Handicap Accessible Bicycle

BME 301 Final Report | May 3, 2017

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ABSTRACT

The life of some adult TBI(traumatic brain injury) patients is very limited in physical ability and the capacity to participate in activities such as going for bike rides. Although there are adult sized attachments and recumbent bikes on the market, none of them fit the need for that of an adult that lacks normal mobility, but has enough ability to still participate. These current designs are mostly passive, do not provide adequate stability required for TBI patients, and are not cost effective. A novel design was created to provide a solution to these problems. The final design is composed of steel rods welded in a tricycle formation that attaches to the seat of a standard bicycle. This two wheeled attachment includes features of arm bars, shock absorbent tires, and a separate drivetrain allowing for passenger participation. Three separate methods have been proposed to make entering and exiting the device safer and more convenient for the passenger. These include a swivel chair design, slide bar design, and dip bar design with the latter two requiring change in composition of the frame.

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INTRODUCTION

Motivation

Family activities are important to creating a positive family environment. One such activity is a family bike ride. Unfortunately for family members suffering from disabilities, bicycle rides are made difficult. Family members suffering from paralysis are often left behind on these family adventures and lose the opportunity to grow closer with their family in an active setting. In order to combat this issue, bicycle sidecars should be able to accommodate various levels of physical ability. Current market bicycle sidecar designs are mostly passive, do not provide adequate stability required for TBI patients, and are not cost effective, with most ranging between $1000-4750 for basic models. One example of these current designs is the Walk & Bike Company's extra large special needs bicycle trailer currently available for $980. This is a passive trailer that is large enough for an adult rider, but does not allow the rider to pedal along. Another example currently on the market is The Duet Wheelchair Bicycle Tandem which is available for $4,750 and is also a passive design. This product is attached to the front of the bicycle, which is potentially very dangerous for the rider if any head-on collisions were to occur. Custom bicycles are extremely expensive, but this novel design would provide the same benefits to a larger population at a more affordable cost.

Problem Statement

The Elias family has requested that an inexpensive sidecar be created for Mrs. Elias who suffers from partial paralysis below the waist and suffers from a TBI. Her husband would like to be able to go on bike rides as a family. This sidecar should be easily accessible to the client, should not aggravate her brain injury, and if at all possible should include pedals for her to use to act as a form of rehabilitation and to keep her engaged during the journey.

BACKGROUND

Traumatic Brain Injuries (TBIs)

About 1.7 million people in the U.S. sustain a TBI each year. Levels of brain injury vary between each individual and their circumstance, being classified as either mild, moderate, or severe. Mild for example being the result of a minor concussion and severe being most commonly an open head injury [1]. Those affected by TBIs are more likely to experience trouble with engaging in different levels of physical activity. Loss or weakening of the use of one's limb is a common happening amongst those with moderate to severe TBIs [2]. To deal with this, patients will work with a physical therapist to regain some or all ability. Not all may are able to return to their preinjury status, but can still improve in tasks such as walking or in being able to operate a wheelchair independently. Though this product is being made for the clients' own personal use, the attachment has potential for more than just TBI individuals to participate in something physical and engaging, such as people with autism who also struggle with limited mobility, coordination, balance, and strength. Aside from a physical benefit for these individuals, the use of the trailer will promote outdoor recreation as a therapeutic outlet. It has been shown that aerobic exercise can decrease the frequency of negative self stimulating behaviors without affecting the current positive behaviors.

Handicap Accessible Bicycles

Current Handicap accessible bicycles come in a variety of styles including sidecars, trailer attachments, front end attachments, tandem, and others. As seen in figures 1 and 2, these existing devices are passive products, and offer no engagement of its passenger leaving them to sit while someone else operates the bicycle. The Duet **(Fig. 2)** poses the major safety concern of head on collisions. The Extra Large Special Trailer **(Fig. 1)** does not allow an

individual with limited mobility and stability to get into the attachment easily, given the complexity of the canopy, as well as the undesired step height of 10 inches over the frame.

The benefits of exercise for someone who spends most of their time sitting stationary in a wheelchair are helpful not only physically but can have a positive effect psychologically. It can reduce anxiety and depression as well as boost self-esteem [3]. The passenger is unable to get the full effect of going on a bike ride without some kind of engagement.

In most of the detachable on the market designs, the handicap accessible part can be used independently of the device, however the bicycle portion cannot. This means that independent usage of a bicycle would require the possession or purchase of a single bicycle. With the average current market price of handicap accessible bicycles falling mostly in the $1000-$4500 range, having to buy an additional bicycle would mean higher overall cost to the consumer. This could cause a decrease in the consumer market because these products are not necessities and may not be worth buying if the consumer will get only a limited amount of use from them.

Figure 1: Competing design of a trailer. This trailer is the *Extra Large Special Trailer* by The Walk and Bike Company[6].

Figure 2: Competing design of a front end attachment tandem bicycle. This front end attachment is *The Due*t by Wheelchair Bicycle Tandem[7].

Design Specifications

The device to be fabricated is intended to be detachable from any adult bike to make storage easier. The height of the passenger chair should be about the height of a wheelchair for an easier transition, and the overall size of the attachment should be small enough to store easily in the back of the client's minivan for transportation.
It needs to also be stable and comfortable for the passenger to avoid any potential damaging movements of the head. The current budget for the device is $1000.

A storage space is needed for trip essentials like medication, water, and snacks. The position of the sidecar relative to the bicycle is preferred to be a side or back attachment. In order to add a more engaging and therapeutic element to the device, pedals should be attached for use by the passenger. A detailed list of design specifications can be found in **Appendix A**.

PRELIMINARY DESIGNS

Previous Design

Last semester, a prototype was fabricated **(Fig 3)**. The design focus last semester was the safest placement for the attachment. An attachment to the front, side, and back of the bike were considered. It was decided that the back trailer attachment was the safest and most feasible design for incorporating pedals. The prototype was a working model of the design, but required some improvements. The most important factors that needed improvement were the ease of entry, the hitch attachment, and the stability of the seat. The hitch attachment and stability of the seat were solved by purchasing a stronger hitch and seat with seatbelt and armrests, however the ease of entry required further design considerations. Therefore, this semester the focus of the project was to design a final product that was accessible to the client and others with physical ability impairments.

Figure 3: Fall 2016 Prototype- This prototype was tested by the clients and their feedback was the basis of the improvements made to the spring 2017 design.

Design One - Swivel Chair

The first design involves a swivel chair attachment for the sidecar (**Fig 4)**. The idea behind this design is that the seat will be pulled forward and swivel toward the side of the device. This would allow the passenger to be assisted into the seat while whoever is assisting them slides the seat back and helps lift the passengers legs up and over the frame. The seat being used for this design already comes equipped with sliding capabilities. To accomplish the swivel aspect of the design, an attachment must be installed beneath the seat. The attachment itself will have the ability to be adjusted by hand. The problem with this design is that the attachment will be adding some extra weight to the device. It also adds safety concerns due to the multiple elements needed that, if not used correctly, could potentially break while in use.

Figure 4: Swivel chair- The seat being used for our device will attach to a mechanism that would allow for a swivel action to occur as well as front and back movement.

Design 2 - Slide Bar

The second design involves an inner rod that can slide open. This design allows for the passenger to be walked right through the frame and into the seat. The inner rod is a smaller diameter than the rest of the frame and would be fastened in using knurled head screws (**Fig 5**). A bolt would be welded to the bottom part of the bar to let the screws be removed and then refastened. Ideally whoever is assisting the passenger would be able to remove the screws by hand and slide the bar over enough for the passenger to walk through. Some issues with this design involve creating a weakness in the frame because it creates a break in the frame. Additionally, if the screws were not tight enough while the device is in use, shearing stresses on the screws could lead to breaking or loosening. To combat this structural weakness, this design also includes the addition of a cross bar at the front end of the attachment. This would provide more stability of the frame mainly while the rod is being moved.

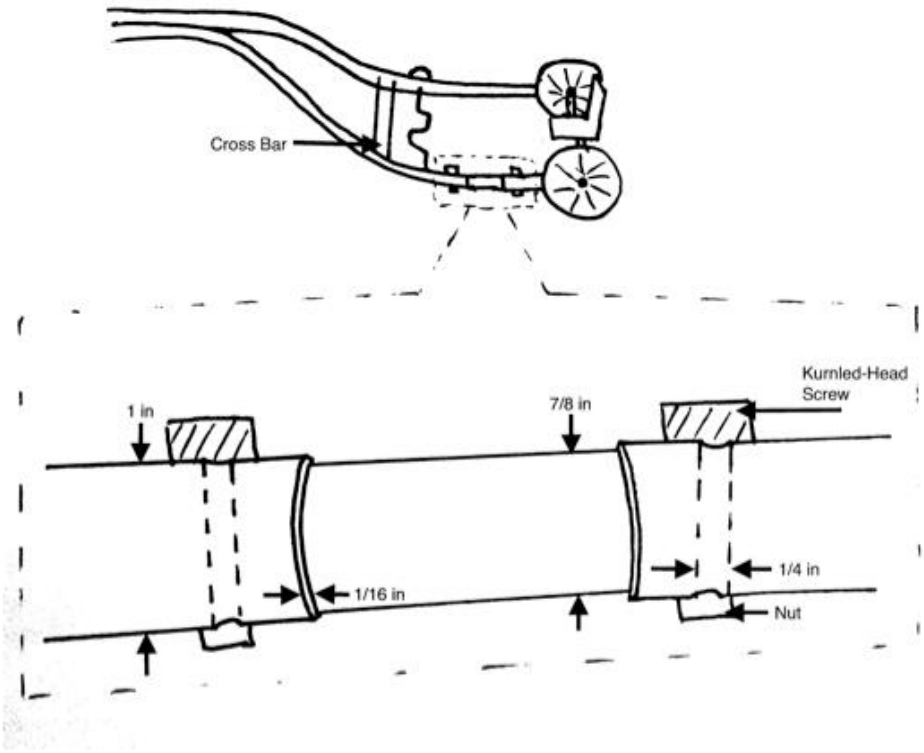


Figure 5: Slide Bar- An inner rod structure connected to the frame by removable screws along with additional cross bar for stability and strength.

Design 3 - Dip bar

The third design would involve additional bending of the frame rod to lower the point of entry (**Fig 6**). This would make it less strenuous for the passenger to get over the bar. The current prototype's frame is raised about 13 inches off the ground. The standard step height for building code is 7.75 inches [4]. The goal for this design is to bend the bar to a height of 7 inches. The purpose of not going any lower is to reduce the chance of the bar coming into contact with the ground or any curbs while the device is in motion[5]. The bends in the bar already contribute to a weakening of the frame's structure and contact with the ground could weaken it further. Another potential issue with this design is that there is a risk of the passenger's foot getting hitting the ground during rotation if the frame was not high enough from the ground. This presents a risk for tripping if not being supported well enough by the assistant. This design provides no additional cost to the project because we will be using the same rod being used for the frame, while just creating more bends.

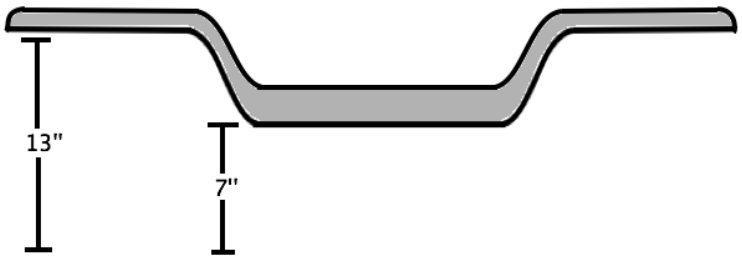


Figure 6: Dip Bar- Additional bending in the frame along the side of the device.

PRELIMINARY DESIGN EVALUATION

The criteria in our design matrix (**Table 1**) includes safety, ease of use, durability, manufacturability, and cost. In our design matrix, safety is defined to be the ability of avoiding any possible injuries and keeping our passenger stable and comfortable. This includes how safe it is for our client to be able to get in and out of the trailer design and how safe and stable she is once sitting in the seat. Avoiding any undesired headaches and possible seizures is the main concern of our client. The main parameters to consider for ease of use is how easy is it for our client to assist his wife and how easy it is for our client's wife to get into the trailer with her limited mobility. This does not include the ease of pedaling because each of the considerations should allow the pedaling action without interference. Durability is defined to be how strong and tough each design will be once manufactured. This includes being able to withstand stresses applied to the specific design features of the frame and of the seat over a long duration of time. Also taken into consideration is how well it performs in rough terrain/bike paths. Manufacturability is the ease at which our team will be able to fabricate our design. This includes how much time and effort will go into welding, cutting metal, drilling, etc. The cost is defined to be the amount of money that will be spent to completely fabricate each of our designs. This includes the purchasing of every part that makes up the design, as well as any extra frame materials.

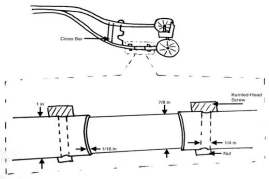
Criteria	Swivel Chair		Slide Bar		Dip Bar	
						
Safety (25)	3/5	15	2/5	10	4/5	20
Ease of Use (25)	3/5	15	4/5	20	3/5	15
Durability (20)	5/5	20	3/5	12	4/5	16
Manufacturability (15)	2/5	6	3/5	9	5/5	15
Cost (15)	2/5	6	4/5	12	5/5	15
TOTAL (100)	62		63		81	

Table 1: Design matrix that evaluates three preliminary designs. Criteria are listed in descending order of importance. The Dip Bar received the highest score overall due to its performance in safety, manufacturability, and cost. The Slide Bar received the highest score in ease of use because the knurled head screw will allow for easy removal of the inner rob by sliding it to one side, allowing walking space to enter the trailer. The Swivel Chair scored highest in durability because it does not disrupt the structural integrity of the frame as the other two designs will do.

The Swivel Chair scored highest in durability because the parts that would be used to create this design would not interfere with the structure of the frame. It scored low in cost because to fabricate this design, multiple expensive pieces will need to be purchased. It also scored low in manufacturability due to the fact that a significant amount of drilling, welding, and mechanical set up that our team is not experience in.

The Slide Bar scored highest in ease of use because it will not require our client to step over the trailer's frame. This is an attractive feature knowing that the mobility of our client and other traumatic brain injury patients is very limited. Another attractive feature includes the ease at

which our clients will be able to operate the slide bar. It only requires the loosening and fastening of two knurled head screws in order slide the bar lying internally to one side for free access into the design. It scored low in safety because a lot of the structural integrity will be sacrificed in the frame of the trailer attachment which will result in a greater failure risk. Once our clients slide the bar to one side, it is possible that the weight of the trailer could result in the collapsing of our design.

The Dip Bar scored highest in safety, manufacturability, and cost. The Dip Bar scored highest in the category of safety because the design does not sacrifice the structural integrity of the frame bars to the same degree that the other two designs will. It was not awarded a perfect score for safety because when lowering the height of our design, the concern of our design scraping curbs, paths, and other environmental factors starts to arise. There is also a slight concern that our client will still struggle to get in and out of the trailer attachment, ranking the ease of use lower than the Slide Bar, but tying the ease of use of the Swivel Chair. The Dip Bar scored the highest in manufacturability because it only requires a small amount of additional bending of the trailer's frame. This bending feature also reduces the overall cost of the design because it does not require the purchase of any extra materials.

FINAL DESIGN

The final design consists of a double framed trailer attached to the seatpost of a any bicycle. The frame was made of 1" diameter .065" thick steel tubes that were welded to support a seat as well as a complete drive train. The seat on the trailer attachment is not a traditional bike seat, but rather consists of a foldable chair with armrests and a seatbelt. The seat is the approximate height off the ground of a Tsunami rigid frame wheelchair of 14 to 23.5 inches [6] . In front of the seat there is pedal system modeled after a paddle boat this is connected to a gear on the side which connects and powers the back tires. In order to assure coordination throughout pedaling, our pedals completely enclose the shoes of the rider as seen in Figure 7.

As the frame continues back towards the rear of the trailer attachment, there are attachment points for wheels. We plan on using wide wheels similar to those found on winter bikes to maximize the area in contact with the ground which will make the ride smoother and less likely to be affected by uneven surfaces. The wheels enable our client to coast without continued movement of her legs during some durations of the ride. The trailer's' wheels are connected to the pedals by a custom length chain and custom made axle. The entire trailer's attachment point is on the seat post of the standard bike using a common burley travoy hitch.

The decision to not include the dip bar in the final product came after deciding on a smaller wheel diameter. The prototype had wheels with a diameter of 26" which lifted the frame 13" off the ground and would require the dip bar for easier entry. The final design uses a 16" diameter wheel which effectively lowered the frame by 5-6", making the addition of the dip bar unnecessary. Had there been a dip bar, it would have been 2" lower and the bends necessary to do that would add too much strain on the frame and contribute to some structural instability at these points.

Figure 7: Final design consisting of a 2 wheeled, double framed trailer attachment. Contains independent drivetrain mechanism powering rear wheel of trailer.

FABRICATION AND DEVELOPMENT PROCESS

Materials

The majority of our design is composed of steel. The frame is made from steel that is welded together to create the supports for the seat and the drivetrain. Many of the drive train components are also be composed of steel including the pedal arms, the cassettes, the seat track supports, pillow block bearing supports and the chain. The seat is made of leather and other plastics. Our wheels are steel with rubber tires and inner tubes. The pedals are made of plastic. The majority of attachments are secured by welds.

Methods

For fabrication, we used the University of Wisconsin - Madison Baja Team's pneumatic pipe bender. To connect the bars, we used MIG welding. Attachment points were created for drivetrain, and seat. The seat is attached by two 90 degree steel bars to support the track on top of the two positive arches spanning the frame. The drive train is incorporated into our design through two specific attachment points. The first being the side gear located to the left of our pedal attachment, and the second being at the rear wheel where our cassette will be located. Our frame is fabricated with the proper dimensions to allow for bottom bracket incorporation and the rear wheel is anchored in a way that allows for our chain to propel the attachment without impediment. The wheels are supported by a custom lathed and threaded axle to maximize the

strength within the smaller sized wheels. The axle is then connected by two pillow block bearings which allow for rotation of the axle with reduced friction. The pillow blocks are attached to the frame through steel plates with holes for bolt attachments. These plates are welded onto the inner side of the frame.

Testing

To test the load-bearing capabilities of the trailer, team members weighing the same weight as the client as well as team members with weights exceeding the client rode in the trailer. The trailer was considered a success because with a 210 lb subject, there was no failure of any components of the bike or trailer and another team member could successfully pedal the bike forward without difficulty.

Positive arch and axle displacement was tested by recording videos of a 210 lb subject sitting down on the trailer. Screenshots of before and after sitting were then analyzed in imageJ for a change in angle between the axle and the positive arch. An average angle change of 0.922° and a p-value between 0.05 and 0.1 showed no significant displacement of the axle or positive arches.

Turn radius will be defined as the radius at which the bike is able to turn without being jackknifed by the trailer. Due to the safety of testing, this had to be determined by turning the trailer at different angles in relation to the bike and testing for the maximum angle at which the bike rider is still able to begin riding forward. It was found that the trailer can be turned at a maximum angle of 90° in relation to the bike and still be successfully ridden. This indicates that the chance of jackknifing is low.

For on-site trials, the team rode the bike both inside ECB as well as on the sidewalks outside. Here, several observations were made, such as smoothness, stability, turning ability and size. Almost all comments were positive, including that the ride both inside and outside felt very smooth and with the seatbelt, the rider felt stable and secure even when making 180° turns. The trailer was able to make 90° turns on the sidewalk without any part of the bike or trailer falling off of the sidewalk. While riding on the sidewalk, there was enough space for a bike or two pedestrians to pass by. It was observed that another trailer of the same size would not fit, however. When riding through curb cutouts, it was also observed that if centered, the trailer could pass through the curb cutout without hitting the curb on either side. The only negative observation was the stability of the pedals. The pedal bars were too thin to support the weight of the rider's feet without bending. The shoes also slid side to side, hitting the pedal bar and occasionally getting stuck. The heel of the shoes also were able to scrape the ground if not held in the proper position. These observations were compared to the trailer's turn radius, weight, height, and size to determine that the product is suitable for these locations.

This summer, the pedal bar will be improved by using a thicker bar, securing the shoes on either end, and centering the shoes so that they will not be able to touch the ground. With this improvement, along with added safety features such as fenders, reflectors, and a bell, this design will be well-suited to meet the client's needs.

CONCLUSIONS AND FUTURE WORKS

The task is to create an attachment for a standard bicycle to allow a TBI (traumatic brain injury) patient to be able to ride along with a companion. This attachment needs to be considerate of the patient's needs for stability and limited mobility. The trailer design encompasses the model of our clients' current wheelchair with arm bars and seat belt for added safety. For extra stability, the design includes wide tires providing extra cushion on the uneven parts of the trails. The design is removable from a standard bike, allowing for maximum usage and storage. The overall lowered frame due to smaller wheel diameter allows for easier access into the trailer as well as added safety from the client touching the wheels.

Additional features that have been added to the design this semester better accommodate a wider range of potential riders. An adjustable seat will allow riders of different heights to still be able to comfortably reach the pedals. Enclosed pedals which hold the foot in the proper pedaling position allow for riders with different levels of coordination can safely pedal while riding. Added storage on the bike allows the couple to bring needed items such as medications.

This summer the design will be completed upon strengthening the pedal bar to prevent bending as well as adding extra accessory features. These features include reflectors, fenders, a water bottle holder, a mirror and a bell. The fenders will provide shielding from possible rocks or backsplash from the tires. The mirror and bell will be added to aid in the communication between the two riders while in motion. Although our client will not be riding in the night, we believe it is best to add extra safety features such as reflectors for visibility. After all accessories and pedal changes have been added, we plan to pursue a patent for our design.

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Appendix

A. Project Design Specifications

Handicap Accessible Bicycle

Product Design Specifications | February 1, 2017

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Function: Handicapped Accessible Bicycles vary greatly in style and design based on the specific person's needs, age, and financial income. The objective of this design is to create an easily accessible bike attachment for an adult client who has limited mobility and is still affordable for most persons. In addition to its function this design should be similar in dimensions to that of a common wheelchair.This design will improve the quality of life and also provide therapeutic exercise for the client.

Client Requirements:

- Budget
  - Sidecar cost must stay within a $1,000 budget but under $500 is preferred
  - Bike cost preferably no more than $100
- Sidecar
  - Height must be around the height of clients Tsunami rigid frame sn: ts009326 wheelchair (14-23.5 in)
  - Should contain a small storage space for medications
  - Preferably detachable
  - Must be able to fit in trunk of Honda CRV (50.79 in W X 107.09 in L X 49.41 in H)
  - Sidecar must be on the side or the back of bike
  - Prefer sidecar to have pedals
  - Seat belt for safety in case of uneven surfaces
  - Arm rests on seat

Design Requirements:

1. Physical and Operational Characteristics:

a. *Performance Requirements:* The sidecar must have the proper size to contain the client's 5'4" height. The totality of the bike and the sidecar must be able to hold around 350 pounds of maximum weight. The seating for the client must also be very secure. If the client is moving around too much, her brain injury could be aggravated. Ideally, the bicycle should be easily storable in a minivan and in a basement. Ideally, the sidecar will be next to the bicycle driver, or behind the bicycle.

b. *Safety:* Safety is a major concern for our sidecar design. Biking is a dangerous endeavor by itself, and when the sidecar is attached, it will increase the space the bike takes up on the road and increase its risk of getting hit. We need to ensure our bike is as visible as possible to prevent any accidents. In addition to the risk of impact injuries, our client specifically needs a smooth ride to prevent injuries from excessive bouncing or contractions due to a bumpy road. A final safety concern that must be accounted for is in the stability of our sidecar attachment. Our client doesn't have the best stability, so we will need to make sure she is secured with a seatbelt or harness style design.

c. *Accuracy and Reliability:* This design must provide a smooth reliable ride. The accuracy and reliability of the side car must be of top priority. Faults in this category can cause severe headaches and potential seizures for our client.

d. *Life in Service:* Our sidecar should withstand the conditions of the terrain and maintain mechanical stability for as long as the client decides to use it to demonstrate its durability. The sidecar itself should be durable enough to withstand the weight of the passenger. It should also hold up during long periods of storage in the winter months.

e. *Shelf Life:* The shelf life prior to purchase of our design should be years. Shelf life for the duration of the winter should also be met.

f. *Operating Environment:* The bicycle must be able to withstand the bumping from standard bicycle trails. The sidecar and bicycle may also be ridden on roads on occasion. It must also be able to withstand the total weight of our clients, about 350 pounds maximum. It should withstand environmental conditions such as rain, snow, and cold temperatures.

g. *Ergonomics:* Our sidecar must be comfortable for the rider to be in for extended periods of time. The attachment also must be easy for the rider to be assisted into and out of the sidecar. Should we pursue a design that includes a detachable aspect, it should also be easily removed and attached so our clients can spend less time setting up their bike and more time enjoying it.

h. *Size:* The size of the sidecar and bike combination must not exceed that of what can be stored within the drunk of a Honda CRV. (50.79 in W X 107.09 in L X 49.41 in H)

i. *Power Source:* The sidecar does not require a power source because it is not contain any circuitry or motors. The sidecar care will be powered manually.

j. *Weight:* The total weight should be able to be lifted by the average person. The average person can lift a weight similar to their own, so this will vary based on the individual storing it. The client should be able to lift it into a vehicle for transportation.

k. *Materials:* The client is in need of a bicycle, so a cost effective bicycle capable of having a form of a sidecar must be found and attached. In order to create the strongest possible frame for sidecar must be used. It should incorporate thick metal poles and thick metal sheets that must be welded in an appropriate manner. A suitable secure seat must also be used for to ensure our client's safety. If need be, safety harnesses may be employed to prevent jarring to our client's head.

l. *Aesthetics, Appearance, and Finish:* The most important aesthetic requirement from our client was that the attachment should not look childish. It is also preferable by our client that the sidecar attachment didn't substantially increase wind resistance to prevent fatigue for the rider. From a safety perspective, our design's finish should be highly visible to drivers in a variety of weather conditions.

2. *Product Characteristics:*

a. Quantity: The client desires one functional product that can allow the passenger to participate in a bike ride.

b. Target product cost: The client would like to keep the sidecar expenses under $1,000 but would prefer it to be no more than $500. A bike purchase will be necessary and should not exceed $100.

3. Miscellaneous:

a. Standard and Specification: The intended bike trails of our client include the Capital Springs state recreation area, Lake Shore path, and the lake farm park trail. Ride tests at these locations will need to be performed after fabrication for comfort.

b. Patient-Related Concerns: Bicycles are notorious for being unstable. The bicycle must be made as stable as possible because serious injuries to our client could leave her severely injured given her current situation. Bicycle are also very jarring when going over bumps. The seating system must be made as secure as possible to prevent aggravating the client's condition.

c. Competition: There are competing designs for a variety of handicapped accessible bike attachments. Some incorporated a trailer attachment for placing a wheelchair on and stabilizing it. Some were modeled after bike taxis used in east asia. Others had more of a traditional sidecar design. They range in price from around $1000 up to $4500.
http://www.wicycle.com/index.php/products/special-needs-trailers/wike-extra-large-special-needs-trailer#accessories-tab
http://frankmobility.com/duet.php

d. Customer: The sidecar is designed for a client with limited mobility and balance who can operate a common the pedals of a stationary bike.