



# DESIGN OF DURABLE WHEELCHAIR FOOTRESTS

BME Design 200/300

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## Abstract

Wheelchair footrest durability is important for the long-term safety and health of users. Challenges often arise due to the complexity of parts that comes with increased adjustability, as well as manufacturers and patients being constrained by cost and the need for mass-manufacturing. However, footrests may also need to be highly adjustable to suit patient needs. With repeated, significant applied forces, the adjustable footrest components may experience wear or even complete failure in addition to other non-adjustable parts. For this project, novel wheelchair footrests were designed which feature reinforcements to the frame with a locking mechanism and decreased joint complexity in order to increase durability.

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## 1. Introduction

### 1.1 Motivation

Wheelchairs are amongst the most common assistive devices used worldwide, with 3.6 million people aged 15 and older in the United States alone reporting using a wheelchair to assist with mobility in 2010 [1],[2]. Ideally, each chair and its many components should be highly customized to suit the needs of each patient in terms of size, adjustability, support, and safety. This includes the footrests, which encompass the hangers or bars and their connection to the wheelchair frame and to the footplates. If this structure experiences wear or stress, chipping, torsion of the bar or other elements, or even complete failure of certain components and thus the footrest itself, this can pose a safety risk for the patient [3]. Additionally, if the desired footrest configuration is not maintained due to these failures, patient support may be negatively affected [3]. Ideally, wheelchair footrests should be durable long-term and not necessitate excessive maintenance or replacement before the chair is replaced.

### 1.2 Current devices

Mark Hindle currently uses the IRIS™ Manual Tilt Wheelchair manufactured by QUICKIE® Wheelchairs. This chair features an angle adjustable frame in order to change position in space, prevent sores, and support Mark's frame during prolonged sitting. Additionally there are several custom elements to this standard chair, including a custom headrest. Because of the patient's specialized musculoskeletal needs for footrest height adjustability and specific foot angle tilt, the IRIS™ chair also features custom footrests from Freedom Design Incorporated. These metrics are set after evaluation by Mark's medical team, and are adjusted as muscle strength, spasticity, and tension change over the years. The custom footrests provide tailored fit, but have not proven to be durable long-term. There are multiple points of failure with the current footrests, including the locking mechanism, bolts, and lengthening rod, though each of the patient's past footrests have experienced complete failure at some point.

### 1.3 Problem Statement

Current wheelchair footrests are not typically built to withstand repeated, significant applied forces and stresses. Footrests which are mass-manufactured and mass-marketed must suit the needs of a wide range of clients, and thus balance adjustability and durability, while keeping costs accessible. As a result, a given footrest which must be highly adjustable to accommodate musculoskeletal needs is not likely to also be highly durable. Especially in cases where patients with retained muscle leg strength experience seizures, have muscle spasticity, or do not generally have movement control, wear occurs in the footrests over time. This can ultimately lead to failure of the structure. The effects may be exacerbated when feet need to be strapped into the plates for safety, and movement is restricted. Therefore, a more durable foot rest design is needed.

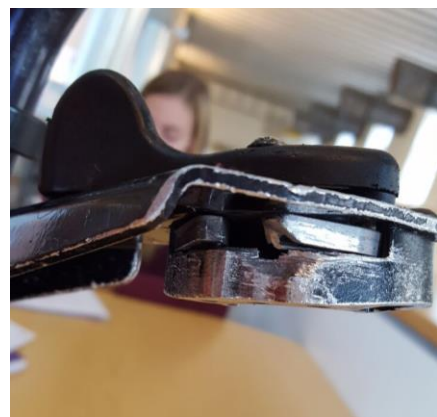


**Figure 1.** Quickie IRIS Wheelchair

Figure 1 shows the generalized version of the wheelchair that Mark currently uses. His particular chair has some adaptations like a modified headrest for his use. Some common points of failure for his past footrests include failure of the locking mechanism, breakage of the footplates, shearing of the connecting bolts, and torsion of the lengthening rod. The current breakage of his footrest locking mechanism is shown in figures 2 and 3.



**Figure 2.** Breaking of Locking Mechanism Pin



**Figure 3.** Wear of Locking Mechanism

## **2. Background**

### 2.1 Medical Information Background

Worldwide 17 million people are afflicted with cerebral palsy. Cerebral palsy is a physical disability which affects movement, muscle coordination, and posture. As of this time, it is a permanent and incurable disease caused by brain damage due to an injury during development. This can happen before birth, during birth or after; however, most occur prior to birth. The condition can frequently be accompanied by difficulty with hearing and vision, seizures, and intellectual disabilities. Spastic cerebral palsy is the most common type of Cerebral Palsy where the person has hypertonia - increased muscle tone that causes muscles to be stiff, weak, or tight[4]. The seizures experienced may cause straightening of the legs, as well as jerking motions.

### 2.2 Client Information

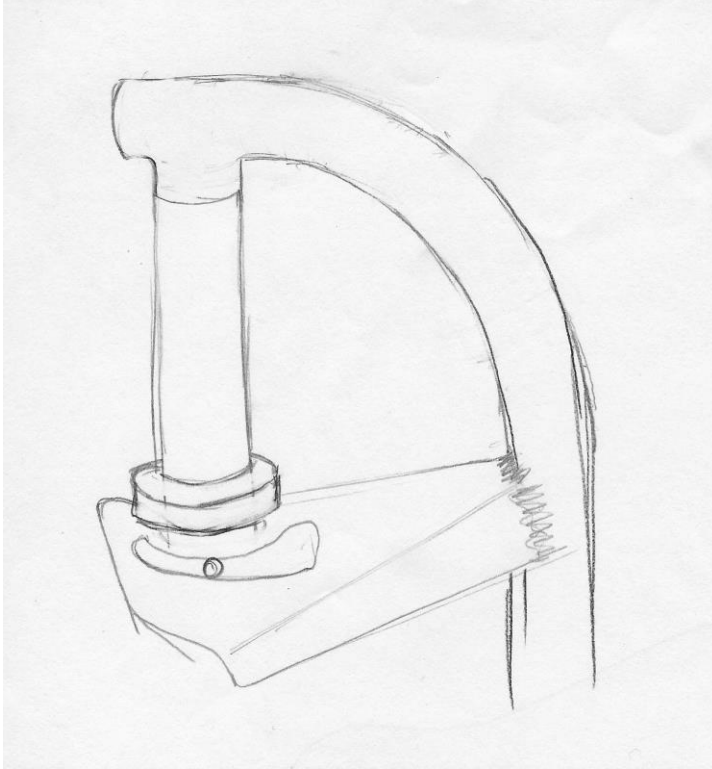
Our client, Andrea Gehling of Avenues to Community, is a case manager for Mark Hindle, the recipient of our product. Mark is a 32 year old male with spastic cerebral palsy and an intellectual disability. Mark uses a wheelchair for transportation, during which his feet are strapped in for safety. Being strapped in helps prevent any injury when the chair is in motion and during his uncontrolled movements. Due to his strength and muscle spasticity along with the forces applied during his seizures, he often breaks the foot rests on his wheelchair.

### 2.3 Design Specifications

Mark's father and primary caretaker, Chris Hindle, focused on creating the most durable footrest possible while maintaining Mark's safety and comfortability. In the past, Chris has had to replace and fix multiple parts so the goal is to make a device that he will not have to fix or replace. He also mentioned that he would like the device able to accommodate the lift and be intuitive for use by a single caregiver. Ideally, this device would still be adjustable in terms of ankle flexion and length to the footplate. In addition, since this device is a long-term solution, it would ideal for the footrest to be transferable to future wheelchairs since Mark gets a new wheelchair every five to eight years. All of this needs to be accomplished within our budget which is currently \$100 but subject to change. Please see the complete Product Design Specifications attached in Appendix A.

## **3. Preliminary Designs**

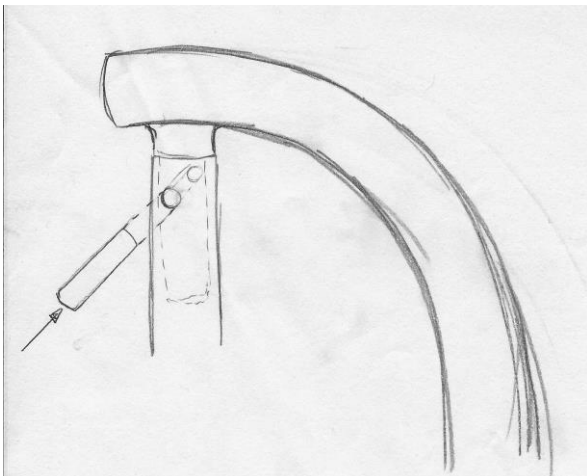
### 3.1 Upper portion/Locking mechanism



**Figure 4.** Current Pin and Flange

### 3.1.1 Current Pin and Flange

The current locking mechanism involves a spring loaded lock that locks into place when it is pressed against a pin located to the side of the frame of the wheelchair. It is unlocked by a lever attached to the footrest. The top of the foot rest sits into the frame of the wheelchair which provides extra support. Design one does not change any of this. A metal flange is built off of the footrest which contains a locking mechanism. The locking mechanism would then attach the footrest to the wheelchair itself. The flange would deflect a portion of the force that is being placed on the current locking mechanism as well as stabilize the footrest. Both the current locking mechanism as well as the additional locking mechanism would unlock when rotation of the footrest is desired.

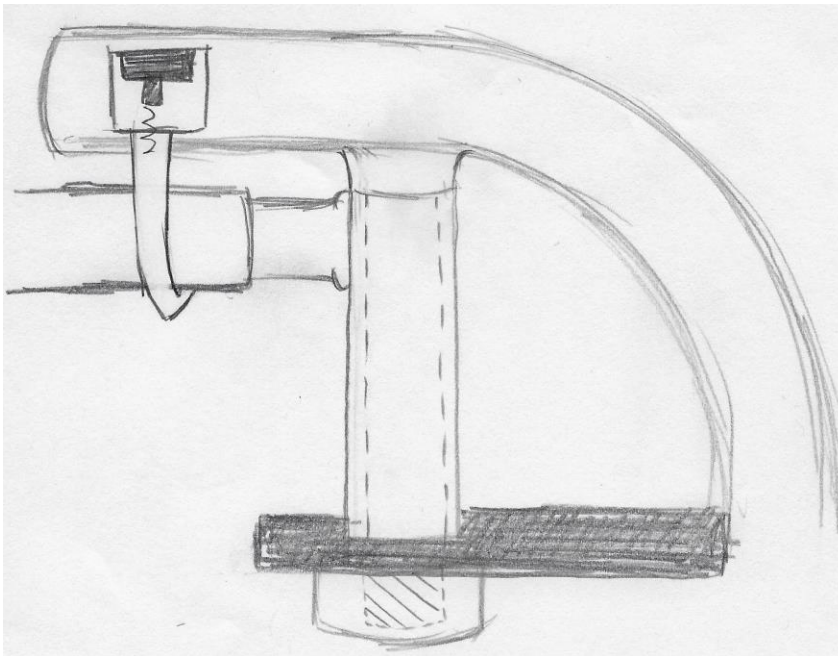


**Figure 5. Hole and Pin Sketch**

**Figure 6. Pin Mechanism**

### 3.1.2 Hole and Pin

This design utilizes the current footrests but bypasses the current locking mechanism. It focuses on the frame of the wheelchair and the footrest extension rod which fits into the frame. A hole is drilled through both the frame of the wheelchair and the footrest extension rod. A pin is then inserted into this hole. The ends of the pin have larger parts than the middle in order to keep the pin in the hole. The ends of the pin can be removed in order to take the pin out. The pin would maintain the position of the footrest extension rod inside of the frame of the wheelchair. This prevents all motion and directs the force entirely on the pin instead of the current locking mechanism. When the pin is removed the footrest extension bar has the ability to rotate freely from its position in the frame of the wheelchair.



**Figure 7. Extended Hanger**

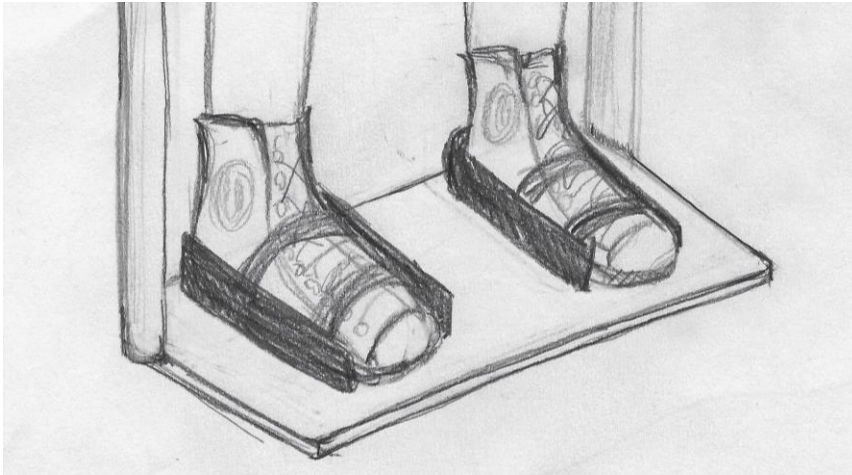
### 3.1.3 Extended Hanger

This design involves the fabrication of completely new footrests. The footrest extension rod is extended to be approximately equal in length to the hollow tube coming off the frame of the wheelchair. This utilizes the stability of the entire hollow tube as opposed to the two to three inches that is currently used. The bottom of the footrest extension rod is threaded and screws into a cap which is also threaded. This would prevent the footrest extension rod from moving up and out of the frame of the wheelchair. The hanger above the footrest extension rod that sits in the frame of the wheelchair would deflect all of the downward vertical force. The hanger of the footrest is extended behind the hollow tube on the frame of the



wheelchair. A locking mechanism built off of the hanger attaches to the frame of the wheelchair behind the hollow tube. This would prevent all rotation while it is locked. When rotation is desired the mechanism can be unlocked and the footrest extension bar can freely rotate inside the frame of the wheelchair.

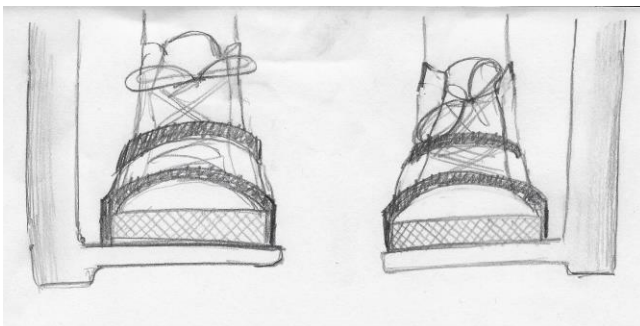
### 3.2 Extension Rod and Footplate



**Figure 8.** Solid Bar With One Footplate

#### 3.2.1 Solid Bar, One Footplate

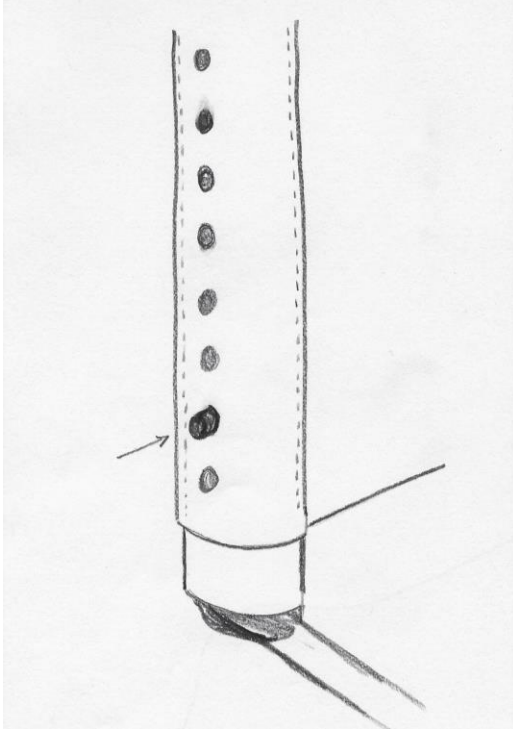
This design is one footplate that is connected to the frame of the wheelchair by two solid bars. The footplate is a solid metal plate with bindings on the top that the client's feet are strapped into. The solid footplate reduces the centripetal force of two separate feet moving in different directions by keeping them connected. The solid bar does not contain connecting bolts and thus limits points of failures. Due to the fact that connection points are limited in both the footplate and the extension bar, the design is significantly durable. The footplate cannot be rotated outwards and must be removed completely in order to access the space directly in front of the wheelchair.



**Figure 9.** Solid Bar with Two Footplates

#### 3.2.2 Solid Bar, Two Footplates

The design shown in Figure 9 is made up of two individual footplates connected to the frame of the wheelchair by solid bars. The footplates contain bindings that the client's feet are strapped into. The individual footplates along with the solid bar are built to sustain forces in all directions. The solid bar does not contain connecting bolts and thus limits points of failures. The individual footplates allow the footrest to be rotated in order to access the space directly in front of the wheelchair.



**Figure 10.** Crutch Extender

### 3.2.3 Crutch Extender

This design, seen in Figure 10, is an adaptation to the extension bar of the footrest. There are two shafts with one fitting into the other. Holes are drilled through the shafts at fixed intervals. Bolts and wing nuts that fit into these holes allow for the length of the extension bar to be adjusted. This bar can be used with either two footplates or one footplate. This design offers adjustability while reducing durability.

## 4. Preliminary Design Evaluation

The design areas were broken up into two main categories. The first category is the upper hanger and it involves the connection from the footrest to the wheelchair and the mechanism that prevents rotation of the footrest. The second is the lower hanger and footplate, which involves the lengthening rod and footplate. Separating the ideas allowed the designs to be evaluated based on the function of each aspect, and for the importance of each area to be accounted for.

**Table 1:** Design Matrix 1- Upper Hanger.

Criteria	Weight	Design 1- Current pin & flange		Design 2- Hole & Pin			Design 3- Extended Hanger	
Durability	25	4	20	2	0	1	5	5
Safety	20	5	20	4	6	1	5	0
Cost	15	4	12	5	5	1	3	9
Range of Motion	15	5	15	4	2	1	4	2
Ease of use	10	3	6	3		6	3	6
Transferable (to future chairs)	10	3	6	2		4	4	8
Ease of fabrication	5	4	4	5		5	3	3
Total	100	83		68			83	

#### 4.1 Evaluation of Design Matrix 1

Durability is the category of most importance given that the product is expected to withstand multiple years of use. The Extended Hanger design is scored the highest because it provided the most stability and was the strongest of the three designs. The design would eliminate the necessity of the existing pin locking mechanism which has failed in the past. This pre-existing pin failure is the reason that design 1 was scored lower than design 3. The Hole and Pin design is scored the lowest due to the pin not being strong enough to support the forces applied to it.

Safety is weighted second as the product cannot cause the user any harm. Design 2 is scored the lowest because the structural integrity of the pin is not guaranteed. If the pin did fail, the footrest could detach completely from the chair and injure the client. The flange in design 1 and the threaded cap and locking mechanism in design 3 prevent vertical and side-to-side movement that could cause injury to the client.

Cost is ranked high because the budget is \$100 and the materials required are expensive. Design 2 is scored the highest due to its simplicity. The only purchase that would need to be made for the Hole and Pin design is the pin. Design 1 is also relatively inexpensive as a result of using the existing locking mechanism. The Extended Hanger design proves to be the most expensive as it requires the most materials to be purchased.

Range of motion is an important category for the client. The footrest must be able to swing to the side to allow access to the lift required to move Mark in and out of his chair. All of the designs allow this motion however only the Current Pin and Flange design allow for the footrest to be locked in its outward position.

Ease of use is a category that must be taken into consideration. Mark has multiple caregivers when at his care center away from home, so the design of the locking mechanism must be intuitive for the caregivers. All of the designs scored low in this category because they are all slightly more complicated than the current locking mechanism.

The footrests should be made transferable to other chairs. Mark gets a new wheelchair every 5-8 years and as we are designing footrests that are expected to last longer than that, the footrests need to function on other wheelchairs. The Current Pin and Flange design as well as the Hole and Pin design are scored poorly because they both involve making modifications to Mark’s chair. In order to make these designs transferable, the client would have to make the modifications to his chair himself. The Extended Hanger design does not require any additional attachments to the chair which is why it received the highest score.

Finally, ease of fabrication must be considered when scoring the designs. The Hole and Pin design is the simplest design to manufacture because it would only involve drilling a hole through the wheelchair and finding a pin. The Current Pin and Flange design is a close second due to the fact that the only fabrication needed is to attach the flange to the wheelchair. The Extended Hanger design is much more complicated in that the hanger would have to be completely fabricated from scratch and it would involve welding and more complex machinery.

**Table 2:** Design Matrix 2- Lower Hanger and Footplate

Criteria	Weight	Design 1- Solid Bar, 1 Footplate		Design 2- Solid Bar, 2 Footplates		Design 3- Crutch, 2 Footplates	
Durability	20	5	20	5	20	4	16
Safety	20	5	20	5	20	5	20
Cost	15	4	12	5	15	3	9
Comfort	15	3	9	4	12	5	15
Ease of use	10	3	6	5	10	4	8
Adjustability	10	1	2	1	2	4	8

Removability	5	4	4	5	5	5	5
Ease of fabrication	5	5	5	4	4	3	3
Total	10	78		88		84	

#### 4.2 Evaluation of Design Matrix 2

Durability is the most important category for the lower portion of the design because Mark's feet will be strapped in but still applying lots of force directly onto the footplates. Design 3 was scored slightly lower due to possibly wearing down sooner due to the more complex and adjustable parts with the crutch design.

Safety is once again a major concern for the final design of the footrest. All of the designs are weighted equally safe due to their durability, lack of complexity, and low risk of failure.

Cost, as mentioned before, is a consideration that must be made due to the low budget that has been provided. The two footplate scored the higher than the single footplate because two footplates are sold more frequently than a single footplate. The crutch design scored lowest because of the additional complexity and cost of the crutch mechanism.

Mark spends most of his time in his chair so the final design must fit his comforts and needs. The crutch design is scored the highest as a result of its adjustability. The length adjustability allows for ensured comfort over time. As Mark's needs for longer or shorter footrests changes over the years, the length of the rods can be changed accordingly. The single footplate design means that the feet need to be strapped to one plate limiting the comfort for each foot. Two footplates would provide comfort individualized to each foot.

The lower hanger design, like the upper hanger design, must be easy to use and relatively intuitive. The single plate design is scored the lowest due to the fact that the caretaker would have to completely remove the footrest in order to access Mark's lift. The crutch design is the most complex however it maintains the swing-away function so it is easier to use. Finally, the two footplate design is the easiest to use because it is the most similar to the existing footrests.

Adjustability is a category that needs to be considered based on the changing of Mark's needs over time. The solid bar designs are not adjustable which is why they are scored very low. The crutch design allows for lengthening and shortening of the rods.

Removability is important for Mark's transportation needs. The footrests are removed when Mark travels to limit the amount of space the chair occupies. All of the designs are removable however the single footplate design is more difficult to remove due to its geometry.

Once again, ease of fabrication must be factored into the final design decision. Fabricating the crutch design would be very difficult due to the complexity and machining necessary. The single footplate design would be the easiest as it would involve the least fabrication and the two footplate design would be slightly more difficult.

#### 4.3 Proposed Final Design

Our final design ideas resulted in two options based on what we have been presented with so far by our client. If we are able to modify the existing footrests or obtain access to spare parts, we will be building off of these existing structures to utilize the current pin and flange design with the solid bar and two footplates. However, if the client would prefer that the current equipment remain unaltered, the frame will be manufactured from scratch. In this scenario, the design would feature the extended hanger, a solid bar, and two footplates.

### 5. Discussion

Most ethical considerations for this design are centered around the health and safety of the user. If the prototype is promoted as a safe alternative, we have to ensure that the product will meet all medical standards. Mark requires specific flexion and length for his footplates which will be collected from his medical documentation. The footrests must also prove not to be dangerous to Mark or the caregiver by ensuring it will not break, and by avoiding jagged edges in final production. Final geometry of the current wheelchair and footrest is also being collected in order to make our design dimensions compatible with his wheelchair. The other ethical consideration is cost to the consumer. A cost effective product is required so that there is a possibility for future replication and users.

### 6. Conclusion

It is estimated that 65 million people worldwide have a disability which requires the use of a wheelchair [5]. Mark is one of the many with a wheelchair that does not completely suit his needs. We aim to provide Mark with durable, long lasting footrests that will accommodate his needs by limiting the number of connection points and adding reinforcements.

There is a lot of continual work to be done including receiving some important information from the client and creating a manufacturing plan. Detailed technical specifications on Mark's current wheelchair and footrests are required from the client in order to quantify the designs with accurate dimensions. Mark's medical requirements are also needed for appropriate footrest length and the degree of flexion for his ankle. In order to complete a manufacturing plan, continued research in durable metals and their properties is needed. TIG and MIG welding training will also be necessary for the current designs to be realized. After this information is gathered and implemented, fabrication will begin. Once prototypes are completed they will need to undergo multiple force tests to ensure their durability and eventually be tested with use by Mark. In the end Mark should have a pair of fully functional, durable footrests.

## 7. References

- [1] World Health Organization (2008). Concept note: World Report on Disability and Rehabilitation [Online]. Available: [http://www.who.int/disabilities/publications/dar\\_world\\_report\\_concept\\_note.pdf](http://www.who.int/disabilities/publications/dar_world_report_concept_note.pdf)
- [2] M.W. Brault, "Americans With Disabilities: 2010," in Current Population Reports, Washington, DC, U.S. Census Bureau, 2012, pp. 70-131.
- [3] R. P. Gaal, N. Rebholtz, R. D. Hotchkiss and P. F. Pfaelzer. Wheelchair rider injuries: Causes and consequences for wheelchair design and selection. *Journal of Rehabilitation Research and Development* 34(1), pp. 58-71. 1997. Available: <http://search.proquest.com.ezproxy.library.wisc.edu/docview/215296901?accountid=465>.
- [4] K.A. Stern. *Definition of Cerebral Palsy* [online]. Available:<http://www.cerebralpalsy.org/about-cerebral-palsy/definition>
- [5] "Fact Sheet on Wheelchairs," *World Health Organization* , pp. 1–4, Oct. 2010.

## 8. Appendix

### Appendix A. Product Design Specifications

#### **Product Design Specifications:**

Design of Durable Wheelchair Foot Rests

**Client:** Andrea Gehling, Avenues to Community

**Advisor:** Dr. Jeremy Rogers

**Team:** Rachel Craven-Team Leader

Allie Hadyka- BWIG

Makayla Kiersten- BSAC

Kobe Schmitz- Communicator

Shannon Sullivan- BPAG

**Function:** Our client at Avenues to Community works with Mark, a 32 year old man with cerebral palsy and an intellectual disability. Mark uses a wheelchair for transportation while in their community. Due to his spasticity he often kicks his legs, so for safety reasons his feet must be strapped in during transport. As a result, he often breaks the foot rests on his wheelchair. A more durable foot rest design is needed for his use.

**Client Requirements:** New wheelchair footrests must be suitable for the safety needs of Mark and function without breaking.

Design Requirements:

1. Physical and Operational Characteristics

- a. *Performance Requirements:* Must withstand maximum forces during leg kicks due to spasticity from the user, a 32 year old male with cerebral palsy.
  - b. *Safety:* Must safely support and secure the user's legs during wheelchair use, particularly transport. Must prevent injuries such as circulation, restriction, or bruising. Must be able to swing or remove out of the way in order for a lift to be used.
  - c. *Accuracy and Reliability:* Must never break during use.
  - d. *Shelf Life:* Our goal is for our product to work for Mark's lifetime use
  - e. *Operating Environment:* Our product will be used in coordination with an existing wheelchair.
  - f. *Ergonomics:* Foot rests should be comfortable for the user of the wheelchair, keep his ankle at the correct flexion, as well as be easy to use for his support staff.
  - g. *Size:* Should not increase the current amount of space that his wheelchair currently encompasses.
  - h. *Weight:* not an important factor, must be light enough to be removed by Chris, no more than 15 lbs.
  - i. *Materials:* Materials should be as durable as possible without compromising safety, adjustability, and weight.
  - j. *Aesthetics, Appearance, and Finish:* Aesthetics are not a main concern, but the product should look professional.
2. Production Characteristics
    - a. *Quantity:* At least one set of functioning footrests.
    - b. *Target Product Cost:* As affordable as can be for the family of the user, staying within our design budget which is currently \$100.
3. Miscellaneous
    - a. Patient Related Concerns:
      - i. Footrests should allow the wheelchair to have easy accessibility and removability
      - ii. The footrests should be completely safe for the patient.
      - iii. Must be intuitive and simple in nature
    - b. *Competition:* Composite footrests vs metal footrests; swingaway or elevating, removable or fastened, and footplates



## Appendix B: Project Gantt Chart

Task	September			October				November				December			
	12	19	26	3	10	17	24	31	7	14	21	28	5	12	19
<b>Project R&amp;D</b>															
Preliminary Research	X	X	X												
Brainstorming		X	X	X	X										
Choose Design						X									
Order Materials															
Fabrication															
Testing															
Product Revision															
Final Product															
<b>Deliverables</b>															
Progress Reports	X	X	X	X	X	X									
Preliminary Presentation				X	X										
Preliminary Deliverables					X	X									
Final Deliverables															
Poster															
<b>Meetings</b>															
Advisor	X	X	X	X	X	X									
Client				X											
Team		X	X		X	X									
<b>Website</b>															
Update	X	X	X	X	X	X									

**Key:** colored cells=projected timeline; X= task completed