Portable Assisted Mobility Device

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Project definition

The portable assisted mobility device senior design project, from the School of Engineering and Technology at Central Michigan University, required the design of a one person, ultralight weight, and portable, powered transportation device. Due to rapidly growing population rates and high population density in urban areas the need for a portable assisted mobility device (PAMD) is now greater than ever. The PAMD needed to be a lightweight, small, electric powered mobility device that can be taken on a train, bus, and also carried indoors with easy storage capabilities.

The main concerns in the design phase of this project were weight, power capabilities, speed, and size. The weight and size constraints are characterized by the need for an average adult to be able to comfortably carry the device and also be able to easily bring it with him or her wherever is convenient. Also, the PAMD must have a power source capable of transporting them throughout their daily commute. During this transportation the speed needs to be greater than walking and also comparable to other powered transportation devices.

In order to accomplish this design project, the team set forth a design plan by continuing to follow the Engineering Design Process: background research, specify requirements, brainstorm solutions, choose the best solution, development work, build a prototype, and test.

Benchmarking

Research was done on existing products that fit similar criteria to those of this project. There are many products on the market that are similar to this PAMD description. Most of the similar designs on the market, however, are significantly heavier and much less portable. Concepts in this project's design are benchmarked against two very popular products, the E300 Razor scooter [1] and the IZIP E3 Zuma [2] electric bicycle. Both of these designs are popular mobility devices with the main drawbacks being heavy weight and non-portable. The E300 Razor has a total weight of 46 pounds, and the IZIP E3 Zuma electric bicycle weighs in at 53 pounds. Neither of these devices has any folding mechanisms, therefore the ability for easy maneuvering and storage while using public transportation is impossible. The maximum speed for the E300 Razor is 15 mph while the IZIP E3 Zuma's max speed is 20 mph. The weights of the two devices are within 7 pounds of each other, but neither is light enough for easy manual maneuverability. The speed difference between the two compared mobility devices is due to the larger wheel size on the IZIP E3 Zuma electric bike.

One of the main objectives of this project is to create a product that is light weight and highly portable when using other forms of alternative transportation. That goal could be accomplished by incorporating strengths of the existing products while eliminating their flaws.

Identification of customer needs

The customer needs used in the development of this design are very well defined in the PAMD project guidelines [3]. The needs given by the outline include weight and size restrictions, speed requirements, and power capabilities. This device must have the ability to be charged indoors or outdoors from a regular power outlet (110v / 60Hz), have space to store small items, and be built within the $1,000 budget provided by the school. All the given needs can be found in Table 1.

Table 1. Customer Needs

#	**Customer Need**	**Importance**
1	Design a powered device (electric or other clean source)	5
2	Have a one-person capacity	5
3	Be able to carry small cargo	3
4	Ultralight	4
5	Easily portable by average adult	5
6	Stored easily	4
7	Be able to charge battery indoors and/or outdoors (110v/240v)	4
8	Travel faster than walking	5
9	Follow electric bike speed regulations (>15mph)	3
10	Weather proof (rain, wind, heat, humidity, etc.)	1
11	Affordable	4
12	Good battery life	2
13	Theft protection	2
14	Easy to use	3

The priority of each need was determined through discussion with the project advisor, Dr. Shabib, and amongst the team. Importance is ranked on a scale of 1-5, where 5 is the most important and 1 the least.

The engineering specifications and the various needed metrics were then defined by examining the customer needs. The metrics were developed to quantify the customer's needs in an easily analyzed method. A list of the engineering specifications and their metrics can be found in Table 2.

Table 2. Engineering Specifications and Metrics

Metric #	Metric	Units	Needs #	Range Specification	Target Specification
1	Weight of device	Pounds	4,5	25 - 35	30
2	Max speed of device	Mph	8,9	10 – 20	15
3	Wheel diameter	Inches	5,6	10 – 14	12
4	Cost to build	Dollars	11	700 – 1000	800
5	Number of joints	Unitless Number	5,6	1	1
6	Voltage	Volts	8,9	24 - 48	36
7	Current	Amps	8,9	8 - 12	10
8	Battery life	Minutes	12	40 – 65	45
9	Number of wheels	Unitless Number	14,5,6	2 – 3	2
10	Max weight capacity	Pounds	2	180 – 220	200
11	Number of carrying straps	Unitless Number	5	1 – 2	1
12	Size of base	Square Inches	2,14	≤192	112
13	Max height of handlebars	Inches	5,6,14	42 – 48	42
14	Width of handlebars	Inches	5,6,14	12 – 18	18
15	Max time to prep for use	Seconds	14	1 – 30	20
16	Microcontroller	Binary	14	y/n	y
17	Digits for passcode on lock	Unitless Number	13	4 – 6	4
18	Compartment for storage	Binary	3	y/n	y
19	Charging connection	Binary	7	y/n	y

In order to ensure that all customer needs were addressed in the design, the engineering specifications and customer needs were compared using a quality function deployment (QFD) chart. The QFD for this project can be seen in Figure 1.

Target Specification	Range Specification	Units	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Need #
			Easy to use	Theft protection	Good battery life	Affordable	Weather proof (rain, wind, heat, humidity, etc.)	Follow electric bike speed regulations (>15mph)	Travel faster than walking	Be able to charge battery indoors and/or outdoors	Stored easily	Easily portable by average adult	Ultralight	Be able to carry small cargo	Have a one-person capacity	Design a powered device (electric or other clean source)	Customer Need / Specifications and Metrics
			3	2	2	4	1	3	5	4	4	5	4	3	5	5	Scale
30	25 - 35	lbs										X	X				Weight of device
15	10 - 20	mph						X	X								Max speed of device
12	10 - 14	in									X	X					Wheel diameter
800	700 - 1000	dollars				X											Cost to build
1	1	unitless									X	X					Number of joints
36	24 - 48	volts						X	X								Total voltage
10	8 - 12	amps						X	X								Total Current
45	40 - 65	minutes			X												Battery life
2	2 - 3	unitless	X								X	X					Number of wheels
200	180 - 220	lbs													X		Max weight capacity
1	1 - 2	unitless										X					Number of carrying straps
112	≤192	in^2	X												X		Size of base
42	42 - 48	in	X								X	X					Max height of handlebars
18	12 - 18	in	X								X	X					Width of handlebars
20	1 - 30	seconds	X														Max time to prep for use
y	y/n	binary	X														Microcontroller
4	4 - 6	unitless		X													Digits for passcode on lock
y	y/n	binary												X			Compartment for storage
y	y/n	binary								X							Charginng connection

Figure 1. Quality Function Deployment Chart

Concepts generated

Three simple concepts were developed for the project using the engineering specifications and metrics. The first concept, concept A, is a scooter that requires the user to stand while operating. It includes an internal hub motor in the rear wheel and a battery mounted under the base. Concept A also uses three wheels, two in the front and one in the back, that are 12.5” in diameter and 2.25” wide. The base is approximately 8” wide, 24” long, 0.5” thick, and made from composite materials. The front frame is made of 6061-T6 aluminum. The handlebars are approximately 18” wide with an adjustable height ranging from about 24” to 36” above the base. A microcontroller will be placed in the middle of the handlebar and a small storage bag will be in the middle of the handlebars facing outward. Concept A can be seen, with the exception of the storage bag, in Figure 2(a).

Figure 2. (a) Concept A, (b) Concept B, (c) Concept C

Concept B shares most characteristics with Concept A, except it only uses one wheel in the front and one wheel in the back. Concept B can be seen in Figure 2(b).

Concept C is built off of Concept A. It has all of the same features and characteristics, but includes a seat for the user to sit on while riding the scooter. The seat would be removable by unscrewing it from the base. Concept C can be seen in Figure 2©.

Evaluation of concepts

Concepts were evaluated by comparing their respective features and specifications against the customer needs chart, as presented in Table 1. All three concepts were given a score on a scale of 0 – 5 for each customer need depending on how well that concept met the requirement. A score of 0 indicates that the concept did not meet the need at all; while a score of 5 means that the concept fulfilled the requirement exceptionally well. Each score was then multiplied by the corresponding need’s relative importance. Then, the relative scores for each concept were totaled to determine a final score. A score of 250 would indicate a perfect design. The concept evaluation table can be seen in Figure 3.

			Conceptual Designs						
			Score (0-5)			Score * Importance			
#	Customer Need	Importance	A	B	C	A	B	C	Ideal
1	Design a powered device (electric or other clean source)	5	5	5	5	25	25	25	25
2	Have a one-person capacity	5	5	5	5	25	25	25	25
3	Be able to carry small cargo	3	4	4	4	12	12	12	15
4	Ultralight	4	2	3	1	8	12	4	20
5	Easily portable by average adult	5	3	4	2	15	20	10	25
6	Stored easily	4	4	4	3	16	16	12	20
7	Be able to charge battery indoors and/or outdoors	4	5	5	5	20	20	20	20
8	Travel faster than walking	5	5	5	5	25	25	25	25
9	Follow electric bike speed regulations (>15mph)	3	4	4	4	12	12	12	15
10	Weather proof (rain, wind, heat, humidity, etc.)	1	0	0	0	0	0	0	5
11	Affordable	4	3	4	3	12	16	12	20
12	Good battery life	2	5	5	5	10	10	10	10
13	Theft protection	2	2	2	2	4	4	4	10
14	Easy to use	3	3	4	2	9	12	6	15
					Total	193	209	177	250

Figure 3. Concept Evaluation Table

Selection of concept

The concept that was selected to pursue was Concept B because it had the best total score. It finished with a final score of 209, while Concept A and Concept C only had scores of 193 and 177, respectively. The areas that Concept B surpassed the other two include the weight, portability, affordability, and ease of use. Concept A and C's use of three wheels is a major drawback because it limits the dynamic stability of the device and adds unnecessary weight and size to the scooter.

Design development

There were many different considerations taken when developing each component of the scooter. A couple of motor types were compared and contrasted against the customer needs, and ultimately, a direct drive hub motor was chosen to use instead of a gear based chain motor. One benefit in picking the hub motor is that it eliminates external moving parts, which should reduce the risk of operating failure. The gear based chain motor has a larger probability of mechanical failure. Another key factor influencing this decision is how the motor is going to be primarily used. Gear based chain motors are extremely beneficial when it comes to all terrain uses and intensive hill climbing. The goal of the PAMD, however, is having a lightweight scooter that will help with inner-city travel. It isn't designed with the need for rigorous use. One last advantage of the hub motor is that it minimizes the amount of noise it produces, whereas a gear based chain motor is much louder.

Both the size and weight of the motor also play a large factor in the final motor choice; while purchasing a motor with a large power output may increase the device's speed, it also increases the device's weight. Looking at the target specifications in Table 2, it was decided that using a 200-400 watt open voltage hub motor is light enough to keep the device highly portable and would fulfill the customer needs. The motor is compatible with input voltage anywhere from 24-48 volts, as long as the input power is between the 200-400 watt range. The chosen motor can be seen in Figure 4.

Figure 4. Hub Motor [4]

With a 36 volt battery, the motor is capable of reaching a maximum speed of 13 mph with a 160 pound rider. Wheel size is also an important factor in determining the speed capabilities. As the diameter increases, so does the maximum speed. A 12.5" wheel diameter was chosen for the design because it provides an acceptable speed while keeping the device relatively compact. The dimensioned drawings of the wheel to be used can be seen in Figure 5.

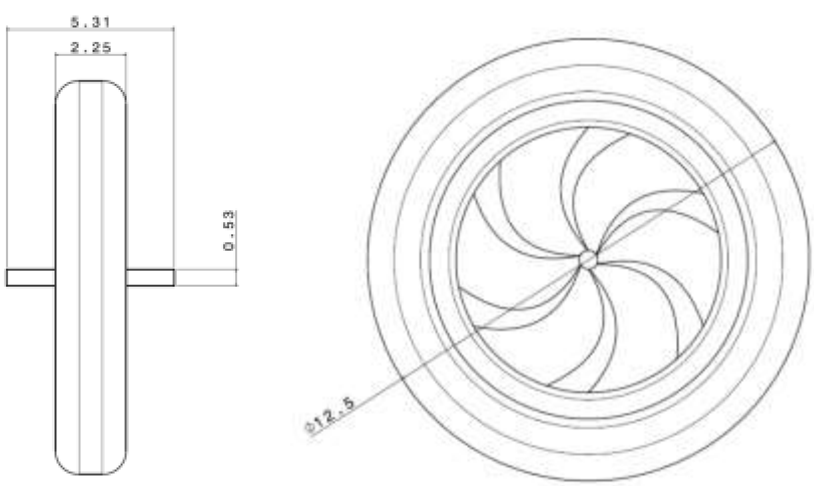

Figure 5. Wheel Dimensions (a) front view and (b) side view

A lightweight front fork was then picked that would fit the wheel and axle size being used. The fork, weighing 2.35 lbs, can be seen in Figure 6.

Figure 6. Front Fork [5]

After realizing that increasing the voltage of the battery would not increase the device's speed, a 36 volt, 10 amp battery size was settled upon. Using a battery of this size will produce approximately 45 minutes of driving time based on the power needs of the motor while operating in the normal consumption region. After comparing weights and prices of various batteries available on the market, it was decided that making and assembling the battery in-house would cut down the weight from 11 pounds to approximately 7 pounds. The extra weight will be conserved by not using a dense outside case on the battery, but a lightweight, low-heat resistance substance, such as plastic, instead.

The material that the group decided to use for the frame of the scooter (handle bars and joint) is 6061-T6 specific grade aluminum alloy. It is a strong, lightweight material that has good mechanical properties and is able to be welded. This particular alloy has a maximum tensile strength of 50 ksi and tensile yield strength of 42 ksi, making it highly durable for heavy duty performance [6]. The 6061-T6 aluminum is heat treated and artificially aged to make the material stronger. It is also one of the most common aluminum alloys used in manufacturing, making it easy to find. Originally, 5083 aluminum was desired for its higher strength and weldability, but because of its scarcity and cost, 6061 aluminum was chosen. The alloy's relatively lightweight characteristics make it ideal to use for the PAMD project.

The joint is comprised of two plates attached to the base of the scooter with a length of square tube between them. The end of the square bar is pinned into the plates, creating a hinge for the handlebar and front wheel assembly to pivot about. Further up the square tube, but still within the plates, a second, larger transecting pin spans the exact width of the plates and tube with the quick release binder clamp going through the second pin. When the binder clamp is in its locked position, the frictional force it exerts on the plates will hold the square tube in position. When the clamp is disengaged, the square will be free to pivot. The design for the folding joint was made because of its simplicity. Within the whole joint there are only two moving parts; the pin that the front assembly pivots on, and the quick release binder clamp. A similar style of folding mechanism has also been previously used in industry products. A side view of the joint can be seen in Figure 7.

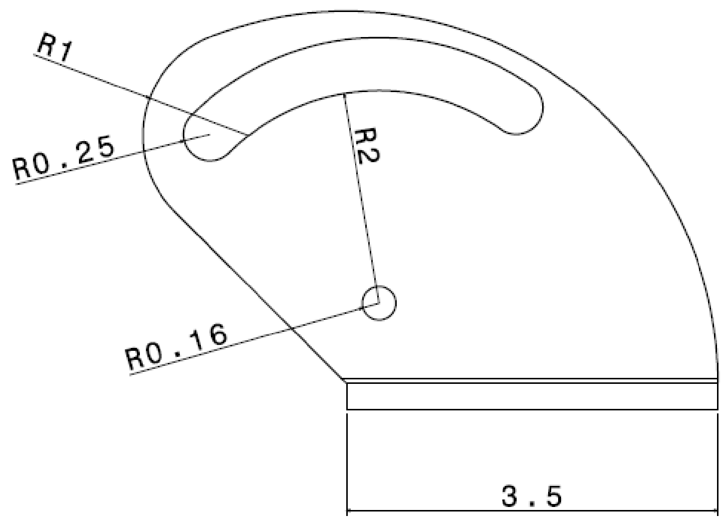

Figure 7. Side View of Joint Plates

For the material of the base, the group decided to stray from use of aluminum, unlike most scooters on the market. It was determined that the use of a composite material, such as wood and fiberglass, would provide sufficient strength and be much more lightweight. Using 0.5” thick birch plywood with two layers of fiberglass on the top and bottom, the base will deflect less than 0.4” with 220 pounds of force located at its center. Using the composite base instead of aluminum saves over 4 pounds of weight on the scooter. The dimensioned drawing of the base can be seen in Figure 8.

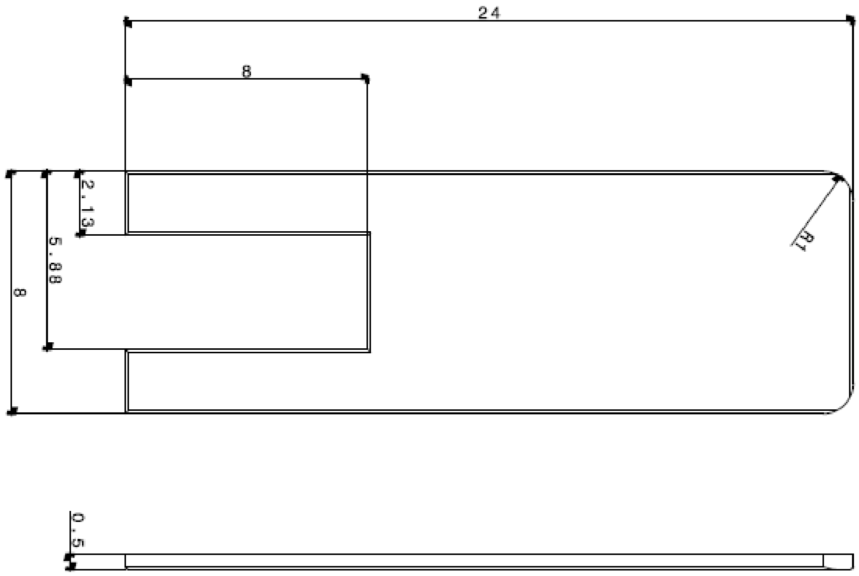

Figure 8. Base Design

A more developed version of the PAMD design can be seen in Figure 9. The PAMD in its folded, portable, position can be seen in Figure 9(b). Figure 10 then shows the approximate size of the full scooter.

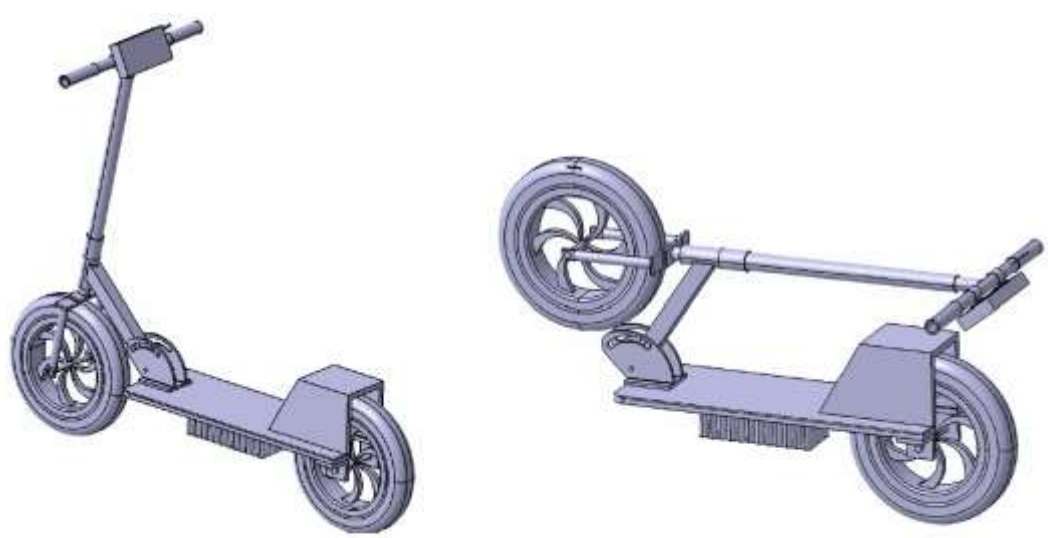

Figure 9. Developed Concept in (a) unfolded position and (b) folded position

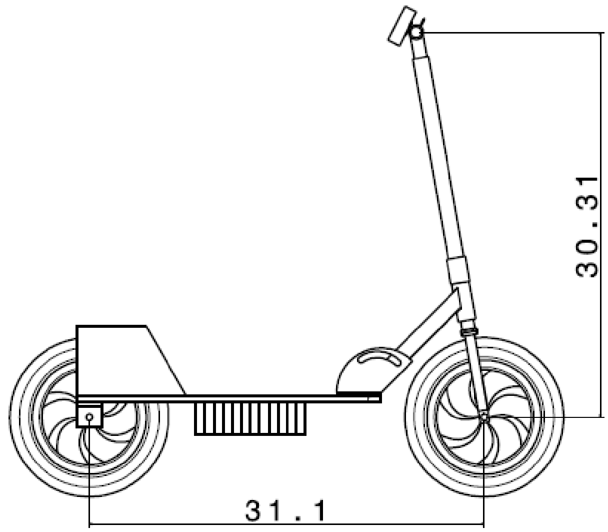

Figure 10. Size of Developed Concept

Prototyping

Building of the prototype began at the beginning of the Spring 2015 semester. All materials needed to be ordered and group members needed to go through machine shop training. Then, the base was built and the aluminum tubes were cut to size. During that time, the motor was tested to determine the optimum input voltage and current to use in order to build the battery. The aluminum will soon be sent to be welded and cut in order to build the handlebars and joint. The battery will also be put together, as well as programing the microcontroller. Then, the complete prototype will be assembled.

Testing

Once the prototype is completed, testing will be done on it to determine how well it meets the original goals set for it. Quantitative testing that will be done includes testing its speed, battery life, braking distance, weight, and deflection of base. Qualitative testing will include testing its carrying/storage abilities, as well as functions of the microcontroller.

Conclusion

It was critical that the group remember the objectives of the project throughout all stages of the design process. The PAMD needed to be a lightweight device that would easily get someone from one place to another. Once the problem was clearly defined and the customer needs understood, background research could begin. It was important to know what products already exist and what their flaws were. The group could then start developing design concepts that attempted to improve upon those flaws. Decisions had to be made regarding what materials to use, the size of various components, and design features to be included. These many decisions ultimately affected the size, weight, speed, and user experience of the device. The best concept is chosen by comparing the design to the customer needs and further refining it. Finally, the device gets to be built and tested. The team gained valuable experience working together, and discovered the many types of unexpected problems that arise throughout the design and prototyping phases. The PAMD senior design project was a great opportunity for the group members to learn firsthand how an idea becomes a finished product.

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