FMC Wheelchair Team

Final Proposal

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DISCLAIMER

EXECUTIVE SUMMARY

Our Capstone project is to design an improved wheelchair based on existing designs. Based on the existing product, we decided to put our focus on the brake performance of the wheelchair, the comfort degree of the calf support, the folding and telescoping leg support and the damper mechanism of the wheelchair. Every member took the responsibility on their own part and then shared their research to the whole team. We used brainstorming to come up with all kinds of possible solutions and then used scientific methods such as Morph Matrix to get our initial design, finally we used decision matrix to select the top designs of them. After that, we started to add our new ideas to the existing wheelchair design by CAD.

Our improved wheelchair design introduced a handbrake device at the handle and beside the seat to replace the original design of stopping the wheels by hand to facilitate people in wheelchairs and strollers. Besides, we decided to use a calf pad as our calf support. The calf pad is adjustable along the leg support to satisfy everyone's requirement. The calf pads are fixed by fasteners when the leg supports are moved up and down and folded so as not to shake. In our design, we realize to put the leg supports under the wheelchair by folding and telescoping. We also use rotary damper design to achieve the stable up and down movement of the leg rests to ensure that the wheelchair user will not suffer secondary injuries.

Figure 1

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1 BACKGROUND

1.1 Introduction

Our project: FMC Enhanced Wheelchair is asked to improve the wheelchair based on our client's requirements and current existing designs.Our project aims to solve three main contemporary problems. First of all,improving brakes for wheelchairs.[1]Secondly, it aims to fold the leg support under the wheelchair to save space when no one uses the wheelchair.[2]Thirdly, we try to design a controlled leg support. The leg support can be raised or lowered slowly and steadily, which can prevent patient's legs from being injured again due to the rapid fall of the leg support.[3] The success of this project is crucial because It can provide convenience for people in wheelchairs and people pushing wheelchairs behind. Besides, it can improve user experience and increase safety.

Differing from our initial design introduction,we removed the anti-theft design because the anti-theft design was not cost-effective and could not be fully realized for practical reasons.

1.2 Project Description

Following is the original project description: " We want to have a FMC Enhanced Wheelchair which has folding leg supports permanently attached to the wheelchair and provides more safety in the details."

2 REQUIREMENTS

This part of the report is showing the team's new CRS and ERS based on client's requirements, the team's design of the product has changed, which is directly reflected in the black box model and function model, and specifically reflected in QFD.

2.1 Customer Requirements (CRs)

Customer Needs	Customer Weights
High safety	5
Comfort	4
Low cost	4.5
Easily cleaned	3.5
Long durablity	4
Good adustability	4.5
Slowdown effect	4.5
Light weight	4

Figure 2.1

The customer needs is shown in figure 2.1, because wheelchairs are provided to patients with mobility impairments, their safety occupies the highest weight, and the adjustability of leg support occupies the second highest weight (4.5), because the client's requirement is that the leg pads need to be removable and both horizontal and vertical Can move freely. Of course, price is also a factor that consumers must consider, so price also has the second highest weight (4.5). After discussion with the sponsor, the team also set its weight ratio at 4.5.

The change made by the team is to add slowdown performance to customer needs, because when the patient uses a wheelchair to pass a steeper slope, the brake performance needs to be considered. So the team positions it as 4.5.

2.2 Engineering Requirements (ERs)

Engineering Requirements							
Weight	Selling price	Wheelchair Torque	Friction force when braking	Size(length*width*height)	Maintenance fees	Fault tolerance	
3		9	9	3			
			3			3	
3	9	3			9		
				1		9	
		3	9		9		
						9	
9	3		9		3		
N	$	N*m	N	mm^3	$	%	Technical Requirement Units
175	500	14.83	211	1132*680*980	125	0.02	Technical Requirement Targets
64.5	52.5	70.5	129	18.5	88.5	84	Absolute Engineering Requirements
6	5	4	1	7	2	3	Relative Engineering Requirements

Figure 2.2

Figure 2.2 shows the engineering needs of the team project, According to the specific requirements of the client and the defined customer requirements, the team defines the following engineering requirements and measurement units. The engineering requirements and Units of measurement are the following: Weight of wheelchair (N), selling price ($), friction force (N), size (mm^3), maintenance fee ($), fault tolerance (%). The technical requirements values and absolute engineering requirements are shown in this figure, Weight: (125N), selling price ($200), maintenance fee ($88.5), tolerance for fault (0.02%).

According to the professor's suggestion, the team replaced the electromagnet with a disc brake. Therefore, the Engineering requirement has also changed: the power of the electromagnet has been replaced with the torque provided by the brake disc to the wheelchair when braking. The technical requirements value for torque is 14.83 N*m. Samely, the magnitude of ideal friction force when disc brake working is (211N)

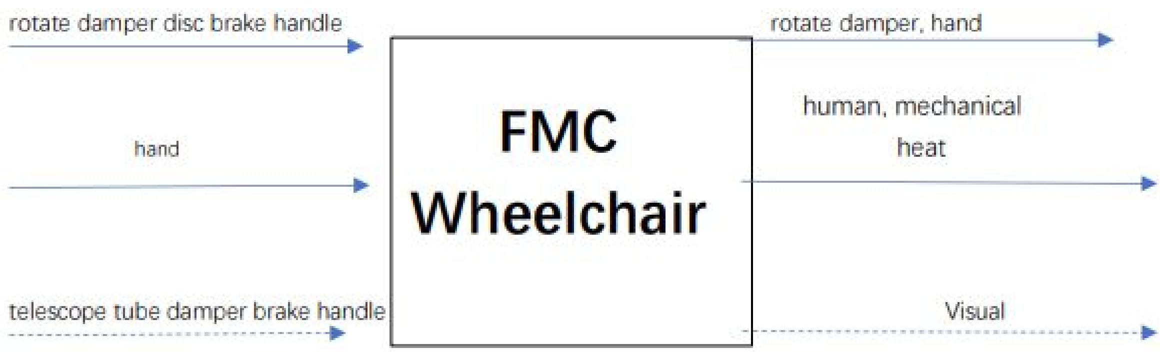
2.3 Functional Decomposition

This part of the report reflected the black box model and functional model after the team has improved the project. They are based on client and customer suggestions.

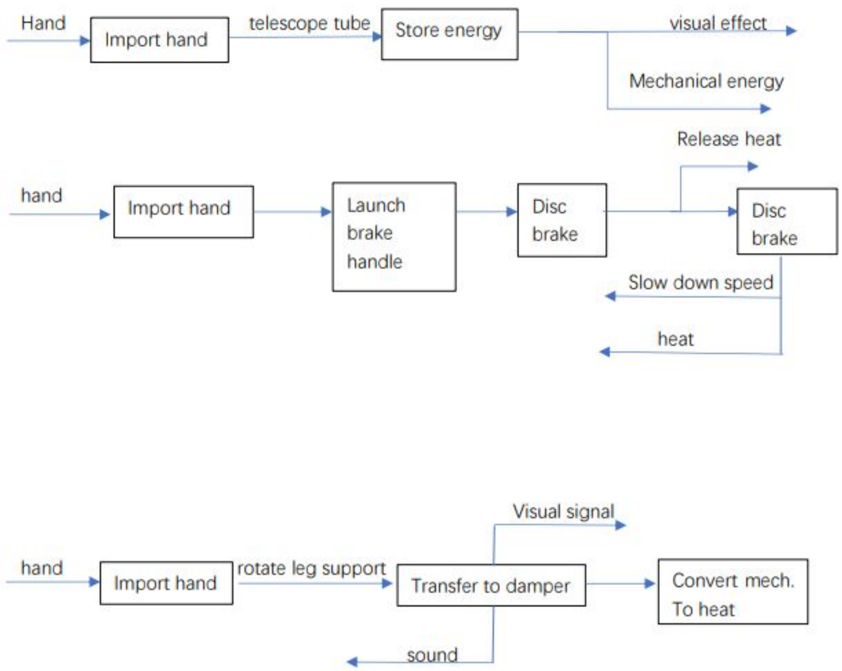
2.3.1 Black Box Model

This part is the black box model diagram of the team, which reflects the output mode and energy signal of the project equipment. Since the team changed the electromagnetic brake system to the brake disc system, the original electrical signal was changed to manual input, and the output power was due to braking The presence of the disc is converted into heat energy.

The new Black Box Model can help us figure out the team’s thinking when designing the new wheelchair, such as clarifying the change from the electromagnetic brake system to the brake disc system, knowing the energy conversion process, and the material of the brake disc.



2.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis



The team made some changes to the original model based on the professor's suggestion, mainly to provide telescopic ducts at the joints of the leg frames, so that there is enough space under the wheelchair seat for the leg frames to fold in. The second point is to replace the electromagnetic brake system with a more feasible disc brake system. The two improvements are done by manpower, and the output energy is changed from the original electric energy to the heat energy released by the brake disc during friction.

The new function model can help team members improve the existing wheelchairs more conveniently based on the energy output relationship

2.4 House of Quality (HoQ)

		Engineering Requirements							
Customer Needs	Customer Weights	Weight	Selling price	Wheelchair Torque	Friction force when braking	Size(length*width*height)	Maintenance fees	Fault tolerance	
High safety	5	3		9	9	3			
Comfort	4				3			3	
Low cost	4.5	3	9	3			9		
Easily cleaned	3.5					1		9	
Long durablity	4			3	9		9		
Good adustability	4.5							9	
Slowdown effect	4.5								
Light weight	4	9	3		9		3		
Technical Requirement Units		N	$	N*m	N	mm^3	$	%	Technical Requirement Units
Technical Requirement Targets		175	500	14.83	211	1132*680*980	125	0.02	Technical Requirement Targets
Absolute Engineering Requirements		64.5	52.5	70.5	129	18.5	88.5	84	Absolute Engineering Requirements
Relative Engineering Requirements		6	5	4	1	7	2	3	Relative Engineering Requirements

Figure 2.4

Table 2.3 is the QFD designed by the team, which shows the customer needs and engineering needs of the team project, giving the weight ratio of different customer needs and the Technical Requirement Units, Technical Requirement Targets, Absolute Engineering Requirements and Relative Engineering Requirements. Through calculation and analysis, the team came to Three Most Important ERs: 1：Friction force when braking (N), 2: Maintenance fees($) 3:Fault tolerance (%)

2.5 Standards, Codes, and Regulations

Standards are documents created by professional and/or government organizations that contain technical definitions, specifications and guidelines to ensure the consistency, safety, and quality of materials, products, processes, and services.

The use of standards is voluntary, but it is encouraged to promote interchangeability between companies and support international trade.

The regulations establish mandatory legal requirements. They are implemented by different levels of government and regulatory agencies, such as federal or state agencies and municipalities, and incorporate standards created by the agency or standard setting organization. Regulations refer to specific standards as a method of meeting requirements.

Standards and codes come from many organizations and societies. Examples of those that most directly apply to Mechanical Engineering projects include (but are not limited to):

- Aluminum Association (AA)
- American Gear Manufacturers Association (AGMA)
- American Iron and Steel Institute (AISI)
- American National Standards Institute (ANSI)
- American Society of Mechanical Engineering (ASME)
- American Society of Testing and Materials (ASTM)
- American Welding Society (AWS)
- American Bearing Manufacturers Association (ABMA)
- Industrial Fasteners Institute (IFI)
- Institute of Electrical and Electronics Engineers (IEEE)
- International Standards Organization (ISO)
- National Institute for Standards and Technology (NIST)
- Society of Automotive Engineers (SAE)

For NAU's engineering library resource on standards and codes, visit: https://libraryguides.nau.edu/engineering386/patents-etc

Table X: Standards of Practice as Applied to this Project

Standard Number or Code	**Title of Standard**	**How it applies to Project**
ANSI / RESNA 331317	Aluminum rolling, drawing, extruding and alloying	Durability and material fatigue test of wheelchairs made of this material
ANSI / AGMA 1010-F14	Appearance of Gear Teeth - Terminology of Wear and Failure	Provides information that in many cases enables users to identify failure modes and evaluate the extent or changes from the original conditions.
ASTM F2527-16	Standard Specification for Seamless, Welded, and Drawn Cobalt Alloy Small Diameter Tubes for Surgical Implants	This specification addresses those product variables that distinguish small-diameter medical tubing from the bar, wire, sheet, and strip product forms covered in this specification.
ASME Y14.5-2018	Dimensions and tolerances	This standard specifies the symbols, rules, definitions, requirements, default values and recommended practices used in engineering drawings, models defined in digital data files and related documents. It specifies the dimensions used to interpret engineering drawings and digital data files. Tolerances and related requirements.

3 Testing Procedures (TPs)

A test method is a method used in the science or engineering of tests, such as physical experiments, chemical experiments, or statistical tests. This is the definitive procedure for producing test results. To ensure accurate and relevant test results, the test method should be "clear, clear and experimentally feasible.", as well as effective and reproducible.

Think of a test as an observation or experiment that determines one or more characteristics of a given sample, product, process, or service. The purpose of testing includes determining the expected observations in advance and comparing them with actual observations. The results of the test can be qualitative (yes/no), quantitative (measured value) or categorized, and can be derived from personal observation or the output of precision measuring instruments.

Usually, the test result is the dependent variable, which is the response measured according to the specific conditions of the test or the level of the independent variable.

3.1 Testing Procedure 1: Wheelchair caster test

Wheelchair casters often fail, causing physical, social and economic consequences for wheelchair users. Despite the establishment of wheelchair testing methods and regulations, these failures still occur, indicating that existing tests may not be sufficient to screen poorly designed casters. In order to study this topic, we can study the impact of impact exposure on the durability of casters. Research on corrosion and wear exposure data, and then draw conclusions that affect the causes of caster failure.

3.1.1 Testing Procedure 1: Objective

Wheelchairs are known to cause negative consequences for users in time [frequent failures in a short period of time. In the United States, Scotland, Kenya, India and Mexico carried out community-based data collection and maintenance research reports from a few weeks of failure and two-year wheelchair usage with casters, brakes, seat components and tires. Failure will bring serious adverse consequences, such as user injury or detention. For example, a fractured castor bean bolt can cause the wheelchair to overturn and the user falls into the wheelchair, which is the most common wheelchair injury. Delayed maintenance can lead to failures, which may not be resolved due to lack of maintenance and repair services, parts replacement, and lack of skilled labor. Without a functional wheelchair, the user may have to stay in her bed and/or it is within the confines of her home associated with secondary health complications. Therefore, product failures can lead to lower user satisfaction and lower quality of life.

In order to improve the quality of casters and wheelchairs as a whole, we can test the effects of corrosion and wear on the casters, find out the reasons and solve the problems.

The reason for exposure to shocks is due to bumps, containment, and drops that cause the casters to suddenly bear loads. Generally, the yielding part due to sudden impact is failure caused by impact or fatigue fracture after repeated fluctuating load. In this study, an accelerometer mounted on a frame near the casters was used to measure the impact of the wheelchair casters.

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Corrosion is caused by the electrochemical reaction of the metal with the environment, which causes the metal to oxidize, thereby damaging the surface, causing cracks to form and reducing the strength of the material.

Tire wear is caused by friction between the tire and the ground during rolling and sliding contact, which leads to loss of tire material and tread. In this study, the measurement of wear is the change in the outer diameter of the tire over a specified time interval.

3.1.2 Testing Procedure 1: Resources Required

For the impact test, we will use different wheelchair models with accelerometers, and select 400Hz sampling rate as the fastest sampling rate available for low-cost portable sensors in different road conditions such as grass, gravel roads and testing. These low cost sensors can record data within a few days in the field without adding weight or ropes to the wheelchair. The sampling rate is suitable to prevent aliasing and is fixed above the caster hub.

For corrosion testing, prepare several different outdoor steels. Corrosion tests are carried out in the laboratory. The standard recommends the use of salt spray equipment and corrosion assessment procedures. If physical experiments are not possible, virtual experiments can be used. An experiment with a mass loss test panel was subsequently performed to determine the amount of corrosion seen in the salt spray over time. According to the results, the corrosion rate in the salt spray was calculated and correlated with the outdoor corrosion rate.

For the wear test, samples of failed tires of three wheelchair models were collected. Take it as a benchmark for wear exposure. The service life of casters is recorded in months. The difference between the outer diameter of the old caster and the newscaster was measured at three different points on the periphery of the tire to calculate the annual wear of the caster. Use sandpaper to simulate rough surfaces in the caster test. Obstacle patterns found using the impact verification method evaluated different particle sizes.

3.1.3 Testing Procedure 1: Schedule

This process could last a long time. It is mentioned before that corrosion and wear tests will last months. However, the team just needed to make measurements about the initial values and compared it with final results. Team scheduled to do the test once we figured out the model of casters.

3.2 Testing Procedure 2: Advanced leg support lifespan test

3.2.1 Testing Procedure 2: Objective

Our client gave us the main concerns and risks, as we discussed before, the problem that leg support may suffer free fall is solved by applying a rotary damper on the connection part. However, the advanced leg support may not meet the engineering requirements of fault tolerance, which is 1 in 5000. How many times that the ratchet joints with dampers may rotate is still a question.

3.2.2 Testing Procedure 2: Resources Required

Team needs to test the lifespan of the dampers in the future. The test procedure could be accomplished by two steps. One step is weighing the maximum torque that it could withstand by adding weight until connection breaks. Another step is fatigue testing, material under cyclic loads will suffer damage and failure. Team could figure out the lifespan by doing such tests. Both the testing procedures could be done in the NAU engineering lab room. Team needs to bring a sample of leg support and do the test.

3.2.3 Testing Procedure 2: Schedule

This testing procedure will not cost the team too much time. Team could contact relative workers in the engineering building to test the leg support. In the testing process, the estimated weight and torque that leg support can withstand can be acquired. Besides, the team could get the expected lifespan of ratchet joints. Team could do this test at the beginning of next semester. Our main goal at this time is to figure out the perfect ratchet joints with a damper.

4 DESIGN SELECTED – First Semester

During the whole semester's work, the team finally came up with the final design. Some essential changes were born to make the product more creative and satisfactory for clients. The idea of rotary joints with a damper was brought up to help make the product more controllable. Telescoping mechanism leg support was a more comfortable version compared to the preliminary model etc. A Gantt chart is also come up with by team to make everyone’s future work more clearly. Team could finish their work according to the schedule.

4.1 Design Description

At the end of semester, we made more changes to perfect the wheelchair in the actual function. Overall, this wheelchair has the length of 1132mm, width of 680mm and height of 980mm. The weight of it is 165N. Here is the final design. As it is shown in Appendix A.

Compared to preliminary design, we made some modifications to the design according to the customer's requirements. First of all, for the sake of patient safety, we designed two brake systems, both of which are similar to bicycle brake systems. One is for wheelchair users and the other is for patients. For wheelchair transport, we redesigned Leg Support into a four-segment format, consisting of two outer tubes and two inner tubes. This allows Leg Support to flex and flex freely and fold down in the middle. Previously, we joints were not taken into consideration. We did improve it by using ratchet joints with a damper. Such improvements could allow certain angles of movement and ensure the soft motion of leg support. Here is some detailed explanation of the latest changes:

- Here is our brake system visual. There is a handbrake device at the handle and beside the seat respectively to replace the original design of stopping the wheels by hands to facilitate people in wheelchairs and people pushing the wheelchairs.

$$\tau\text{(torque)} = 15\text{N*m}$$

$$r \text{ (radius for wheel)} = 0.5\text{m}$$

$$\frac{\tau}{r} = f = \frac{15N * m}{0.5m} = 30N$$

$$\text{K (Leverage ratio)} = 7$$

$$\frac{k\tau}{r} = 210N$$

$$\text{a (acceleration)} = \frac{v2 - v1}{\Delta s} = \frac{\frac{1.5m}{s} - \frac{0.42m}{s}}{0.08s} = 13.5\frac{m}{s^2}$$

$$\text{F(friction)} = \text{m*a} = 15.6\text{kg*}13.5\frac{m}{s^2} = 210.6\text{N}$$

$$\text{By check } 210\text{N} \approx 210.6\text{N}$$

Then it is our computational proof about how we get our detailed value of friction force combining the torque and weight.

So, through our computational proof and necessary checks, we make sure that our design can proceed successfully. Besides, in our CAD model, we do design an adjustable calf pad to meet everyone's comfort, telescoping leg support which can be put under the wheelchair and a rotary damper design to achieve the stable up and down movement of the leg supports to ensure safety.

- Figure 4.11 is the Cad model of ratchet joints with damper, team made the leg support adjustable by modifying simple damper to ratchet joints with damper, leg support would not only fall down smoothly and softly, but also could be moved to certain angle.

FIgure 4.11 ratchet joints with damper

- We also improved telescoping mechanism leg support. which is shown in figure 4.13. This can be able to flex the length of leg support, make patients comfortable. Besides, it will be easier to attach calf pad and foot panels with lighter weight.

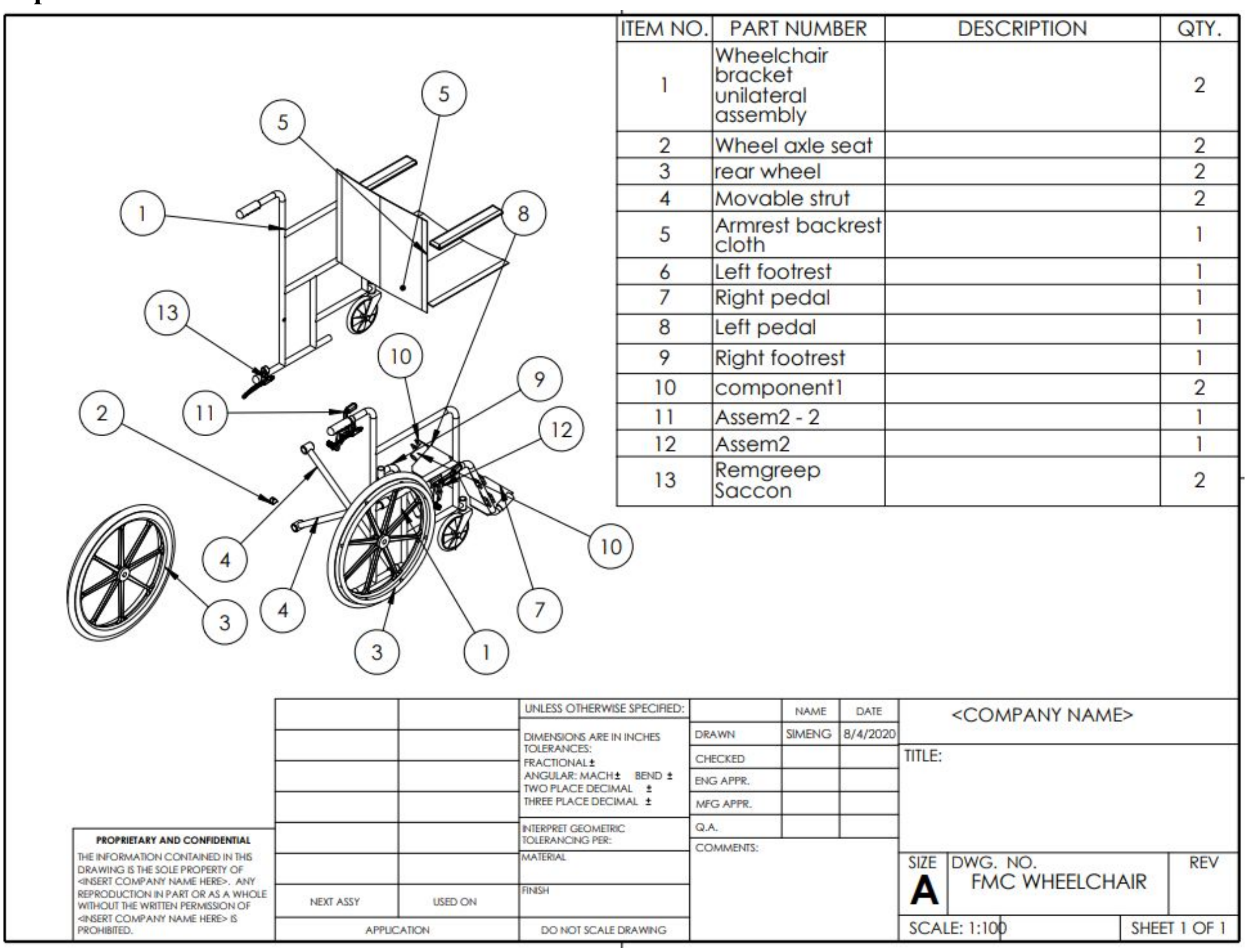
FIgure 4.13 telescoping mechanism leg support

4.2 Implementation Plan

However, in our current design, we have a lot of details to be improved. We still need to do a lot of tests to justify our function model.We plan to improve our design in several aspects. To briefly show what we need to do, we made a BOM to describe it. In this graph it includes a detailed breakdown of all resources needed to implement the chosen design: information, people, materials, facilities.

small-scale prototype cost summary					
Part Name	Number	Price per part($)	Total Price($)	Responsbility	Source
Leg Support	2	59.99	119.98	Haoran	https://www.engineeringtoolbox.cor
Anti-theft system	1	149.99	149.99	Simen	https://www.engineeringtoolbox.cor
Disc Brake	2	79.99	159.98	Simen	https://www.engineeringtoolbox.cor
Dampers for rotary joints	4	73	292	Zhenkai	https://www.engineeringtoolbox.cor
Calf support	2	51	102	Jialan	https://www.engineeringtoolbox.cor
Leg support attachment	2	19.99	39.98	Zhenkai	
Normal wheelchair	1	Hospital Donated	0	hospital	
Workoing and designing time	5	1000	5000		
Total cost			5863.93		

Exploded view of the CAD Model



Gantt Chart

In order to accomplish this plan we made a gantt chart to schedule our future plan in the next semester. A Gantt chart is created to ensure the division of specific tasks to different people, communicating responsibilities clearly and managing time to keep everything within the time table. It is shown that all team members will do their fair share of work. To conclude,the Gantt Chart is a very useful tool to organize tasks. Our Gantt Chart for next semester is in Appendix B.

5 CONCLUSIONS

During this summer semester, we did a lot of work to figure out what we need to improve to FMC wheelchair, we did a lot of research on each separate part. We also search in the market in order to compare our design to formal design. In this report, we clarify the background information and requirements for customers and Engineering. We also design some testing procedures to find out shortcomings in our model. Finally, we discuss our design selected process to show our thinking about the project. Finally, our model is equipped with all the necessary things we want to add in the wheelchair.

This project aims to improve brakes for wheelchairs.Secondly, it aims to fold the leg support under the wheelchair to save space when no one uses the wheelchair.Thirdly, we try to design a controlled leg support. These aspects are not common in some cheap medical wheelchairs.The critical requirement for the wheelchair should be safety. To begin with, our new design should not be too complex other than it can put patients in potential danger. Secondly, we intend to improve its safety based on the original design.

Our final solution for the project has included all the points that we post at the very beginning. First of all, for the sake of patient safety, we designed two brake systems, one is for wheelchair users and the other is for patients. For wheelchair transport, we redesigned Leg Support into a four-segment format, consisting of two outer tubes and two inner tubes.[4] Previously, we joints were not taken into consideration. We did improve it by using ratchet joints with a damper.[5] Such improvements could allow certain angles of movement and ensure the soft motion of leg support. So all the design details in our project have shown our care to patients and medical workers.

6 REFERENCES

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7 APPENDICES

7.1 Appendix A: Final design

7.2 Appendix B: Gantt Chart