure 5.2.6- *Design Alternative Six*

Components: 2.3,3.3,4.3,5.2
Description:
Bendable Axle: Portability plays a large role in a wheelchair user's everyday life. Being in a wheelchair is a very unfortunate event and it does not need to be even harder if the user cannot fit their wheelchair into a storage place like a trunk of a car. The bendable axle is designed to allow the wheelchair to fold easily while still having all of the attachments to the chair. The axle will not be able to break under immense pressure and should have a relatively sturdy design. The axle bends like a folding table, there are clamps that go around the joint and can be removed to help fold the wheelchair into a more compact size.
Stationary Mode: As previously mentioned, one of the main goals of our team's wheelchair final design is to aid in rehabilitation. We have come up with many ideas that allow the user to rehabilitate while moving the wheelchair to get around but what about when they are sitting stationary. In order to help the user go through rehabilitation exercises, the group has created a stationary mode, which allows the wheelchair to spin freely while staying in the same position. This motivates the user to do their exercises more often since they can be done while simply just watching tv.
Steering Rack: The steering rack is a great design method that allows the user to turn themselves but applying pressure to one side of the chair. The pressure will allow the user to turn whichever way they would like and the steering rack is easily adjustable to whichever side is their stronger side. This steering rack is a big safety feature because in the event of a roll away the steering would be able to deter the user from any harm which could be done. It is also nice and fits within our standards that the rack can be easily adjusted to either side of the chair.
Disk Brakes: This wheelchair features a design that allows you to propel yourself with one arm using the blue outer rim as shown in **Figure 5.2.6.** While being able to propel yourself with one arm is great, it is even more important you are able to stop. Disk brakes will be attached to this chair as the overall braking system. Disk brakes are one of the lightest forms of braking systems made, making it the best option in this case because it will not add much more weight to the already heavy wheelchair. Disk brakes seem to be the safest option for this design because it allows ease of use.

5.3 Final Design Selection

Once all six of the design options were created, the team went into the decision making process for choosing the correct design to be the final design. In order to make the best decision possible, the group came up with the eight most important decision factors amongst choosing a design. The eight categories are as follows:

1. **Safety:** Since the task is to design a wheelchair for a person who has just suffered a stroke, it is imperative the design is safe and easy to use to avoid any further injuries.
2. **Stability:** Stability is important because it also ensures safety. So long as the wheelchair is stable, the patient will be able to do all of their daily tasks without the risk of tipping over and potentially causing further injuries.
3. **Lightweight:** A user who has just suffered a stroke has a high probability of only being able to use one side of their body. The wheelchair needs to be lightweight so the user can lift it in and out of storage areas with ease.
4. **Ease of Use:** The goal for our group is to be able to sell the product we create to not only hospitals and rehab centers, but directly to customers as well. The wheelchair attachments must be easy to assemble and learn how to use so the consumer has no issues upon purchase.
5. **Affordable:** Coming off of an injury is very expensive, especially if the patient has been in the hospital for an extended period of time. The wheelchair needs to be affordable for the consumer because they are already having a stressful time of their life, there's no need to add any more.
6. **Comfort & Posture:** It is important for a wheelchair user to have good posture while they are in the wheelchair. Oftentimes, good posture leads to uncomfortability so it is important to create a product that aids in those two areas.
7. **Adjustable:** No two people are the exact same. Because of this, the attachments need to be adjustable for any and every size imaginable.
8. **Durable:** In order to be successful you need customers. If the product does not hold its value the sales will go down and people will no longer buy. For this reason the product needs to be extremely durable.

The eight categories above were transferred into a pugh chart as well as a decision matrix in order to help the team pick the best design possible. All of the designs were entered into the pugh chart (**Table 5.3.1**) and compared to design five which was the Datum amongst all of the designs. Design five was the datum because it partially met the design requirements for the product and partially did not. All other designs were compared to the datum using a plus sign as a symbol to show the design was better than the datum, a minus sign as a symbol to show the design was worse than the datum, or an S to show that the design was the same as the datum.

Concept/ Criteria	Design #1	Design #2	Design 5	Design #3	Design #4	Design #6
Safe	+	+	DATUM	+	+	S
Stable	+	+		+	+	S
Lightweight	-	-		-	-	+
Ease of use	-	-		-	S	+
Affordable	+	-		+	S	+
Comfort/Posture	+	+		+	S	S
Adjustable	+	S		-	S	S
Durable	+	+		+	+	+
∑ +	6	4		5	3	4
∑ -	2	3		3	1	0

Table 5.3.1- *Pugh Chart*

The group was able to narrow the decision down to three designs using **Table 5.3.1**. Once the three designs were chosen, the team used those designs in the decision matrix (**Table 5.3.2**) in which they were given a score between 0 and 100 to grade how well that design performed in each of the eight categories listed above. Once all of the scores were given, they were then multiplied by the weight of importance, then added together to give a final score. As shown in **Table 5.3.2** Design one (**Figure 5.4.1**) had the highest score after going through the decision matrix making it our final design decision. The final design will be explained in detail below.

		Design 1		Design 3		Design 6	
Criteria	Weight (%)	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Safe	20	9	180	7	140	5	100
Stable	15	9	135	8	120	5	75
Lightweight	5	5	25	6	30	6	30
Ease of use	10	7	70	5	50	8	80
Affordable	15	6	90	7	105	7	105
Comfort/Posture	15	10	150	9	135	10	150
Adjustable	10	9	90	6	60	8	80
Durable	10	8	80	6	60	7	70
Total	100		820		700		690

Table 5.3.2- *Decision Matrix*

5.4 Final Design

Following the Decision Matrix (**Table 5.3.2**) it was determined design one was the best overall design for the project. Design one can be found below with an in depth explanation of what the groups goals were for the final design (**Figure 5.4.1**).

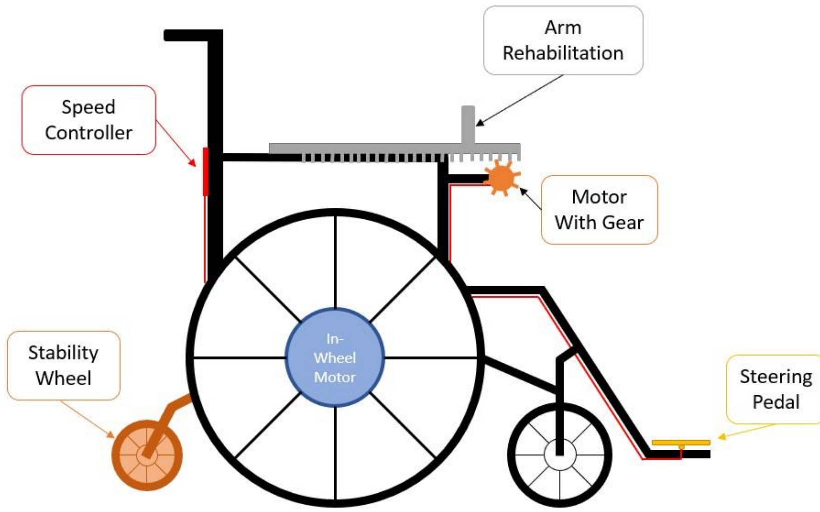


Figure 5.4.1- *Final Design*

Figure 5.3.2 is a rough sketch of the final design the group intends to pursue. This design consists of two safety features, one rehabilitation feature, one increased mobility feature and finally, one increased propulsion feature. All of the features above were subcategories within **Figure 5.1.1**. The two safety features implemented into this design are the speed controller and the stability wheel. As described above, the stability wheel is to prevent the user from tipping back in the wheelchair if they find themselves in tough circumstances. The speed controller has many functions,however it is primarily used for the uphill assist as well as the prevention of rolling backwards, allowing the user to be safe at all times. The rehabilitation feature within the final design is the arm rehabilitation device. This device allows the user to propel themselves forward with one arm while still being able to rehabilitate their body. This device works with the speed controller to give power to the wheels which then allows the wheelchair to propel forward. It is a very adjustable device in the sense that whoever is using it will have no issues with arm lengths and or strength. The user will be able to set the speed controller to any setting they like, allowing them to increase or decrease how much the motor works for them and also allowing them to grow in their rehabilitation process. The increased mobility feature is the steering pedal. As previously explained, the steering pedal allows the user to steer with only one foot and they would either push their toe or heel down, depending on the direction they are trying to go. Finally, the increase in propulsion comes from the in wheel motor. The E assist will work with the speed controller to aid in uphill adventures as well as the rehabilitation process.

6.0 Engineering Analysis of Design

In order to create a design that was built to last, the team divided the engineering analysis into five sections which would contribute to the overall design. The five sections were as follows: Rehabilitation, Wheels, Required Force, Battery, and Stability. Below you will find the engineering analysis for all of these functions as well as Appendices in the Appendices section.

6.1 Analysis of Rehabilitation

The analysis of rehabilitation is important to the project because it allows medical professionals to give a rough estimate to patients about how long they will be in a wheelchair while they are recovering. There are three assumptions for this analysis. The first assumption is there are a total of 45 rehab hours for a stroke patient [3]. The second assumption made for this analysis is that three revolutions of the wheel is equal to one cycle of the arm device. Finally, the wheelchair is moving at three miles per hour.

$$Distance = R \times \pi d \tag{1}$$

In **Appendix A** you will find the small red bubbles consist of different values between 0 and 1. These values correlate to the arm length of the consumer and will be used as the R value seen in equation (1). This R value changes because nobody will have the exact same arm length and they will for sure not have the exact same rehabilitation process. Once the R value is plugged into the equation you will get an output in inches which will be converted to feet and that number is the distance the wheelchair has moved.

$$\frac{Distance\ (\frac{ft}{hr})}{Distance\ (\frac{ft}{rev})} = rev/hr \tag{2}$$

From the assumptions section above we stated the consumer was moving at 3 miles per hour. Using 3 miles per hour as well as equation (2) we will find the amount of revolutions per hour by dividing the amount of feet in 3 miles by the number found in equation (1). Next, using the assumption that 3 Rev = 1 Cycle, you will divide the number given from equation (2) by 3 to get the Number of cycles/hr.

$$\frac{Cycles}{Hour} \times 45\ Hours = Cycles\ to\ Complete\ Rehabilitation \tag{3}$$

Finally, once you have the number of cycles per hour, you can multiply that number by 45 to find the number of cycles to complete the rehabilitation requirements. Using these three equations and the assumptions given shows us the total number of cycles needed to complete 45 rehab hours is 37,800 cycles.

6.2 Analysis of Wheels

The analysis of the wheels and the required load needed for them to carry was analyzed using the assumptions that the person weighs 200 lbs and that the wheelchair weights 50 lbs. Then, a summation of forces in the y-direction was made, identifying the force that would be exerted on the wheel.

$$\Sigma F_Y = F_{Wheel} + F_{Wheel} - F_{Person} - F_{Wheelchair} = 0$$

$$F_{Wheel} = \underline{125 lb}$$

6.3 Analysis of Required Force

The required force for propulsion was calculated using the analysis of forces acting on the patient in the chair. The assumptions made were the patient's weight, which was expected to be 200 lbs, and the rolling resistance coefficient of friction between the wheels of the chair and the floor. This was expected to be 0.012. A summation of forces in the x-direction of the model was then analyzed.

$\Sigma Fx = 0$
FReg - FF = 0
FReg = FF
FReg =FN x μ
FReg =200 lb x 0.012
FReg = 2.4 lb

6.4 Analysis of Battery

First, the battery size needed to be calculated for the design. The team wanted to ensure the patient could use the wheelchair for a long period of time, so two 12 volt lithium ion batteries were chosen. Battery size is usually calculated by multiplying amps by the number of hours the battery should run. This left us with a 60 amp-hour (AH) battery.

6.5 Analysis of Stability

Appendix B shows the equation for the tipping angle of wheelchairs as well as the tipping and height difference for different chairs on the market. Using the assumptions that the armrest height (B) is 30 inches and the length from the center of the wheelchair to the rear-wheel point of contact (A) is 13 inches.

$$Tan\ \theta = \frac{A}{B} = Arctan\left(\frac{A}{B}\right) \tag{1}$$

Using equation (1) and the assumptions given above, you can find the tipping angle. By plugging in 13 inches for A and 30 inches for B in the equation above, you will find the wheelchair has a tipping angle of 23.43°

$$Tipping\ Height = \ Sin\theta \times 2A \tag{2}$$

Using the answer from equation (1) of 23.43° and plugging in 13 inches for A in equation (2), you will find the tipping height for the wheelchair is 10.34 inches. These values are important to the overall safety of the user because it shows anybody who sits in the chair just how far they can push the limits before tipping the chair over.

7.0 CAD Model of Final Design

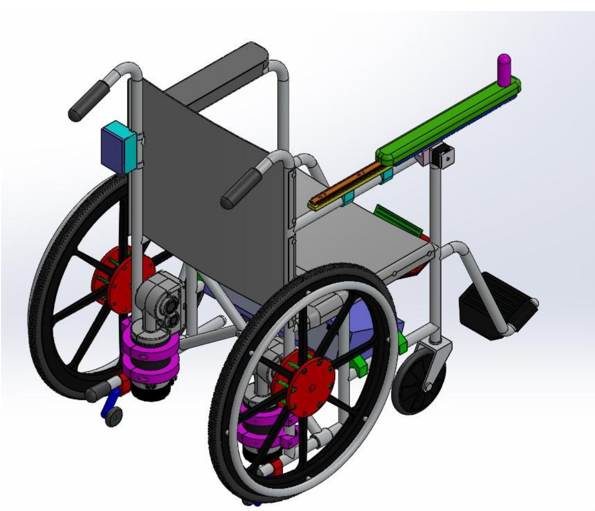


Image 7.0.1 - *3D Model*

The main components shown in the CAD model consist of the speed controller, the arm modification, the foot pedal, and the modification of the wheels and frame to allow for an input shaft from a motor and a carriage for the batteries. Each part was made to easily attach and be removed from the frame. The parts were also designed with the consideration that they would need to adapt to multiple wheelchairs, allowing their design to be flexible. All parts were also made to be as efficient as possible when regarding price and compatibility alike, and all objectives when selecting the design were also considered.

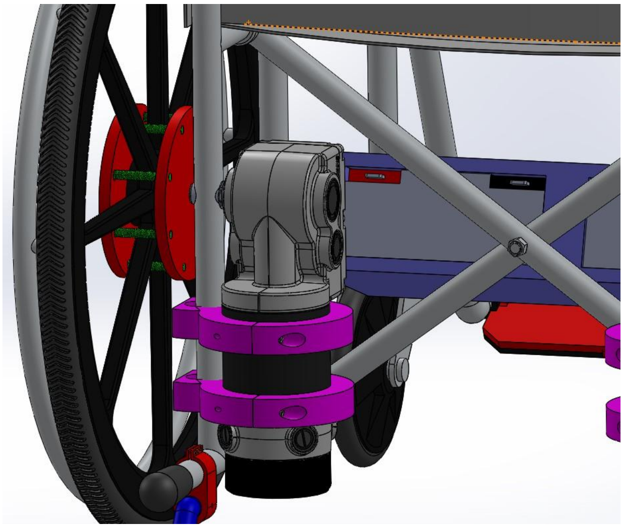


Image 7.0.2 - *Wheel Attachment*

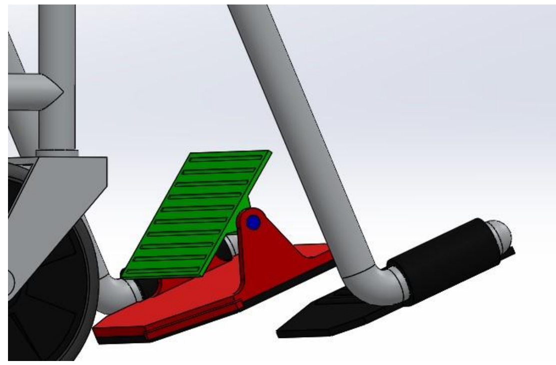


Image 7.0.3 - *Foot Pedal*

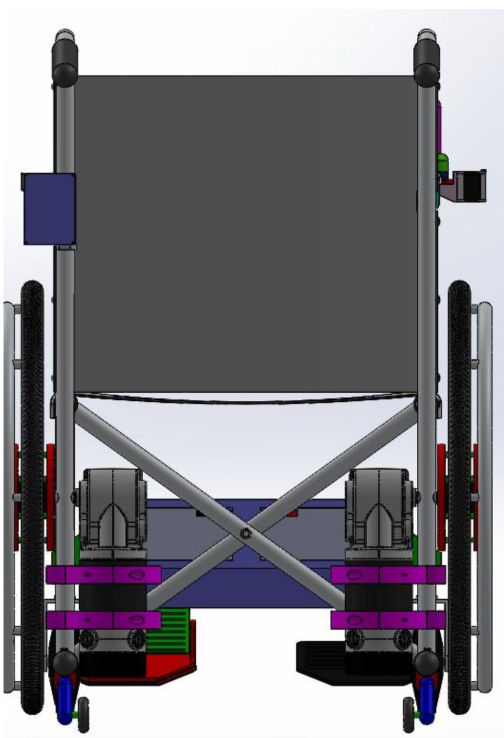


Image 7.0.4 - *Backside of Design*

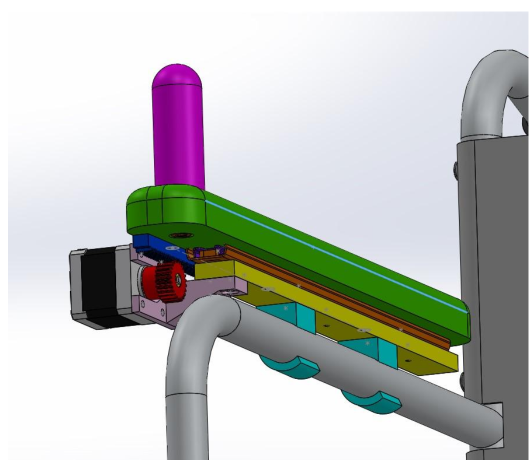
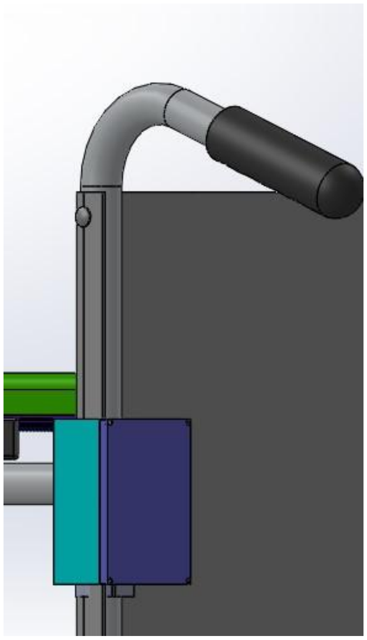


Image 7.0.5 - *Arm Modifications*



The arm modification will contain the methods of rehabilitation expected to be used by the user. It will also allow the patient to modify it to their individual needs through the means of making rehabilitation either increasingly or less intense. The foot pedal is required to allow for turning the wheelchair in the case that a patient's entire body was affected by the stroke they suffered. It will also easily adapt to both feet, accommodating the right and left sides of the patient. The speed controller is also included within the CAD model, receiving signals from the foot pedal to allow for turning. A connection was also made on the rims of the wheel to allow for a transfer of torque from the motor without the input shaft obstructing the design.

Image 7.0.6 - *Speed Controller*

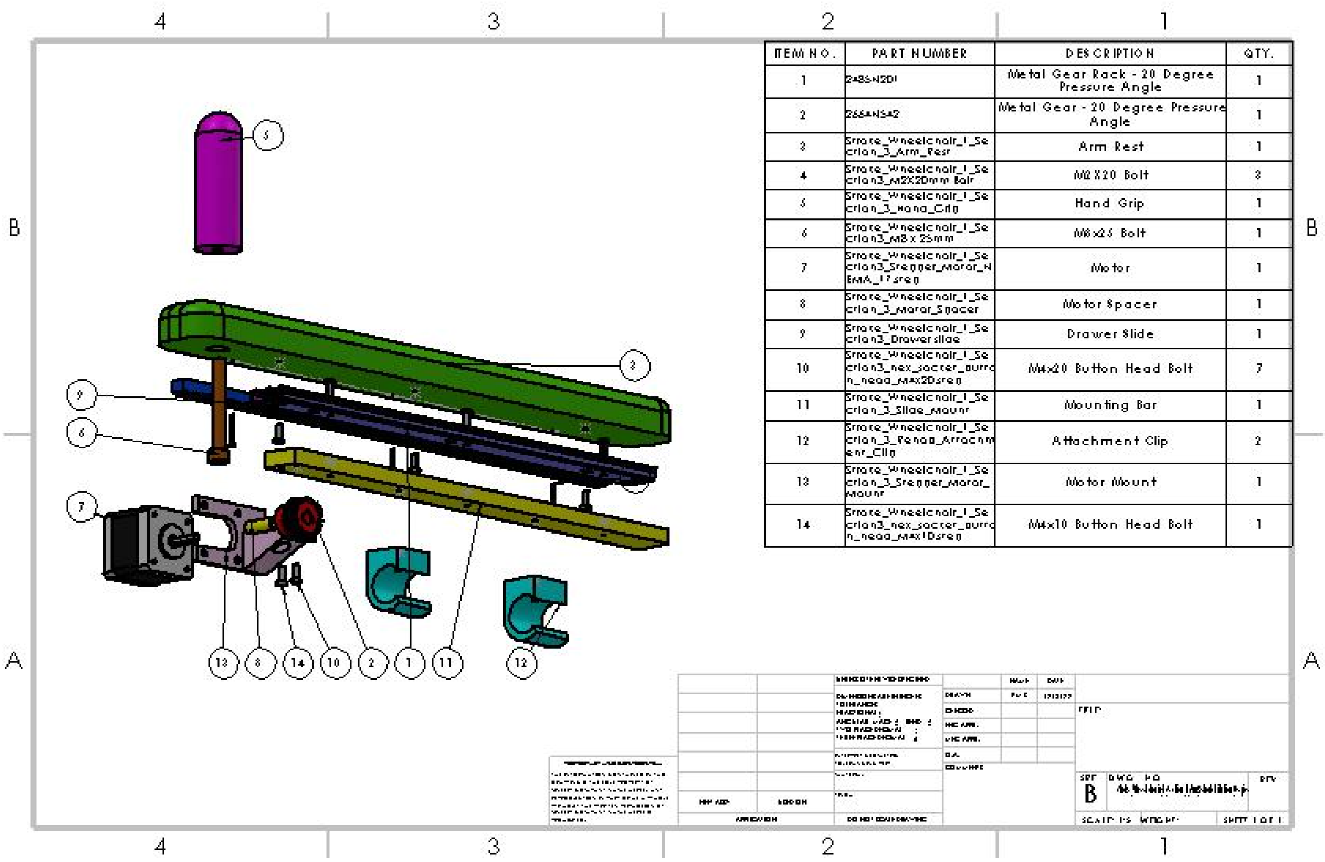


Image 7.0.7 - *Exploded View of Arm Rehabilitation Device*

The exploded view of the arm rehabilitation device shown in ***Image 7.0.6*** includes a bill of materials and provides a detailed view into the assembly of the device. This image shows the simplicity of the design and highlights how easy it will be to assemble the final product.

8.0 Economic Analysis and Justification

In order to create a design for the problem that was presented, the team is going to need money to back it up. In order to get a good estimate of how much money it will cost to complete this project we conducted a cost analysis on the final design given. The cost analysis for this project consists of Time Value Money Calculations, Manufacturing Cost Model, and the Life Cycle Cost Analysis. All of the previously mentioned calculations will be presented in the upcoming sections.

8.1 Time Value Money (TVM)

In order to ensure our approach to the design was reasonable the group used the Present Value Analysis. Below you will find the values used to calculate the Present Value Analysis, all of which were agreed upon within the team.

- Initial Investment: $80,000
  - This is the initial startup loan used by the business constructed by the team. This will be used for production and future business expenses.
- Project Life: 7 Years
  - This is the estimate of the project life. The types of materials used for the wheelchair modifications will be chosen for production.
- Salvage Value: N/A
  - The team plans to make each wheelchair extremely durable, with each part being easily resold aside from parts affected by use over time. The amount reclaimed after a unit is returned is almost maximum due to the flexibility of the team's chosen design, so it will be left out.
- Annual Income: $200,000
  - The business constructed will assume that 50 units per year will be sold at $4000 per unit.
- Annual Payments: $85,000
  - This is the amount including all expenses paid to workers, manufacturing, and testing the design before its finalization of production.
- Annual Interest Rates: 17%

$$P = A * \frac{(1+i)^n - 1}{i(1+i)^n} \tag{1}$$

Using both the values and equation (1) above, the group was able to calculate the Net Present Value in which you will see below.

Annual Income: $200,000 for 18% interest over 9 years.	$676,197.33
Salvage Value: N/A	$0
Annual Payments: $85,000 for 18% interest over 9 years.	-$490,263.78
Initial Investment: $80,000	-$85,000
Net Present Value:	**$100,933.55**

As shown in the calculations above, the design should produce some sort of profit and ultimately should be a successful design for not only ourselves, but for stroke patients as well.

8.2 Manufacturing Cost Model

To ensure the design will be efficiently manufactured, the equation (2) below is used to determine the total manufacturing cost of one unit. The value "n" represents the number of units being made. For our case, this is 50. The value C_m is the cost of materials per unit, while C_l is labor costs. C_w is waste disposal cost, and OH_f is factory costs. The value C_e is the cost of equipment, and C_d is a one-time cost of the design. C_{wr} is a warranty cost, while C_q is the certification of the workers using the machines. Finally, OH_c is the corporate overhead cost.

$$C_{tm} = n(C_m + C_l + C_w + OH_f) + C_e + C_d + C_{wr} + C_q + OH_c \tag{1}$$

Appendix C shows the variables that were used in the equation as well as the values that were plugged into the equation. To summarize:

C_m: The cost of materials for one unit is $1892.61

C_l: The cost of labor for one unit is $1984.66

The above calculations are estimations for the price of both material and labor for one unit. The total between the two brings the grand total to about $3800. This price was quite high and our client (Armin Eilaghi) did not like that, therefore we are in the process of figuring a way to cut costs per unit.

8.3 Life Cycle Cost Analysis

$$C_T = n_p(S_p + C_x + C_O + C_{ps}) + C_{sp} + C_t + C_Q \tag{1}$$

The group wanted to create a product that would hold up well for the consumers who choose to purchase it. In order to do so, the group used the life cycle cost analysis which shows the total cost of the product's lifespan. **Appendix D** shows the variables and values for equation one (1) shown below. Plugging these values into the equation shows the total life cycle cost results below:

S_P: The Price for one unit is $2067.59

C_T: The Price for 50 units is $104,423.46

$$C_{sp} = S_p * f_r * n_p \tag{2}$$

In order to get a true analysis of the life cycle of a product, unforeseen manufacturing problems must be taken into account. The manufacturing problems will be accounted for at an approximated failure rate of 0.01%. This percentage will be multiplied by 50 units as shown in equation two (2) above. This equation will allow the group to be able to determine the cost of spare parts for the desired 50 units. The cost of spare parts can also be found in **Appendix D.** In conclusion, the cost of spare parts for a total of 50 units would be $1033.96.

9.0 Ethics of Design

As stated in the rubric for this section, no engineering project goes without an ethical issue. While our group got along very well and respected one another, there were a couple instances in which we had to make a decision as a team using the NSPE code of ethics[2]. Towards the beginning of the project we had a group member join the group late in hopes they would help with the project. After the first time meeting the group member we never heard from them again. From the NSPE Code of Ethics the group chose to Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession[2]. The group decided to let the client (Armin Eilaghi) know which group member had not done any work since the beginning of the project in hopes there would be an answer for us. Since there was no answer for the group our final decision was to exclude the persons name on any of the work that had been completed up to that point and if they decided to join the class again we would allow them to be in the group. Interestingly enough the second scenario happens to be the exact same. A group of six turned out to be a group of four by the end of the semester. After we had finished the first half of the semester and the preliminary presentations we stopped hearing from a second group member. We continue to reach out until this assignment because the group member has done good work in the past and we would like for them to be a part of the final project. Unfortunately we still have not heard from them therefore the same rules apply and unless they reach out and ask to be a part of the group again they will not receive any credit for the work the rest of us have done.

10.0 Conclusion and Future Work

The stroke wheelchair design is very unique and features safety as our top priority. Our team understands that those who will be using our products have had an injury and do not need their form of transportation to provoke another. The stroke wheelchair features many safety features such as a stability wheel to prevent tipping, a speed controller to aid in downhill movement and finally a pedal to aid in steering. While safety is the number one priority, we are dedicated to getting the patient out of that chair and back to their normal selves. In order to do so they need to rehabilitate their injuries. This is why we have added a rehabilitation arm to help propel them when they are too weak to do it on their own. This will allow the patient/client to get a form of rehab during their everyday movements in hopes they can get out of the chair sooner. Looking ahead the group will need to come up with a reasonable way to rehabilitate the legs without it being a nuisance to the world around them. Lastly, coming up with a better way to break so the patient does not have to think twice about doing so. We are very excited to see what the future has in store for the stroke wheelchair.

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[7] Gene Quinn Gene Quinn is a patent attorney and a leading commentator on patent law and innovation policy. Mr. Quinn has twice been named one of the top 50 most influential people [...see more], “The cost of obtaining a patent in the US - ipwatchdog.com: Patents & Intellectual Property Law,” *IPWatchdog.com | Patents & Intellectual Property Law*, 27-Nov-2018. [Online]. Available: https://ipwatchdog.com/2015/04/04/the-cost-of-obtaining-a-patent-in-the-us/id=56485/. [Accessed: 06-Nov-2022].

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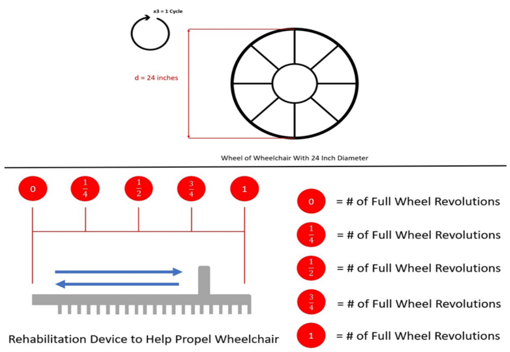
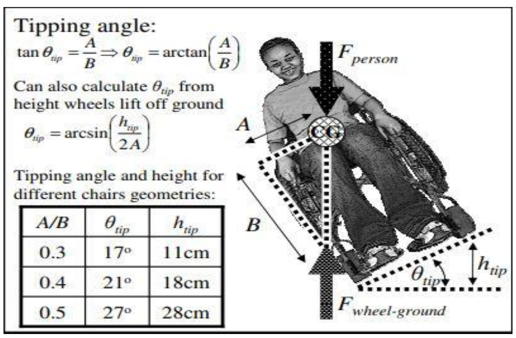
Appendices

Appendix A- Analysis of Rehabilitation



Appendix A shows the analysis of rehabilitation and how the rehabilitation device converts cycles to wheel revolutions.

Appendix B- Analysis of Stability



Appendix B shows the analysis of wheelchair stability as well as the tipping angle and height for different chairs.

Appendix C - Manufacturing Cost Model

Variables	Values
n	50 units
C_m	$1892.61
C_l	$1984.66
C_w	$300
OH_f	Neglected due to amount of units
C_e	Neglected due to amount of units
C_d	$2500
C_{wr}	$10
C_q	Neglected due to amount of units
OH_c	Neglected due to amount of units

Appendix C gives the cost for manufacturing one unit

Appendix D- Life Cycle Analysis

Variable	Description	Value
C_T	Total Life Cycle Cost	$104423.46
n_p	Number of Units	50
S_p	Price per Unit	$2067.59
C_X	Product Related Taxes	N/A
C_O	Cost of Operation per Unit	$0.2
C_{PS}	Warranty per Unit	N/A
C_{SP}	Cost of Spare Parts for n_p Units	$1033.96
C_t	Cost of Operator Training	N/A
C_q	Cost of Certification	N/A

Appendix D gives the cost for the entirety of one unit's life as well as 50 units life.

Appendix E - Bill of Materials

Item #	Item	Item Description	Vendor	Quantity	Costs ($)	Total Cost Per Pair of Units ($)	Website
1	Base Wheelchair	Base wheelchair in which we will add to	VitalityMedical	1	$187.93	$187.93	Link
2	Duracell 12v 20Ah Battery	Battery to power assisted wheelchair	BatteriesPlus	2	$99.99	$199.98	Link
3	Gear Rack						
3.1	Gear Rack	Used for muscle rehabilitation	McMaster-Carr	1	$56.86	$56.86	Link
3.2	Pinion Gear	Used for muscle rehabilitation	McMaster-Carr	1	$25.16	$25.16	Link
4	Arduino UNO	Electronics Controller	Arduino Store	1	$27.60	$27.60	Link
5	Motors						
5.1	Gear Rack Stepper Motor (NEMA 17)	Motor for arm rehabilitation	Adafruit	1	$14.00	$14.00	Link
5.2	In-Line Assistive Motor	Motor for assistive motion	ElectroCraft	2	$552.00	$1,104.00	Link
6	Stability Wheels	Stability wheels ensuring no tipping	VitalityMedical	1 (Pack of 2)	$14.21	$14.21	Link
7	Nuts						
7.1	1/4-20 Nut	Mounting and adjusting	Ocelco	8	$0.66	$5.28	Link
7.2	7/16-14 Nut	High-loading mounting	Ocelco	4	$0.25	$1.00	Link
7.3	1/2-13 Nut	High-loading mounting	Ocelco	5	$0.84	$4.20	Link
8	Bolts						
8.1	1/4-20 x 3" Bolt	Mounting and adjusting	Ocelco	4	$0.63	$2.52	Link
8.2	7/16-14 x 4" Bolt	High-loading mounting	Ocelco	4	$1.03	$4.12	Link
8.3	1/2-13 x 3.75" Bolt	High-loading mounting	Ocelco	5	$1.57	$7.85	Link
9	Steering Pedal	Changing the direction the wheelchair turns	Ebay	1	249.99	249.99	Link
10	Wire						
10.2	#12 AWG Wire	To wire the respective electronic components (High Current)	K.L.Jack	1	$34.95	$34.95	Link
10.3	#24 AWG Wire	To wire the respective electronic components (Low Current)	K.L.Jack	1	$34.95	$34.95	Link
11	Aluminum Stock (For Motor - Wheel Adapter)	Connects the motor to the wheel	McMaster-Carr	1	$92.99	$92.99	Link
12	Arm Rest/Grip	Allows the user to hold on to the rehabilitation slider	ArthritisSupply	1	$12.95	$12.95	Link
With Chair						**$2,080.54**	
Without Chair						**$1,892.61**	

Appendix E is the Bill of materials. The BOM shows all of the parts used in one unit as well as the price