Extendable Pedal Car

A Major Qualifying Project Report
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Abstract

Children grow extremely quickly, and parents are constantly replacing clothes, shoes, and toys to accommodate the size changes. To limit the need to replace toy vehicles, the goal of this project is to design and build a children's toy pedal car that extends with them as they grow between the ages of 5 and 7. This growing pedal car is the only toy automobile on the market in which the whole car extends for the selected age range, making the car useful for several years and comfortable for the growing child. The final design uses a telescoping frame to extend the distance from the seat to the pedals and an adjustable steering wheel to create a 10-inch extension to accommodate the average growth of children in this age range. The vehicle is recommended for a child up to 70 lbs. and tested to a safety weight of 210 lbs.

Acknowledgments

The team would like to thank the many people who assisted with the completion of this project in many varied ways. Professor Eben Cobb: for invaluable advice and support throughout the project. Dr. Carol Cobb: for assistance with editing. Barbara Furhman: for assistance with the purchasing process and problem solving. Payton Wilkins: for assistance with project logistics and scheduling. Washburn machine shop staff: for invaluable assistance with welding and constructing the vehicle. And to all others who lent their valuable expertise and time to the project.

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1. Introduction

Transportation style toys constitute a significant part of the toy market, everything from little red wagons to tricycles, motorized cars to bicycles. The majority of these toys are built for a small age or size range, and once the children grow larger the toys are discarded or sold. Also many children are attached to certain toys and are upset when they can no longer fit inside or on their beloved toy. Also, families often have multiple children of different ages and sizes, who each need different sized toys. Many parents also crave a sturdy, long lasting investment when they purchase a toy for their children. The toy market has adjustable toys for young children that convert from baby to toddler size. There are also adjustable bicycles that have certain associated age ranges. The toy market has little to supply each of these needs in an all-in-one toy for children older than toddlers. Therefore the goal of this project is to design and prototype a children's pedal car that expands to fit the needs of a growing child between the ages of 5 and 7. The toy car should have an adjustable wheel base that extends with minimum effort.

2. Background

In order to create a comprehensive and excellent pedal car design, our team extensively researched many aspects of the design process. We looked into the pre-existing designs currently on the market, designs of the past, safety concerns for children, data on our target audience, and materials that are available to construct our design.

2.1 History of Pedal Cars

Pedal cars were developed shortly after the first automobiles emerged. The first pedal cars appeared in the 1890’s and mostly emulated the car models already on the road. Children desired to copy their parents, and the cars were highly sought after. However, the toys were expensive and mainly marketed to wealthy families. The cars hit a peak in popularity during the 1920’s and 1930’s. Through the time of the Great Depression pedal cars remained pricey yet still the toy of choice for affluent children, but by the time of World War II production had ceased as steel was required for the war effort. The postwar boom in prosperity and children saw the revival of the pedal car. These new designs were far simpler, entirely manufactured out of metal, and thus affordable for the general public. Like cars of the time, the pedal cars came in a large range of models, from inexpensive models such as the miniature Whippet design to more opulent models such as the Studebaker. These pedal cars were designed to be as realistic as possible, often featuring customizable components including working lights, horns, and windshield wipers, as well as custom paint and other decorations, see Figure 1.

Figure 1: Pedal Car Modeled after Motor Car

Pedal car production transitioned away from metal designs in the 1960's with the widespread availability of plastic and introduction of new safety regulations. By the 1970's the first plastic pedal cars were available, however the designs did not follow the previous realistic tradition. The new cars lost much of the craftsmanship in favor of inexpensive and colorful plastic bubble designs. The advent of the Marx Big Wheel tricycle, Figure 2, sounded the death knell for pedal cars.

Figure 2: Marx Big Wheel Tricycle

Many of the most classic pedal cars were designed in the 1950's, and some are still available today through auctions or found in garage sales. Most models from that era were created entirely out of metal, in careful imitation of automobiles on the road. Crafted with high standards the toys were expensive and had impressive longevity.

Pedal cars were almost entirely replaced by the more lightweight and portable tricycle. Current toy cars on the market tend to be motor driven. Our team searched for pedal cars at several major retailers, however the closest readily available alternatives we could find were electric motor cars and tricycles, see Figure 3. Most of the designs on sale were marketed for ages 5 to 7, with a few marketed to the younger age group of 3-5 years old. Most retailers begin marketing bicycles to children of age eight and above.

Figure 3: Toy Vehicles Found in Various Retail Stores

Bicycles are marketed toward an older age group of children, however the toy design has many useful aspects for pedal car designs. The bicycle chain drive is a good method of powering the rear wheels of a car. Also the front wheel steering and welded metal frame inspire pedal car designs. Adult bicycle wheels are generally too large for a children's toy, see Figure 4, however a smaller version of the wheel is an excellent option for car wheels, as it is lightweight, durable, and has good grip.

Figure 4: Bicycle Found at Retail Store

Many people are attempting to bring back the classic 1950's pedal car with "Do It Yourself" (DIY) designs, both for children's and adults' pedal cars, see Figure 5. The widespread dissemination of information through the internet is making DIY construction easy and affordable: crafting websites include instructions and home designers document their own process through design blogs.

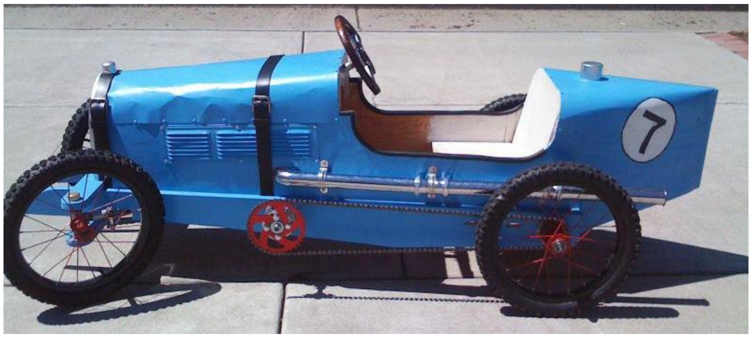


Figure 5: DIY Pedal Car

DIY designs are not limited to pedal cars. There are many options for the creation of homemade Go-Karts. Unlike many of the pedal car designs, the go kart designs tend to be more simplistic, often consisting of a simple frame and motor. One design that we discovered in the process of our research was a Go-Kart created out of PVC piping, see Figure 6. The PVC piping replaced the metal frame, and adds a new design idea to our growing list.

Figure 6: PVC Go-Kart

When researching pedal systems, the first, most obvious choice is the bicycle pedal and chain. However this idea has certain limitations, such as inability to adjust the chain to accommodate a growing child. Another initial pedal design is a simple direct drive pedal where the pedals directly turn the front wheels. The inherent difficulty is steering when the front wheels are in a fixed orientation. This style of pedal design is found in pedal boats, however these boats use a rudder to steer thus circumventing the navigation challenge, see Figure 7. Automobiles use a gearbox and shaft drive system that could be adapted for use in a pedal car.

Figure 7: Pedal Boat

2.2 Children’s Data

In the book, Exploring Lifespan Development, Laura Berk discusses childhood development. According to Berk, “Five- and 6-year-olds simultaneously steer and pedal a tricycle and flexibly move their whole body when throwing, catching, hopping, and jumping.” Starting at five years old, children have the cognitive and physical ability to use a pedal car. Any younger than five, the child may not have the coordination to steer and pedal at the same time. This obviously can pose a safety risk to both the child and those around them.

The growth rate for children across the world is tracked through growth charts that separate children into different percentiles based on their physical development. According to charts obtained from a medical information website, the height of five year old children, both girls and boys, in the fifth percentile is approximately 41 inches. The 95th percentile of height for seven year olds was found to be 51 inches for girls and 52 inches for boys, see Figures 8 & 9. The weight charts show that for five year old children in the 5th percentile the average weight is 35 lbs, and for boys and girls in the 95th percentile the weight is about 75 lbs, as shown in Figures 10 & 11 below.

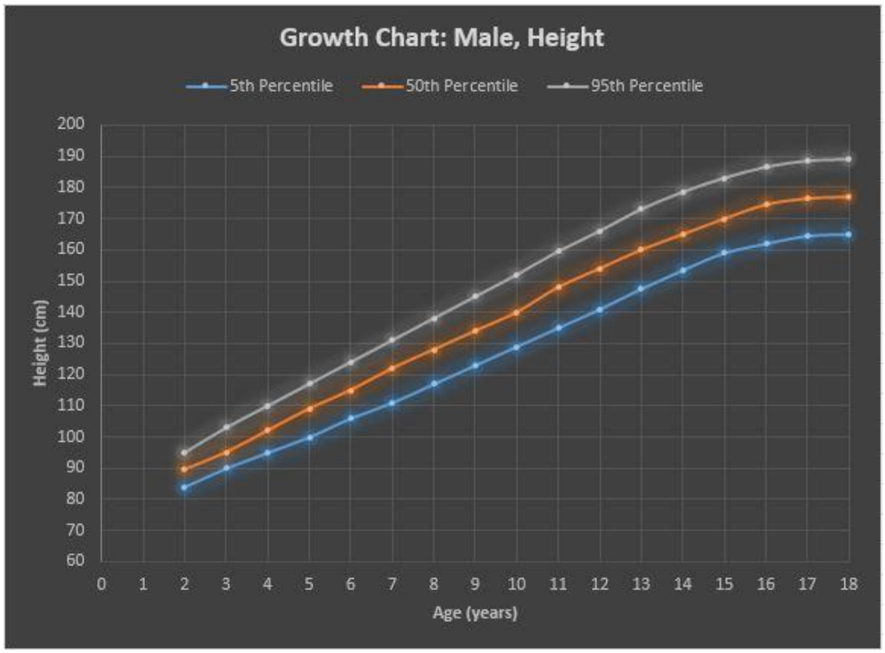


Figure 8: Growth Chart: Male, Height

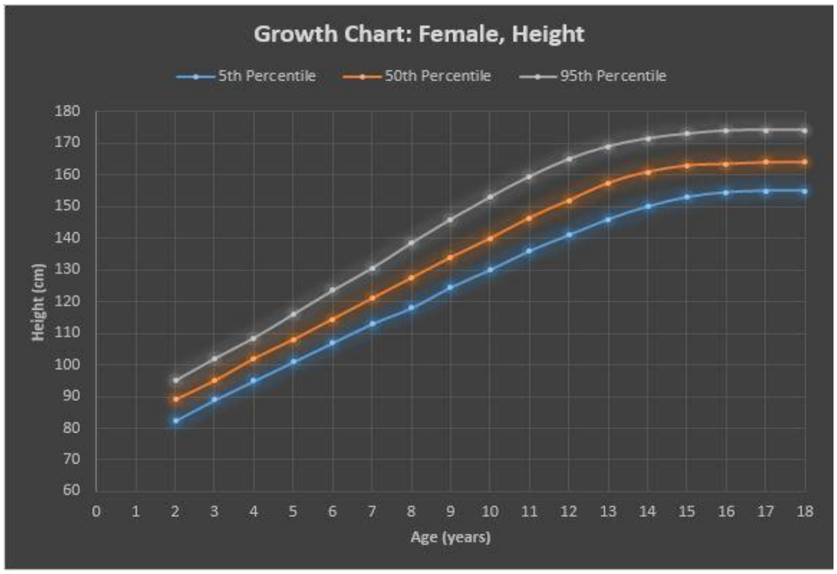


Figure 9: Growth Chart: Female, Height

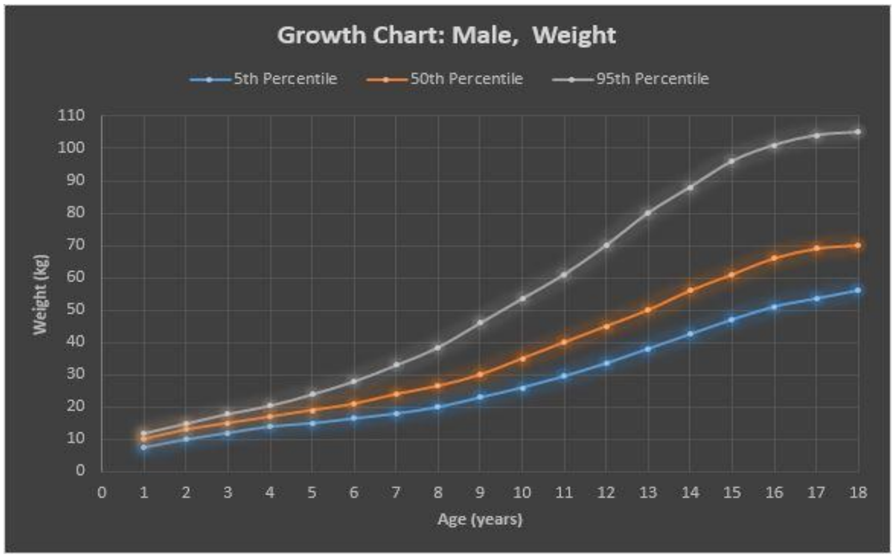


Figure 10: Growth Chart: Male, Weight

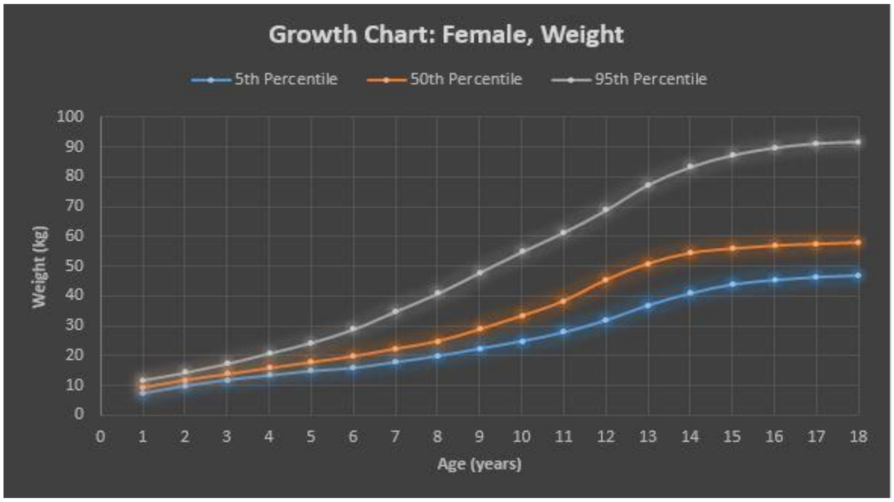


Figure 11: Growth Chart: Female, Weight

According to the National Library of Medicine, the fifth percentile for leg length for 5 year old girls and boys was 17.7 inches (45 cm). The same charts, Figures 12 & 13 below, show that the 95th percentile of leg length for 7 year olds was around 25.6 inches (65 cm) for both boys and girls. Although children's arm lengths cannot be readily found, arm length can be estimated based on clothing sizes. From the children's size chart, Figure 14, an arm length of 10.5 inches can be estimated for the smallest 5 year old (size 4), and 13.5 inches can be estimated for the largest 7 year old (size 8).

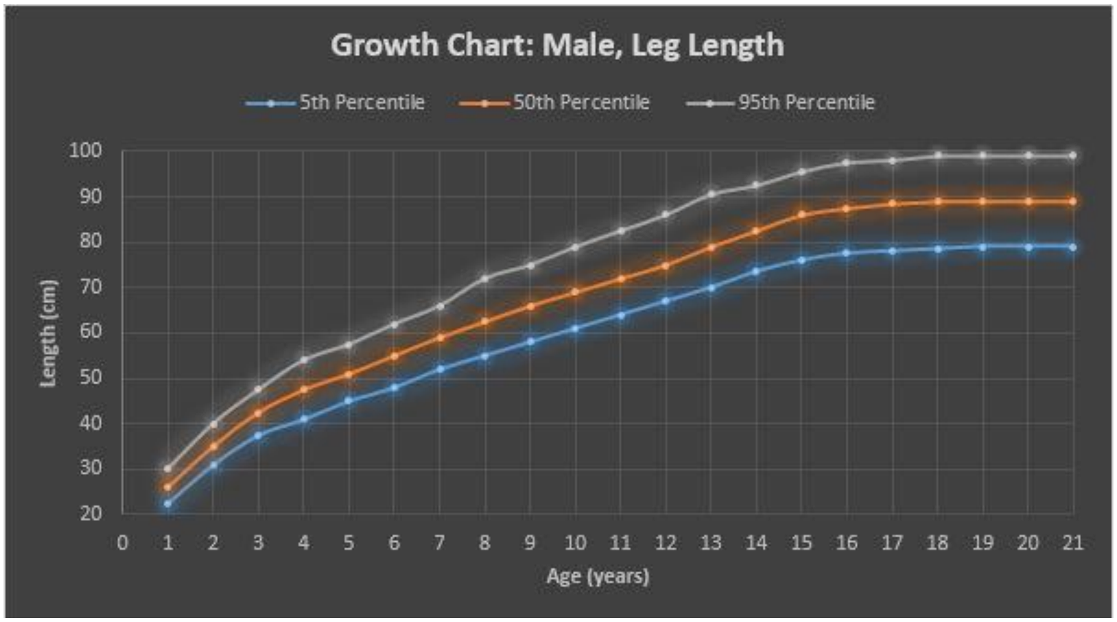


Figure 12: Growth Chart: Male, Leg Length

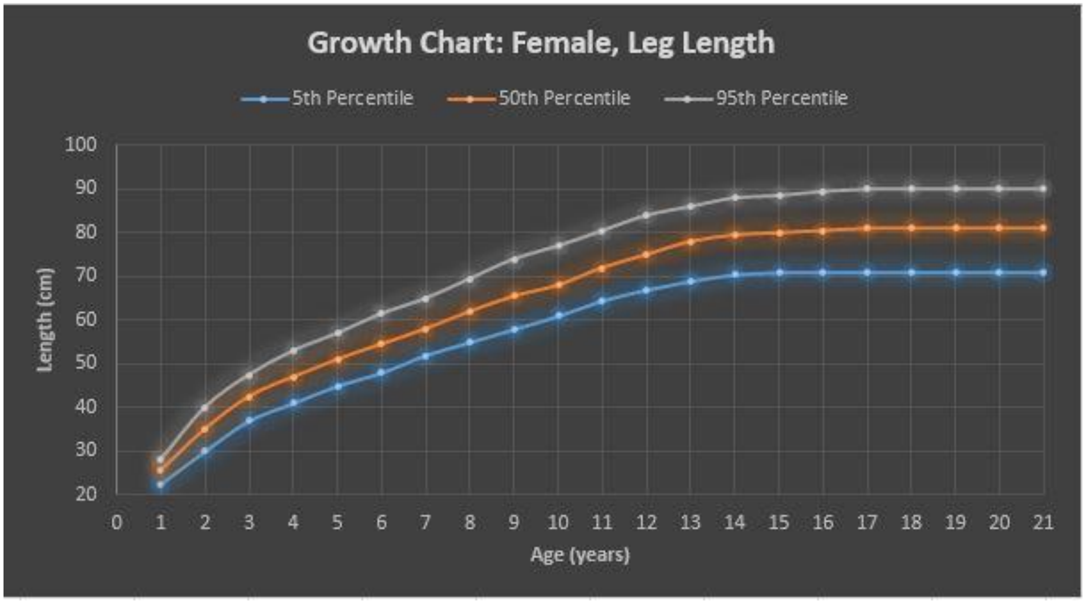
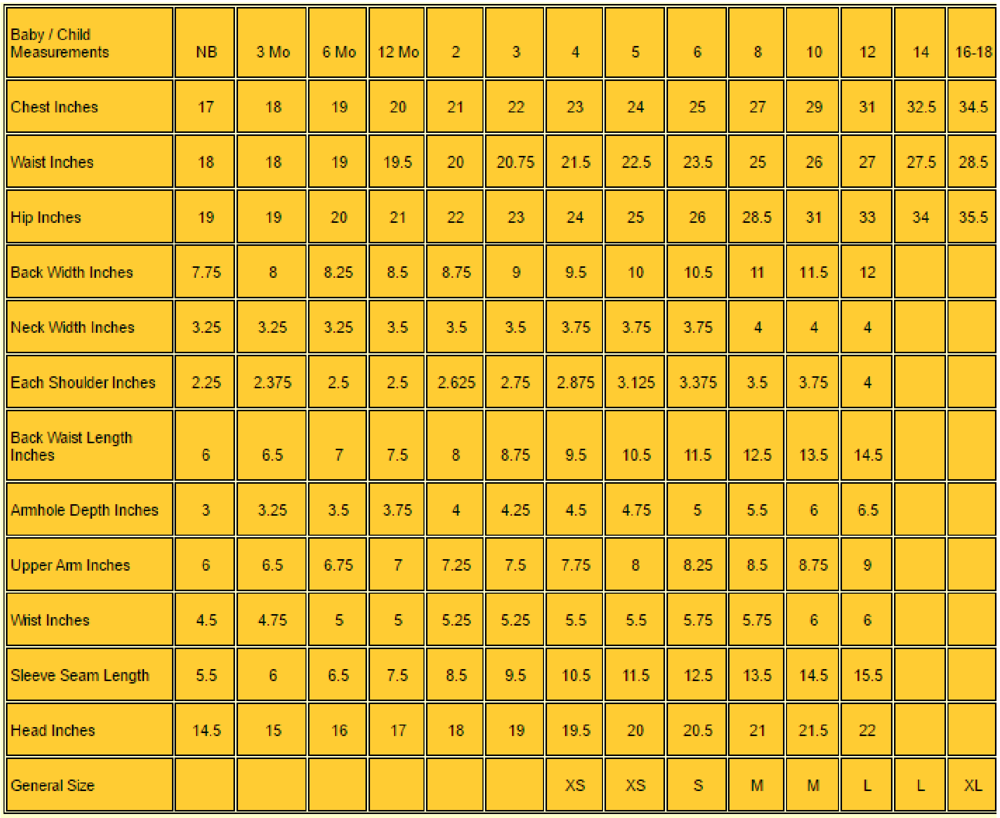


Figure 13: Growth Chart: Female, Leg Length



Baby / Child Measurements	NB	3 Mo	6 Mo	12 Mo	2	3	4	5	6	8	10	12	14	16-18
Chest Inches	17	18	19	20	21	22	23	24	25	27	29	31	32.5	34.5
Waist Inches	18	18	19	19.5	20	20.75	21.5	22.5	23.5	25	26	27	27.5	28.5
Hip Inches	19	19	20	21	22	23	24	25	26	28.5	31	33	34	35.5
Back Width Inches	7.75	8	8.25	8.5	8.75	9	9.5	10	10.5	11	11.5	12		
Neck Width Inches	3.25	3.25	3.25	3.5	3.5	3.5	3.75	3.75	3.75	4	4	4		
Each Shoulder Inches	2.25	2.375	2.5	2.5	2.625	2.75	2.875	3.125	3.375	3.5	3.75	4		
Back Waist Length Inches	6	6.5	7	7.5	8	8.75	9.5	10.5	11.5	12.5	13.5	14.5		
Armhole Depth Inches	3	3.25	3.5	3.75	4	4.25	4.5	4.75	5	5.5	6	6.5		
Upper Arm Inches	6	6.5	6.75	7	7.25	7.5	7.75	8	8.25	8.5	8.75	9		
Wrist Inches	4.5	4.75	5	5	5.25	5.25	5.5	5.5	5.75	5.75	6	6		
Sleeve Seam Length	5.5	6	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5		
Head Inches	14.5	15	16	17	18	19	19.5	20	20.5	21	21.5	22		
General Size							XS	XS	S	M	M	L	L	XL

Figure 14: Children's Clothes Sizing Table

2.3 Safety

In the development of any product, especially one that is marketed towards children, safety is the first concern. The United States has a rigorous set of codes with which all toys sold in the country must comply. The standards are developed and updated through constant research and testing. The U.S. Consumer Product Safety Commission was created to set standards and monitor toy companies. There are several applicable toy safety standards for our pedal car prototype. One is the American National Tricycles- Safety Requirements (ANSI). Other regulations include CFR standards that cover sharp edges in toys, the ASTM standards which cover children’s safety restraint systems, allowable paints, and metals. Safety standards contribute to the selection of a toy’s allowable age range, as well as the selection of materials and design concepts.

Car safety is a massive industry, and many safety standards derive from keeping children safe in vehicles. Car airbags deploy in a crash that create -1.0g deceleration within 10 milliseconds. Bicycles and tricycles have only a fraction of the mass of a car, and can only travel at a percentage of the speed, thus the crashes can be considered a fraction of force of impact in a car.

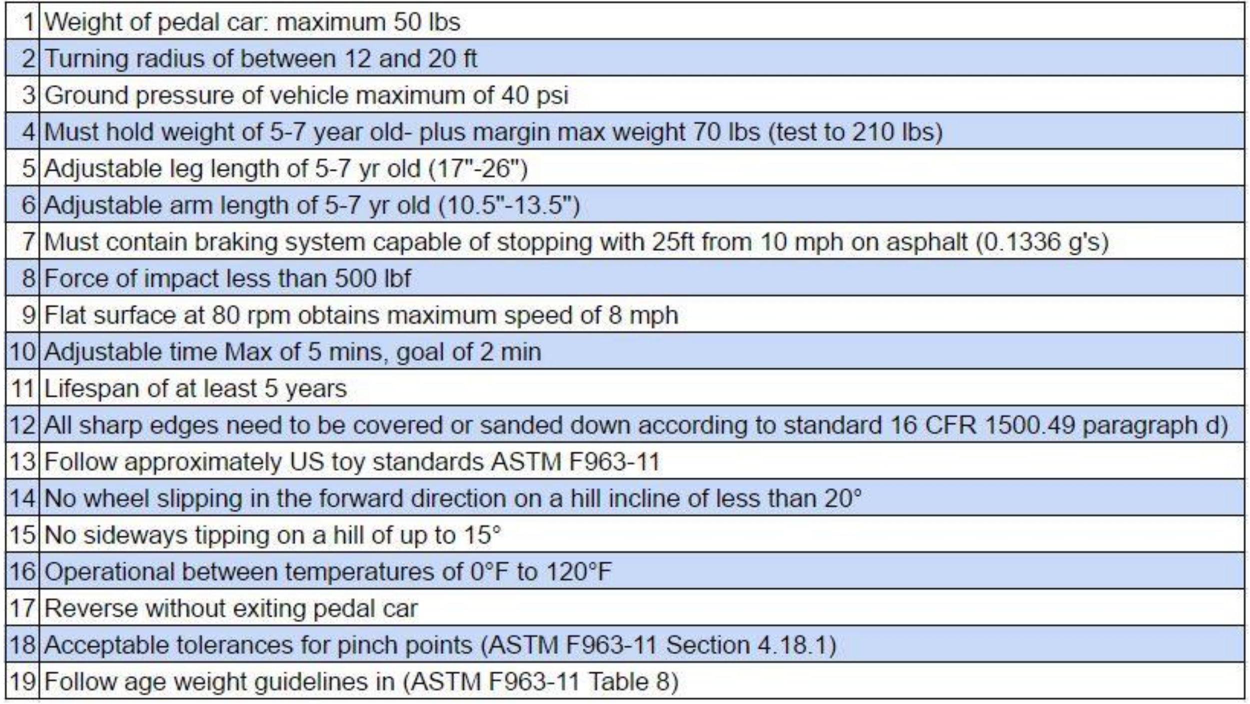
As pedal cars lack the safety documentation and information of bicycles and tricycles, we are applying many of the regulations and safety concepts from those vehicles to our pedal car. The same concept also applies to considering the statistics on children and adults. For information that is difficult to discover on children, mainly through regulations on testing, we can use adult data scaled based on height and weight to approximate a child.

3. Methodology

3.1 Task Specifications

Before designing the adjustable pedal car, a list of task specifications was created to guide the development of the project as displayed in Table 1 below.

Table 1: Task Specifications



1	Weight of pedal car: maximum 50 lbs
2	Turning radius of between 12 and 20 ft
3	Ground pressure of vehicle maximum of 40 psi
4	Must hold weight of 5-7 year old- plus margin max weight 70 lbs (test to 210 lbs)
5	Adjustable leg length of 5-7 yr old (17"-26")
6	Adjustable arm length of 5-7 yr old (10.5"-13.5")
7	Must contain braking system capable of stopping with 25ft from 10 mph on asphalt (0.1336 g's)
8	Force of impact less than 500 lbf
9	Flat surface at 80 rpm obtains maximum speed of 8 mph
10	Adjustable time Max of 5 mins, goal of 2 min
11	Lifespan of at least 5 years
12	All sharp edges need to be covered or sanded down according to standard 16 CFR 1500.49 paragraph d)
13	Follow approximately US toy standards ASTM F963-11
14	No wheel slipping in the forward direction on a hill incline of less than 20°
15	No sideways tipping on a hill of up to 15°
16	Operational between temperatures of 0°F to 120°F
17	Reverse without exiting pedal car
18	Acceptable tolerances for pinch points (ASTM F963-11 Section 4.18.1)
19	Follow age weight guidelines in (ASTM F963-11 Table 8)

3.2 Concepts

From brainstorming ideas for the pedal car design, three areas of the pedal car design were selected on which to focus. They were the frame, the pedaling system, and the steering mechanism. To achieve the goal of making the car expandable, two concepts for the frame were designed. The first was a solid, fixed frame in which the seat and wheel would be adjustable similar to those of an automobile. The second was an expandable frame that works on a principle, similar to an extendable cane, with two circular pipes that slide into each other and a pin that secures the pipes in specific positions. Two main concepts for the steering mechanism were also developed. The first was based on a four-bar linkage, where turning one part of the linkage turns the connected wheels. The second steering concept was based on a rack and pinion design, where the steering wheel turns a gear across a rack to move the wheels. Four separate types of pedaling mechanism were created. The first and simplest was direct drive where the pedals connect to the front wheels and turn them directly. The second was a chain drive mechanism similar to that used on a bicycle, in which the pedals turn a chain that rotates the rear wheels. The third was a pushing mechanism in which two linkages turn an S shaped axle and rotate the rear wheels. The final and most complicated design was a gearbox that drives a drive shaft similar to the mechanism used in a car. The various design pieces were combined to produce 32 different permutations. The designs that physically could not work together were then eliminated and the remaining 7 concepts were modeled using CAD software. Through the CAD software several designs were eliminated on the basis that they would be difficult to manufacture. The remaining initial designs are displayed below.

Concept 4, which is displayed below in Figure 15, includes the fixed frame design with rack and pinion steering and direct pedaling. This design appears to be the simplest, however the joint needed to allow both the direct pedaling and steering to exist on the front wheels is difficult to design and build. This design would also require an adjustable seat and steering wheel, not pictured, as the frame itself does not adjust for a growing child.

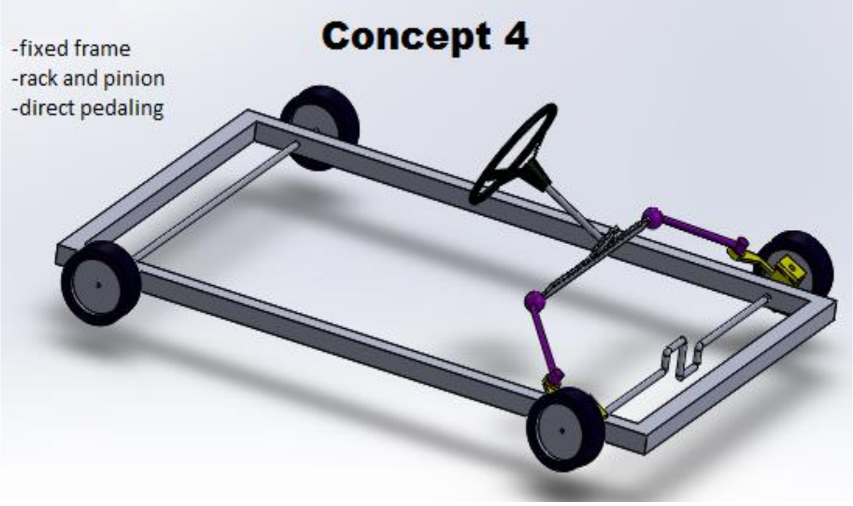


Figure 15: Concept 4

Concept 8, pictured in Figure 16 below, also uses the idea of a fixed frame and rack and pinion steering, but the pedaling mechanism is a chain drive. This design would also require an adjustable seat and steering wheel to compensate for the fixed frame.

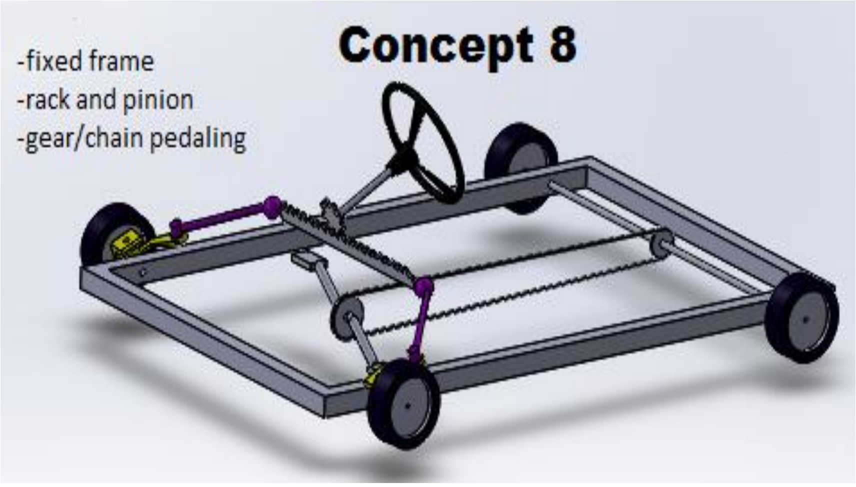


Figure 16: Concept 8

Concept 12, displayed in Figure 17, includes the rack and pinion steering and fixed frame, though the steering is now a gearbox and driveshaft pedaling system. The gearbox and driveshaft are very difficult to manufacture and are expensive to buy. Once again this design would have to include an adjustable seat and steering wheel.

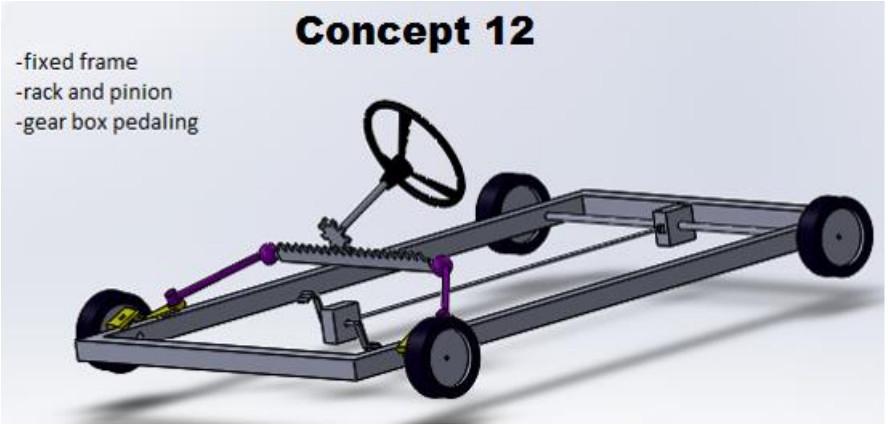


Figure 17: Concept 12

Concept 14, displayed in Figure 18, includes four-bar steering, a fixed frame, and a chain drive. In this particular iteration of the design, the pedal car would need an adjustable seat and steering wheel.

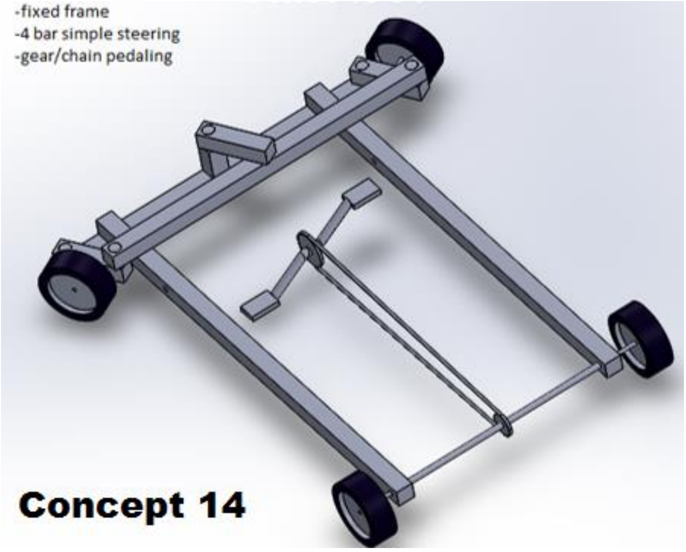


Figure 18: Concept 14

Concept 16, displayed in Figure 19, differs from the previous designs with a push pull pedaling system. The child pushes alternatively on each of the pedals which pulls the S-shaped rear axle causing it to turn. This type of pedaling varies vastly in experience for the user compared to the other three designs which simulate the same style of pedaling as a bicycle. The pedaling has more of a push-push motion rather than the circular motion of bicycle pedals. This design has a fixed frame and would require an adjustable seat and steering wheel.

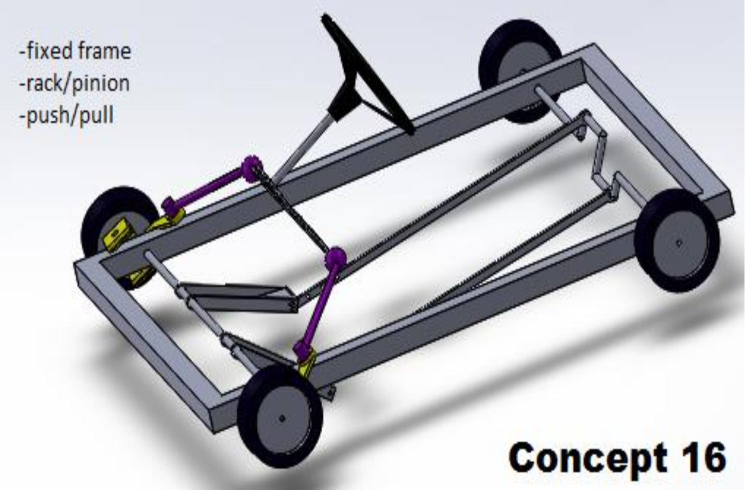


Figure 19: Concept 16

Concept 30, displayed in Figure 20, includes the same push pull pedaling system as the previous design. The design also included the four-bar steering and an adjustable frame. Four-bar

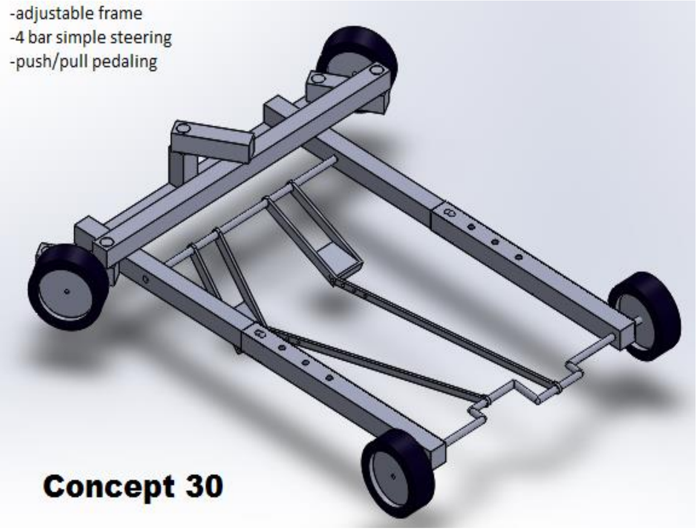


Figure 20: Concept 30

steering is the simplest type of steering due to its manufacturability. The adjustable frame allows for the change in leg and arm lengths of a growing child.

Concept 32, displayed below in Figure 21, is very similar to concept 30. The only change is the steering type, which is rack and pinion in this design.

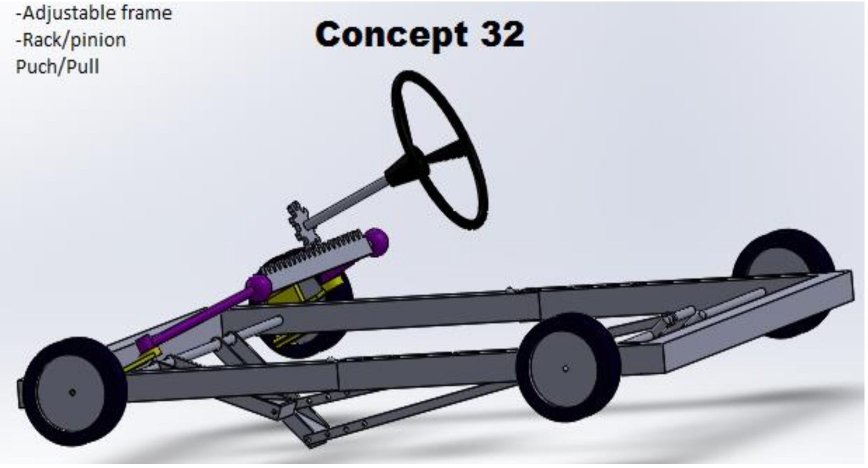


Figure 21: Concept 32

3.3 Scale Model

To aid in the design and selection process, we created a scale model of concept 14 using an erector set, displayed in Figure 22 below. An erector set was used to simulate standard dimensioned materials. In working with the scale model, we found that concept 14 could be adapted to have an extendable frame. In order to accommodate this design change, we would have to incorporate a method for lengthening the chain. Our solution was to have a set number of links to add when lengthening the frame. This method would require the use of a chain breaker, but the adjustment time will still fit the functional requirement of 5 minutes.

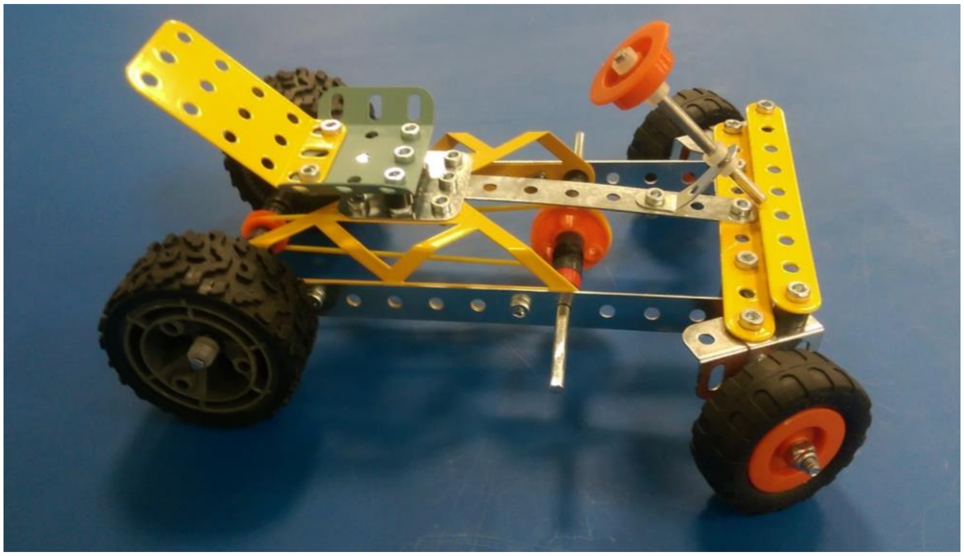


Figure 22: Scale Model Using Erector Set

3.4 Design Matrix

To aid in the selection of a final design, a design matrix was created to rate the various designs and find the strongest concept, displayed in Table 2 below. The concepts were rated on cost (estimated total cost of parts), manufacturability (how easy it is to build), safety (the ease of covering potentially dangerous parts of the design), simplicity, performance, ease of use, durability, and total weight of the design. Each rating factor was given a weighting out of 100% to balance the importance of each consideration. Cost, durability and weight were given the lowest ratings of 5% since in this prototype phase the goal is to stay within the task specifications and total budget, not to optimize the design for production. Simplicity, manufacturability, and performance are important for development of the prototype, though not as important as ease of use and safety, which were given the highest weightings, because safety and usability are especially important as the product is marketed for children. A rating of 1 meant the design was considered to be poor in the rating area, and a rating of 10 meant that the design was excellent in the design area. The first column is the rating out of 10, and the second column is the weighted rating.

Table 2: Design Matrix

		Solution													
	Weighting	Concept 4		Concept 8		Concept 12		Concept 14		Concept 16		Concept 30		Concept 32	
Cost	**5%**	8	0.4	6	0.3	2	0.1	9	0.45	5	0.25	5	0.25	3	0.15
Manufacturability	**15%**	4	0.6	5	0.75	7	1.05	8	1.2	4	0.6	6	0.9	3	0.45
Safety	**25%**	5	1.25	3	0.75	4	1	6	1.5	5	1.25	5	1.25	9	2.25
Simplicity	**10%**	7	0.7	7	0.7	2	0.2	8	0.8	7	0.7	6	0.6	5	0.5
Performance	**15%**	4	0.6	3	0.45	8	1.2	5	0.75	7	1.05	7	1.05	7	1.05
Ease of Use	**20%**	8	1.6	3	0.6	4	0.8	6	1.2	6	1.2	7	1.4	6	1.2
Durability	**5%**	7	0.35	3	0.15	4	0.2	5	0.25	6	0.3	10	0.5	8	0.4
Weight	**5%**	8	0.4	5	0.25	1	0.05	5	0.25	6	0.3	7	0.35	5	0.25
Total	**100%**	**5.90**		**3.95**		**4.60**		**6.40**		**5.65**		**6.30**		**6.25**	

Concept 4 had the simplest appearance, however the joint to connect the direct drive and steering to the wheels is difficult to manufacture. Also the fixed frame necessitates the addition of an adjustable seat and steering wheel, which complicates the design. Concept 8 was docked in durability and cost because of the maintenance and initial cost of the rack and pinion steering. Also the rack and pinion steering is difficult to cover in a way which would prevent children from pinching their fingers. Concept 12 had the same considerations for rack and pinion steering and the addition of adjustable seats and steering wheel, but it had the addition of a gearbox pedal drive. The gearbox had both negative and positive elements, it is expensive to buy and complicated, however placing it in the design is simple and easy to manufacture, since it would be purchased. It is also fairly safe since it can easily be covered to prevent damage to any child. Concept 14 came in as the top pick, since a chain drive can be covered with a chain guard, and the four-bar steering is very simple. Children also are familiar with the bicycle pedaling mechanism. The only drawback to the design is that the frame is not adjustable, which means that an adjustable seat and wheel must be added. Concept 16 is fairly simple and the push pull pedaling is relatively easy to manufacture, however the rack and pinion steering is expensive to purchase. Concept 30 came in second place, since it has an adjustable frame and pedaling system, however there was some concern that children would be confused by the push pull pedaling system. Concept 32 had similar considerations to concept 30, however it included a rack and pinion steering system which made it less safe and more expensive.

3.5 Final Design

Figure 23: Final Design

Our final design, displayed in Figure 23, utilized many of the aspects of concept 14, and one key aspect of concept 32, the adjustable frame. Many of the aspects of concept 14 were highly advantageous for both manufacture and ease of use. Namely, the simplicity of the 4-bar steering, and the cyclical motion of the pedals. The 4-bar steering is easier to manufacture and less expensive than the alternative steering systems. The cyclic motion of the pedals is favorable from a child development standpoint as well as an ease of use perspective. Cyclic motion is fairly intuitive, easy on the joints, and transferable to bicycles later in development. It is also easier to use than the “push-pull” pedal system in the way that it has no top-dead-center stopping point. As mentioned in the scale model section, the chain will need to be able to be adjusted in order to accommodate this design change.

3.6 Stress Analysis

To assist in the design process and the selection of materials, the stress and deflection of the frame were analyzed. The stress was calculated for four different beam cross sections: circle, hollow circle, square, and hollow square. The beams were assumed at first to be two inches in diameter or along the side of the square, then adjusted accordingly up or down in size based on the calculated deflection. The stress was calculated with a force of 260 lbs, 210 pounds for the child (70 lbs times a safety factor of 3) and 50 lbs for the maximum weight of the car itself. The distance to the neutral axis is the distance from the outside of the beam to the centerline. The highest stress was found in the hollow circular beam, which is as expected. From the stress the deflection was found assuming a material of either steel or aluminum. The greatest deflection was in the aluminum hollow circle, however at 0.22 inches it is fractional compared with the task specification of less than 1 inch deflection. Studies show that a 10 degree deflection of a seat is

Table 3: Stress Analysis

Cross Section	Beam Material	Diameter (in)	Thickness of Wall (in)	Force (lbf)	Length (in)	Max Moment (in*lbf)	Distance to Neutral Axis (in)	Area Moment of Inertia (in^4)	Stress (psi)	Elastic Modulus (psi)	Deflection (in)
Circle	Steel	1		260	36	2340	0.5	0.0491	**23835**	$29.5*10^6$	**-0.1745**
Hollow Circle	Steel	1	0.1	100	36	900	0.5	0.0169	**26656.9**	$29.5*10^6$	**-0.1952**
Square	Aluminum	1		260	12	780	0.5	0.0833	**4680**	$10*10^6$	**-0.0112**
Hollow Square	Aluminum	2	0.11	260	20	1300	1	0.2700	**4814.7**	$10*10^6$	**-0.0160**
Hollow Square	Aluminum	1.75	0.11	260	34	2210	0.875	0.1787	**10818.4**	$10*10^6$	**-0.1191**

uncomfortable to the user, in the 4 foot beam used in the pedal car, a 10 degree deflection would be equivalent to a 4 inch deflection in the center of the vehicle.

The equations used in the calculations were found in the textbook Machine Design 5th edition by Robert Norton, and are displayed in Figure 24 below, as well as the picture used to visualize the stress and deflection, Figure 25.

Maximum Moment:

$$M_{max} = \frac{FL}{4}$$

Stress:

$$\sigma = \frac{MC}{I}$$

Area Moment of Inertia- Circle:

$$I_{Circle} = \frac{\pi d^4}{64}$$

Area Moment of Inertia- Hollow Circle:

$$I_{Hollow\ Circle} = \frac{\pi({d_0}^4 - {d_i}^4)}{64}$$

Area Moment of Inertia- Square:

$$I_{Square} = \frac{d^4}{12}$$

Area Moment of Inertia- Hollow Square:

$$I_{Hollow\ Square} = \frac{{d_o}^4 - {d_i}^4}{12}$$

Deflection:

$$\delta = \frac{-FL^4}{48EI}$$

Figure 25: Equations

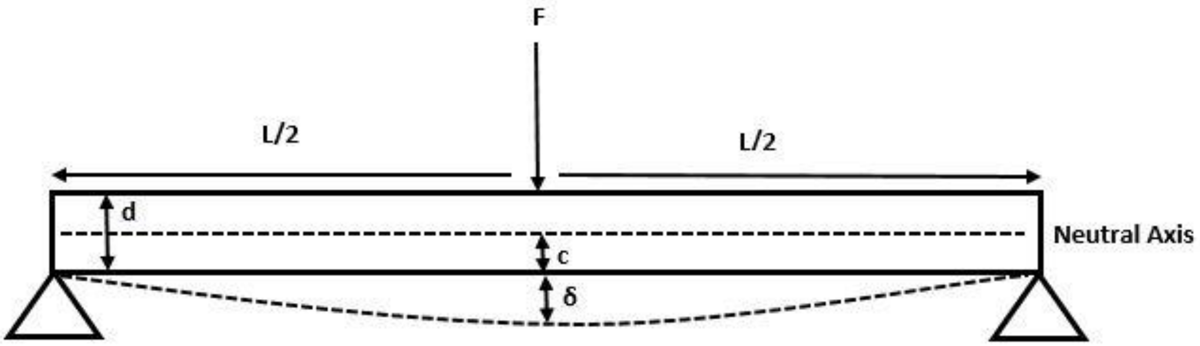


Figure 24: Stress and Deflection Diagram

3.7 Materials

Using the stress analysis to guide our material selection, aluminum was selected for the majority of the frame due to its relatively light weight and low deflection. Aluminum telecscoping tubes were chosen for the central beam of the vehicle. The larger tube is 2 inches a side and has a thickness of 0.11 inches, and the smaller tube is 1.75 inches per side with a wall thickness of 0.11 inches. The seat supports are solid aluminum 1 inch by 1 inch. The steering column was composed of canibalized bicycle parts from several 16 inch children's steel bicycles. The adjustable seat of one of the bicycles was used to make the steering wheel adjustable. A steel rod of one inch in diameter was selected for the rear axle, due to the large amount of weight concentrated in the back of the car. The seat of the car is a tractor seat, and the wheels are from the aforementioned bicycles. The body of the car is constructed from copper wire reinforced with a rigid foam then overlayed with strips of duct tape.

4. Results and Discussion

Upon completing the CAD model and stress analysis on the selected material, the process of building the pedal car began. The first step was to order the parts for the vehicle from several different sources, including Tractor Supply, McMaster Carr, and Alcobra Metals. Once materials began to arrive, construction of the vehicle started. The design was broken down into several components: the frame, the steering, the drive system, and the body.

4.1 Frame

The frame was the first component in the construction process. The base of the frame was designed in the shape of an "I", with the central beam composed of two telescoping hollow aluminum bars, shown in Figure 26. One of the aluminum tubes was 2 inches per side, the other was 1.75 inches on each side, and both had a thickness of 0.11 inches. The tubes were cut to length, lined up, and drilled with a set of sequential holes spaced 2 inches apart so that a ⅜ inch pin could secure the two tubes together. A solid aluminum block was secured to the back of the 2 inch tube and also attached to the back seat support. The rear axle of the vehicle was then attached to the rear seat support using a bearing. Upon testing, the bearing was found to be somewhat loose, not solidly mounted, so supports were added connecting the rear seat support and the axle using two more bearings, as shown in Figure 26.

Figure 26: Lowered Seat with Supports

Solid aluminum bars of 1 inch by 1 inch were used to support the seat, and were drilled and tapped, then mounted to a frame built for the seat of the car. The seat of the car was purchased from Tractor Supply, and had tapped screw holes on the bottom. A square frame was created out of the solid aluminum bars and the seat was screwed onto the frame.

The one major issue with the seat support design was discovered when the front seat support was being mounted. The support could not be screwed into the telescoping tube directly as it would interfere with the smaller tube sliding inside the larger tube. A solution was created by bracing the support rod on either side with aluminum blocks, then all three pieces were drilled through and secured with a bolt to a square bracket place around the outside of the 2 inch telescoping tube, shown highlighted in the red circle in Figure 27.

Figure 27: Adjustable Center Beam and "I" Shaped Frame

The seat was originally positioned 11 inches above the main frame because of clearance issues with the chain drive system, shown in Figure 28. However when the drive system was altered, the seat was lowered to 6 inches to provide a lower center of gravity for the car, and so that children on the 5 year old end of the adjustability range would be able to easily climb into the seat, as shown in Figure 26.

A second major difficulty was discovered when the hubs of the bicycle wheels were drilled. The wheel hubs needed to have a hole drilled through so that they could be secured to the axle of the vehicle. When the drilling operation was attempted, it was discovered that the hubs were most likely case hardened. This made the drilling extremely difficult, since the hubs were extremely hard steel. The problem was eventually overcome through brute force, which resulted in the damaging of several drill bits. In production the hubs could be cast with the hole in the correct place, or drilled before hardening to save time and the cost of damaged tools.

Figure 28: Frame of Pedal Car with Original Chain Drive and Original Seat Height

4.2 Steering

The next component to construct was the steering system. The original design for the steering system featured a flat 4 bar system, where a hook attached to the steering column rotated the rear link of the 4 bar, turning the two attached links and subsequently the wheels, displayed in Figure 29. When constructed this design had several detriments, the first of which was that the flat 4 bar created too much friction and caused difficulty in turning the car. The next issue was that there was a stacking of tolerances between the steering wheel and tires that caused the tires to only turn a fraction of the distance that the steering wheel was turned. These issues were solved by redesigning the steering column and 4 bar linkage.

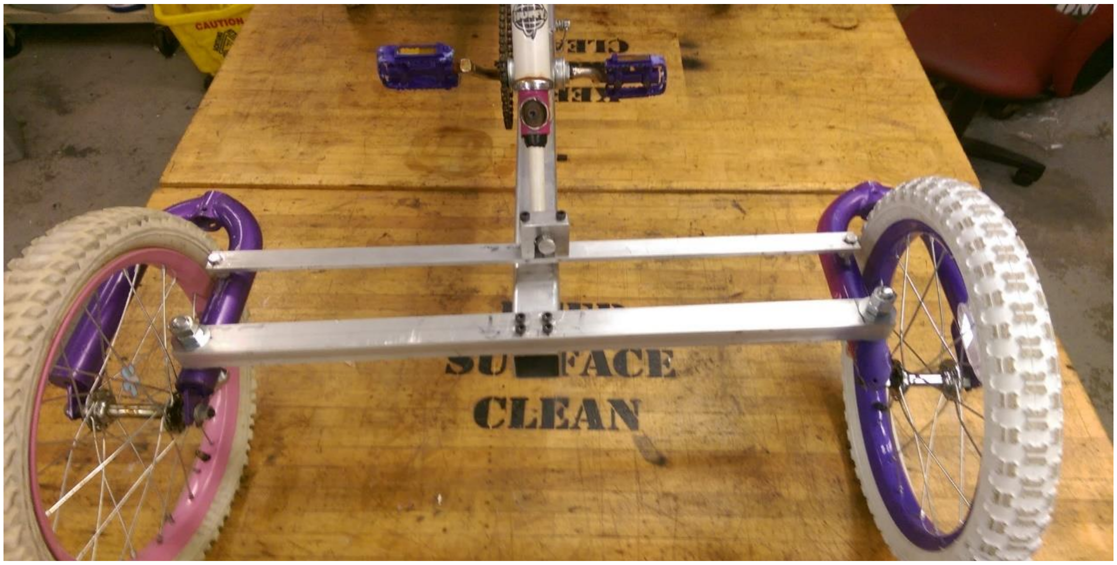


Figure 29: Original Steering System

The steering column was simplified to one rotating rod inside another rod that was connected to the frame for support. The rear link of the 4 bar was replaced with two threaded rods that were connected through rod ends to the 4 bar and the rotating steering column. This allowed for better adjustment in the 4 bar, minimizing friction. The final steering system is displayed in Figure 30 below. The rods for the steering column and steering column support were cannibalized from the frames of the used bicycles from which the wheels came. The adjustable seat mechanism of one of the bicycles was cut off and used to make the steering wheel extend along with the frame. The support for the steering column was screwed into the central beam of the vehicle frame.

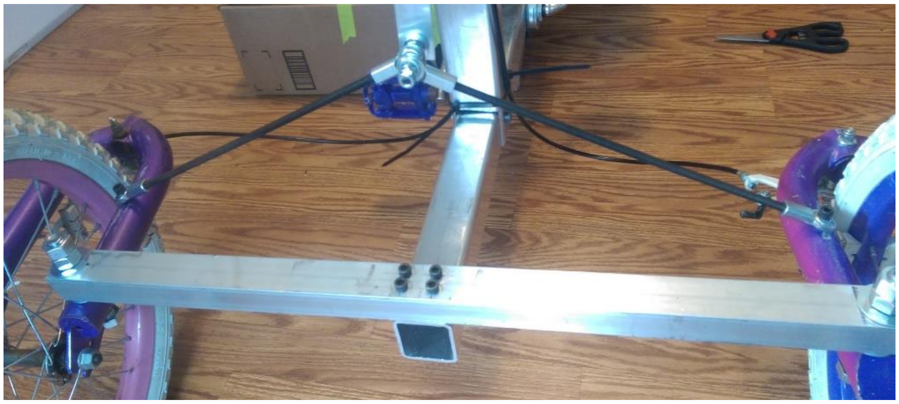


Figure 30: Final Steering System

4.3 Drive System

The drive system was built simultaneously with the steering system and the frame. A hole was drilled through the 1.75 inch aluminum tube of the main frame, and a set of pedals was threaded through. The pedals were tensioned in place with the gear on the right side of the vehicle. Though the original design was for a simple direct chain drive design, during the process of building the pedal car a two chain design was attempted. To make the car adjustable without removing chain links a lever arm was added with a double-sided back pedal braking system. A chain was run from the pedals to one side of the back braking mechanism that also had the ability to freewheel, and another chain was run from the other side of the mechanism to a gear welded to the rear axle, displayed in Figures 31 and 32. There were three major issues with the design. The first, and more significant, was the length of the lever arm required to fully tension the chain, and because of the position of the seat, the lever arm was limited in length. The second issue was that the spring used to tension the lever arm would extend in one direction only. Once at the highest setting, the spring would become immobilized. The final issue was that the stacking of tolerances from the gear on the pedals to the gear on the axle would only rotate the axle a fraction of the pedaling distance.

Figure 31: Lever Arm Drive System

Figure 32: Rear of Lever Arm Drive System

Due to the prevalence of issues with the lever arm design, the original design was restored. This design consisted of a chain threaded directly from the gear on the pedals to the gear on the rear axle as shown in Figure 33 below. To adjust this design four chain links need to be added or removed per notch on the frame that is adjusted. The design had a one to one gear ratio to maintain the safe maximum speed. The final design also had a much more efficient transfer of power from the pedals to the rear axle.

Figure 33: Final Direct Chain Drive

4.4 Body

By necessity the body was constructed after the completion of the rest of the vehicle. The body was inspired by a 1936 Auburn Boattail to carry on the legacy of the original pedal cars. The body was created by shaping copper wire and supporting it with rigid foam, shown in Figure 34. Various colors of duct tape were then stretched over the copper wire to create the appearance of metal and wood. The duct tape and wire frame is meant to simulate injection molded plastic that could be used in production of the vehicle. The finished pedal car is displayed below in Figures

Figure 34: Underpinnings of the Body

Figure 35: Finished Pedal Car

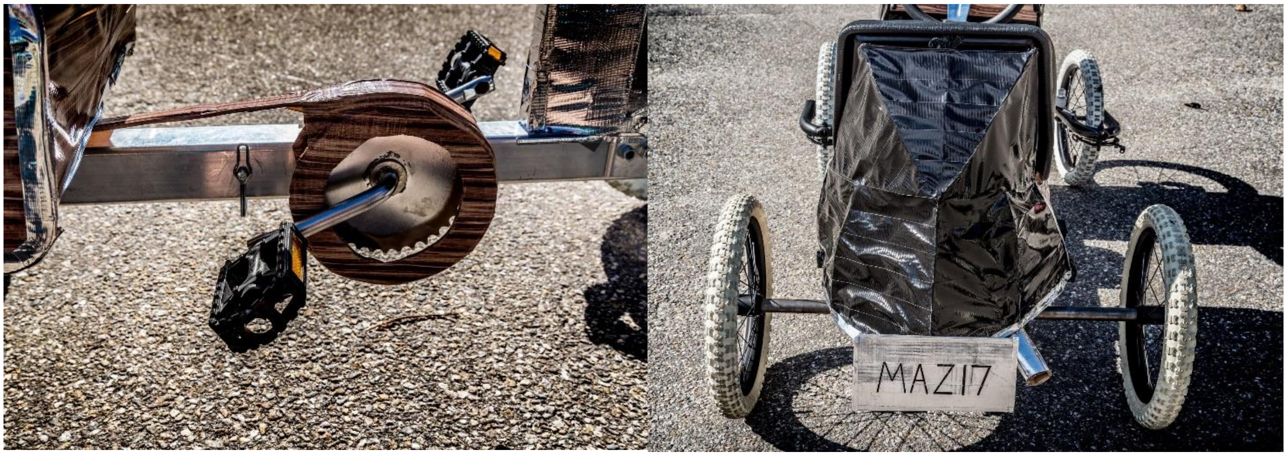


Figure 36: Finished Pedal Car, Pedals and Rear of Vehicle

4.5 Final Assessment

Once the body was completed, a final evaluation of the original task specifications was completed. Eighteen out of nineteen total task specifications were met in the final prototype.

1. Maximum weight of 50 lbs.

The weight of the vehicle was the only task specification that was not met in the final design. The pedal car weighed 66 lbs. upon the final weight test. The weight could be reduced in a further project

2. Turning radius of between 12 and 20 ft.

The turning radius was calculated to be within the tolerance on both ends. At the vehicle’s smallest setting the turning radius is 13.8 ft., and at the largest setting the turning radius is 17.3 ft.

3. Ground pressure of the vehicle of a maximum of 40 psi.

The ground pressure was calculated by dividing the total weight (66 lbs.) by the surface area of the tires (4 in^2) and found to be approximately 16.5 psi, and therefore within the original tolerance.

4. Must hold up to 70 lbs. and be tested to 210 lbs.

The pedal car was tested at the safety weight of 210 lbs., calculated using a safety factor of 3, by using one of the project team members plus a box full of parts to approximately simulate the test weight.

5. Must adjust to the leg lengths of 5 to 7 year old children, approximately 17 inches to 26 inches.

The pedal car has a total adjustable length of 10 inches. The smallest setting has an approximate leg length of 17 inches and the longest setting has a leg length of 27 inches filling the requirement of 17 inches to 26 inches.

6. Must adjust to the arm lengths of 5 to 7 year old children, approximately 10.5 inches to 13.5 inches.

The steering wheel of the car adjusts so that it is within the range of a variety of arm lengths. The steering column itself has 8 inches of adjustability built in, therefore at the vehicle's shortest leg setting the wheel adjusts from 10.5 inches to 3.5 inches of arm length, and at the vehicle's longest setting the wheel adjusts from 20.5 inches to 12.5 inches of arm length fully accommodating the specification.

7. Must contain a braking system capable of stopping within 25 ft. at 10 mph on asphalt (0.1336 g's).

The braking system of the pedal car was tested by increasing the speed to approximately 10 mph (this speed is only possible on a steep hill, not from pedaling alone), then stopping, the vehicle stopped in 15 ft., which is well within the specification.

8. Must have an impact force of less than 500 lbf on a flat surface at a maximum of 10 mph.

There was difficulty in testing the impact force as it is a destructive test. The test was not performed as there is only one prototype in existence, though theoretically the car would have an impact force within tolerance on a flat surface, especially considering the top speed is 4 miles per hour instead of 10 mph.

9. Must have a maximum speed of 8 mph at 80 rpm on a flat surface.

   The maximum speed on a flat surface was tested to be 4 mph at 80 revolutions per minute at the pedals. The vehicle can travel faster down hills and at higher rpms.

10. Must have an adjustment time of less than 5 minutes.

    The adjustment time of the pedal car depends on the familiarity of the operator with the adjustment system. A skilled worker can adjust the vehicle in 3 minutes: 20 seconds for the frame, and 2 minutes and 40 seconds for the chain. The time for adjustment will be improved with the recommended improvements to the chain system.

11. Lifespan of at least 5 years.

    All components of the frame individually have a lifespan of over 5 years. The current body does not have a similar lifespan, however if the body were switched to the proposed injection molded plastic body, that lifespan would improve considerably.

12. All sharp edges need to be covered or sanded down according to standard 16 CFR 1500.49 paragraph d).

    Any existing sharp edges in the pedal car are covered by guards or the body of the car itself. The rest of the vehicle has no sharp edges.

13. Follow approximately US toy standards ASTM F963-11.

    The vehicle was designed and prototyped without any hazardous or toxic materials according to the aforementioned standards. Also as specified in the toy standards, all of the bearings are sealed.

14. Must have no wheel slipping in the forward direction on a hill incline of less than 20 degrees.

The vehicle was tested on a hill of 22 degrees by locking the brakes and there was no slipping.

15. Must have no sideways tipping on a hill of up to 15 degrees.

The vehicle was tested on a hill of 22 degrees and there was no tipping. Also the theoretical center of gravity is on the same plane as the axles. The three foot wheelbase contributes to the stability of the car.

16. Must be operational between temperatures of 0°F and 120°F.

All materials used in the construction of the vehicle are operational between the temperatures of 0°F and 120°F.

17. Must be able to reverse without exiting the vehicle.

The simple chain design allows for pedaling in the reverse direction so reverse is enabled without exiting the vehicle.

18. Acceptable tolerances for pinch points (ASTM F963-11 Section 4.18.1).

All pinch points were covered with guards so that they are not accessible while the vehicle is in operation.

19. Follow age weight guidelines (ASTM F963-11 Table 8).

The pedal car was tested at either end of the weight range by approximating the leg and arm length and the weight of a child at each age. Due to liability, children of that age were not allowed to test the vehicle. The only variable that was impossible to approximate was the strength of a child between 5 and 7.

5. Recommendations and Conclusions

During the project, several opportunities for design improvement were discovered that could be attempted with more time or in a future project. The most important improvement is to the weight of the vehicle. The original plan was for a maximum weight of 50 lbs. The weight specification was exceeded by 16 lbs. A future project could work on bringing the weight below 50 lbs., perhaps down as low as 25 lbs. There are many areas in which the weight can be reduced including: the tractor seat can be replaced with injection molded plastic, the solid aluminum in the body can be replaced with hollow aluminum reinforced tubes, and steering wheel can be replaced with injection molded plastic. The weight improvement is important so that a child can easily move the vehicle and a parent can easily lift the pedal car.

Another consideration is the size of the pedal car. The pedal car prototype is currently 4 to 5 feet long. Many competitors are only 3 to 3.5 feet long. The car could also be reduced in width, as it is currently 3 feet wide, where competitors are mostly 2 feet wide.

One recommendation is to spend time perfecting the chain tensioning lever arm, so that the vehicle could be adjusted simply by sliding the frame. The current method of adjustment requires a chain breaking tool and some knowledge of the chain system. Optimally the vehicle could be adjusted by a young child.

The gear ratio of the pedal car is currently one to one with 16 inch tires. There was little to no data on the amount of force required for 5 to 7 year old children to push a pedal. A future project could collect data on the capacity and ability of children in the specified age range to turn the pedals. Then the gear ratio could be adjusted accordingly.

A secondary project could spend time focusing on material selection to find the optimal materials for the pedal car. The project could focus on finding materials that are lightweight, durable, and strong. The materials used in the prototype of the pedal car were mostly selected because they were readily available.

Future teams could research and design impact zone cushioning. This would require a relatively large amount of prototypes for testing, or at least scale model testing. The testing to determine impact zones and the effectiveness of cushioning placed in those areas is extremely destructive to the prototype. There was only one iteration of the prototype for this project, so destructive testing was avoided.

Some other minor improvements are the addition of cosmetic and highly marketable features such as an extendable, overlapping body for the vehicle that covers the entire frame, headlights, customizable stickers to decorate the dashboard, a horn, and different colors and styles to suit a wide variety of tastes.

References

Association, Inc. Toy Industry. "Safety." Safety Standards. N.p., n.d. Web. 26 Oct. 2016.

Berk, Laura E. Exploring Lifespan Development. Boston, MA: Pearson Allyn and Bacon, 2009. Print.

Denlson, Ray. "A Brief History of the Pedal Car." 95 Customs. N.p., 16 Feb. 2015. Web. 26 Oct. 2016.

Fredriks, A., S. Van Buuren, W. J M Van Heel, R. Dijkman-Neerincx, S. Verloove-Vanhoric..., and J. Wit. "Nationwide Age References for Sitting Height, Leg Length, and Sitting Height/height Ratio, and Their Diagnostic Value for Disproportionate Growth Disorders." Archives of Disease in Childhood. U.S. National Library of Medicine, Aug. 2005. Web. 26 Oct. 2016.

Halls, Dr. "Growth Chart and Average Weight for Adolescents." Moose and Doc. N.p., 22 Apr. 2013. Web. 26 Oct. 2016.

Kendall, Jesse, P.E., and Kenneth Alvin Solomon, Ph.D. "AIR BAG DEPLOYMENT CRITERIA." The Forensic Examiner (n.d.): n. pag. 2014. Web. 26 Oct. 2016.

Norton, Robert L. Machine Design an Integrated Approach. Boston, Mass.: Prentice Hall, 2014. Print.

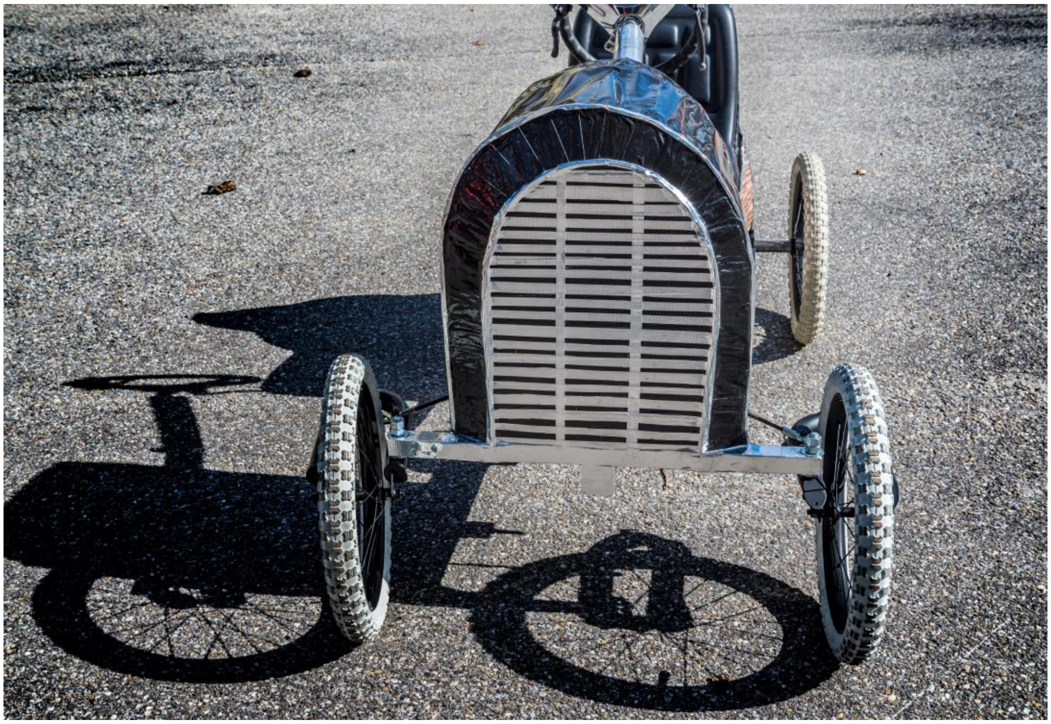
"Pedal Car History." PedalCarPlanet.com. N.p., n.d. Web. 26 Oct. 2016.

"Technical Requirements for Determining a Sharp Metal or Glass Edge in Toys and Other Articles Intended for Use by Children under 8 Years of Age." LII / Legal Information Institute. N.p., n.d. Web. 26 Oct. 2016.

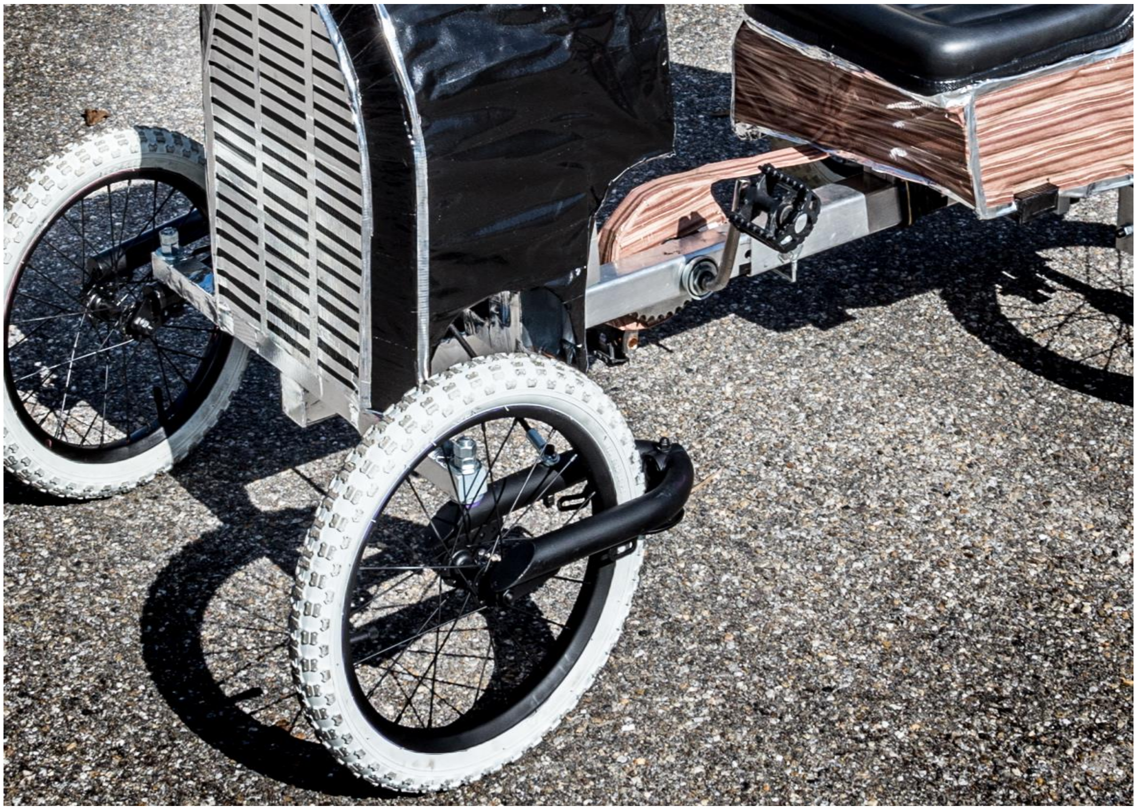
"What Exerts More Ground Pressure – A Human or a Crawler Carrier?" Crawler Carrier News Updates Terramac RSS. N.p., 06 Dec. 2013. Web. 26 Oct. 2016.

Appendix

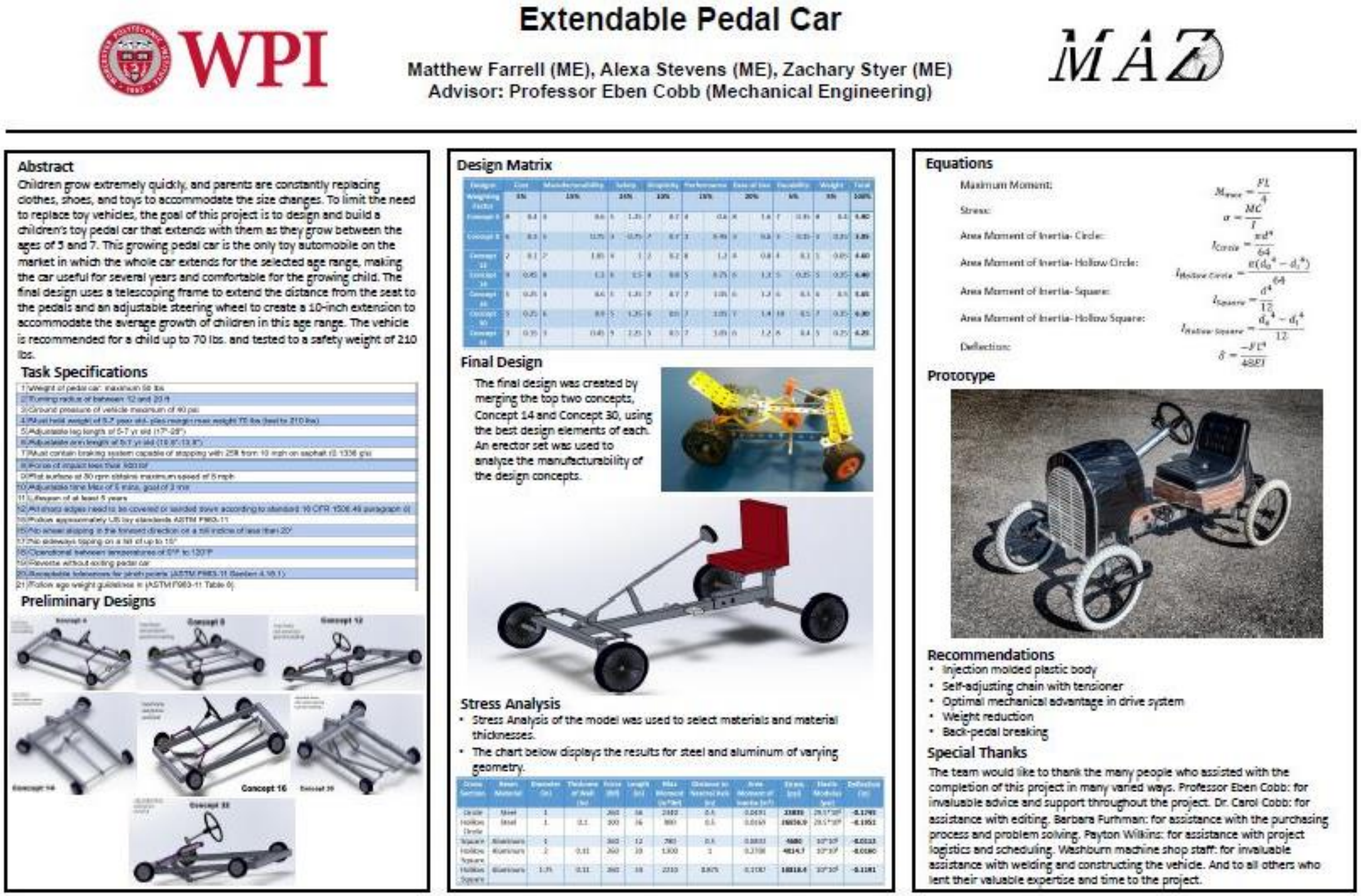
Front View of the Finished Pedal Car



Side View of Finished Pedal Car



MQP Poster



Extendable Pedal Car

Matthew Farrell (ME), Alexa Stevens (ME), Zachary Styer (ME)
Advisor: Professor Eben Cobb (Mechanical Engineering)

Abstract

Children grow extremely quickly, and parents are constantly replacing clothes, shoes, and toys to accommodate the size changes. To limit the need to replace toy vehicles, the goal of this project is to design and build a children's toy pedal car that extends with them as they grow between the ages of 5 and 7. This growing pedal car is the only toy automobile on the market in which the whole car extends for the selected age range, making the car useful for several years and comfortable for the growing child. The final design uses a telescoping frame to extend the distance from the seat to the pedals and an adjustable steering wheel to create a 10-inch extension to accommodate the average growth of children in this age range. The vehicle is recommended for a child up to 70 lbs. and tested to a safety weight of 210 lbs.

Task Specifications

1) Weight of pedal car: maximum 50 lbs
2) Turning radius of between 12 and 20 ft
3) Ground pressure of vehicle maximum of 40 psi
4) Must hold weight of 5-7 year old- plus margin max weight 70 lbs (test to 210 lbs)
5) Adjustable leg length of 5-7 yr old (17"-20")
6) Adjustable arm length of 5-7 yr old (10.8"-13.8")
7) Must contain braking system capable of stopping with 25ft from 10 mph on asphalt (0.1336 g's)
8) Force of impact less than 900 lbf
9) Flat surface at 80 rpm obtains maximum speed of 5 mph
10) Adjustable time Max of 5 mins, goal of 2 min
11) Lifespan of at least 5 years
12) All sharp edges need to be covered or sanded down according to standard 16 CFR 1500.49 paragraph (i)
13) Follow approximately US toy standards ASTM F963-11
15) No wheel slipping in the forward direction on a tilt incline of less than 20°
17) No sideways tipping on a tilt of up to 15°
18) Operational between temperatures of 0°F to 120°F
19) Reverse without exiting pedal car
20) Acceptable tolerances for pinch points (ASTM F963-11 Section 4.18.1)
21) Follow age weight guidelines in (ASTM F963-11 Table 6)

Preliminary Designs

Design Matrix

Design Weighting Factor	Cost	Manufacturability	Safety	Simplicity	Performance	Ease of Use	Durability	Weight	Total
	5%	15%	25%	10%	15%	20%	5%	5%	100%

Final Design

The final design was created by merging the top two concepts, Concept 14 and Concept 30, using the best design elements of each. An erector set was used to analyse the manufacturability of the design concepts.

Stress Analysis

- Stress Analysis of the model was used to select materials and material thicknesses.
- The chart below displays the results for steel and aluminum of varying geometry.

Equations

Maximum Moment:
$$M_{max} = \frac{FL}{4}$$

Stress:
$$\sigma = \frac{MC}{I}$$

Area Moment of Inertia- Circle:
$$I_{Circle} = \frac{\pi d^4}{64}$$

Area Moment of Inertia- Hollow Circle:
$$I_{Hollow\ Circle} = \frac{\pi(d_o^4 - d_i^4)}{64}$$

Area Moment of Inertia- Square:
$$I_{Square} = \frac{d^4}{12}$$

Area Moment of Inertia- Hollow Square:
$$I_{Hollow\ Square} = \frac{d_o^4 - d_i^4}{12}$$

Deflection:
$$\delta = \frac{-FL^3}{48EI}$$

Prototype

Recommendations

- Injection molded plastic body
- Self-adjusting chain with tensioner
- Optimal mechanical advantage in drive system
- Weight reduction
- Back-pedal breaking

Special Thanks

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