Safety Stroller

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ABSTRACT

Kids in Danger desires to guide a team of engineers towards building a redesigned child stroller to address certain safety hazards. Common accidents from current strollers include rolling into traffic, invisibility at night, entrapment of the child, difficult setup, and pinching points. Nancy Cowles of Kids in Danger provided us with basic information regarding stroller malfunctions and what needs to be addressed. Our redesigned stroller targets these safety concerns and reduces the possibility of stroller accidents. In addition, this prototype introduces new technology that addresses safety concerns not currently covered by the ASTM F833 standards. The new features target safety hazards that are responsible for numerous child injuries each year, using an engineering approach to provide solutions.

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INTRODUCTION

One of the missions of Kids in Danger is to combat child product injuries by encouraging engineers to develop safer children's products. They will be working with us to ensure that our stroller protects against known safety hazards that have caused stroller accidents in the past. These safety hazards include uncontrolled rolling (see Figure 1), invisibility at night, entrapment or entanglement of the child, improper setup, and pinching points. We will include elements in our design to address each of these problems. Our product will be tested to determine if these new safety features will properly protect the child against accidents.

While creating the safest stroller possible is our primary concern, we would also like to minimize the price for the stroller. A child's safety is a necessity, and should not be a luxury for parents who can afford to spend more on a stroller. Also, the stroller should be easy to use and ergonomic, creating a comfortable experience for both the parent pushing it and the baby riding within.

We hope that the automatic braking system as well as the nighttime visibility used by our project will decrease the number of injuries and deaths that occur from improper braking and nighttime accidents. We also hope that our design decreases the number of injuries and deaths that occur from suffocation or from the presence of pinching points in strollers.

Figure 1. Stroller dangerously rolling away from parent [1]

Figure 2. Dangerous pinch point in recalled MacLaren stroller [2]

LITERATURE SEARCH

BACKGROUND INFORMATION

A stroller (referred to as pushchair or buggy in Commonwealth countries) is a manual 4-wheeled vehicle for transporting children who are not old enough to travel extended distances on their own. The result of the wheeled vehicle is two-fold: 1) Children are transported in relative comfort and security, and are sheltered from the environment. 2) Parents no longer need to bear the full weight of a young child.

The first 4-wheeled vehicle specifically designed for carrying small children was documented in 1773[3] in England. Today, new materials and manufacturing methods have enabled strollers to become more affordable and durable. Modern strollers come in a number of varieties, namely travel systems, lightweight strollers, jogging strollers and umbrella strollers.
Travel systems are the most expensive and heaviest, but include a car seat that can be used in both the car and integrated into the stroller. This simplifies the process of going from stroller to car and vice versa. This arrangement allows babies to remain asleep and undisturbed during the transition. Travel systems are often better appointed, having the largest canopies and the largest chassis to give it stability not found on other stroller types. Because of the higher cost, travel systems also often have more safety features such as a see-through window for parents to routinely check on their children, and protective guards that cover hinges to prevent pinching.
Lightweight strollers are the lightest and least expensive strollers available but sacrifice many necessary features. These strollers are made of a narrow frame that supports a single continuous piece of fabric that forms both the seat and back of the stroller, usually without adjustment for a reclined position. Lightweight strollers also lack pinch protection since they fold into a very small volume and cost-cutting is aggressive in this very low-priced segment. One feature that they often do have is a half-canopy to protect the baby against sunlight that shines from directly above. Lightweight strollers are suitable only for older children who can remain seated upright without assistance.

Umbrella strollers range in size between travel systems and lightweight strollers, and are priced in between the other two as well. They differ from lightweight strollers with canopies in that true umbrella strollers have canopies that extend far enough to shade most of the child from direct sunlight. However, some lightweight strollers with half-canopies are being labeled as umbrella strollers, even though they do not adequately protect the baby from strong sunlight.
Jogging strollers are designed to give a comfortable ride, low pushing resistance, and remain maneuverable at jogging speeds. They feature three pneumatic tires (one in front, two in back) to achieve this. Even though these strollers are welcome by many active parents and children seem to enjoy the ride, it is not recommended to push a young child at high speeds. Misjudgment can lead to a high-speed impact. It is also much more difficult for motor vehicles to avoid strollers that are traveling quickly, while at the same time parents running behind the stroller cannot always see changing traffic patterns.

Though today’s strollers are better than ever before, there still exists many areas in need of improvement. The area most in need of improvement is that of safety, as safety is the first and foremost priority in any product, especially in one which is designed to protect young children. Most stroller injuries were related to falls [6] while pinching [7], poor night-time visibility, impacts, and suffocation also contributed to injuries. Over 11,160 children needed emergency treatment due to stroller injuries in a recent one year period [4], which makes strollers the baby product most likely to cause injury [5]. ASTM International has been continuing to update stroller safety standards (ASTM F833-09) [8] but it is not mandatory for stroller manufacturers to comply. These standards help manufacturers, retailers, and consumers alike identify safe designs that prevent injury.

There are many pieces of prior art for designs that seek to specifically address the above problems in strollers, including pinch protection, automatic braking, and lighting. Not specific to stroller design, restraint warnings have long been implemented in automotive applications.

Pinching dangers are beginning to be addressed in many designs using plastic covers and cloth cover retrofit kits [9]. However, we will explore other options to determine the best method with respect to reliability and cost. A cloth cover retrofit is shown installed on a recalled Maclaren stroller in Figure 3.

Figure 3. Maclaren retrofit cloth cover pinch proofing apparatus

An automatic braking system as used in a stroller application is disclosed in U.S. Patent 5,116,464, originally filed Sept. 26, 1978 by Frederick J. Haley of Lowell, Massachusetts. The patent describes a mechanism that comprises a secondary spring loaded handle that can be depressed to retract a mechanical cable connected to a dowel pin. The dowel pin is located such that it extends into open space between spokes of a wheel when the secondary handle is not depressed, and retracts to allow 1 degree of rotational motion in the wheel when the handle is depressed. This results in a braking system that automatically applies brake(s) when the parent releases the stroller's handles. Even though the patent has already been expired for over a decade, this design is not implemented by any stroller available in retail. Figure 4 shows three views of the design disclosed in U.S. Patent 5,116,464.

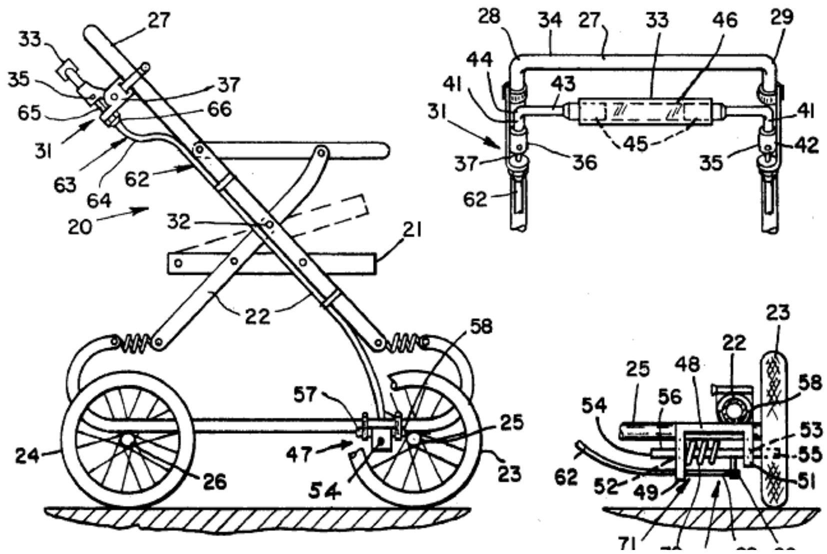


Figure 4. Automatic brakes disclosed in U.S. Pat. 5,116,464

More recently in February 2009, James William Wansey of Australia invented an automatic braking system that utilizes a wheel-powered electric brake that detects its distance from a RF wireless transmitter component worn by the parent. If the wireless transmitter and the stroller wheel become separated by more than 2 meters, the brakes automatically apply. While this design provides more comfortable operation without having to operate a hand lever as prescribed by the automatic brake apparatus of U.S. Patent 5,116,464, it is of great concern that the distance of two meters is much too great to be effective in preventing accidents. The specified distance may be the result of limitations of the ability to use low-cost RF transmitter/receivers to accurately determine distance. A computer rendering of the described device is shown in Figure 5.

Figure 5. Automatic wireless wheel-powered stroller brakes

A lighting system for stroller application featuring LEDs was disclosed in U.S. Patent application number 10/096,970. Filed on October 2nd, 2003, Catherine Comrada describes a device featuring a circular front panel that is adorned by LEDs. The LEDs flash by command of a microcontroller powered by battery. The patent application also describes an optional solar (photo voltaic) recharge system. However, the high cost of a solar module raises concern about the financial feasibility of this mechanism. A flag portion of the device also increases visibility over tall structures. The stroller lighting system of U.S. Patent application 10/096,970 is shown in Figure 6.

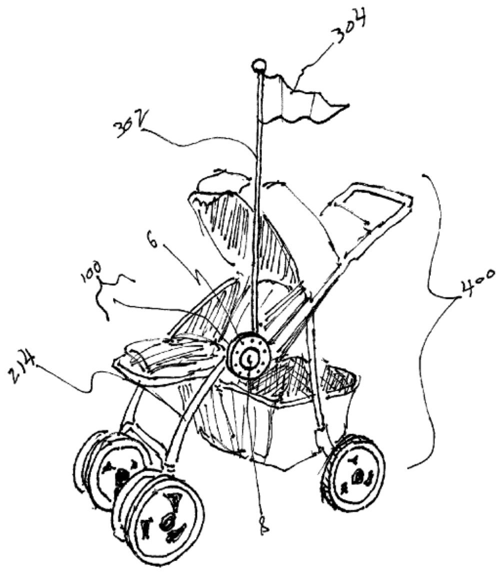


Figure 6. U.S. Pat. Appl. 10/096,970 stroller lighting system

DANGEROUS DESIGNS

Although safety standards such as ASTM F833 which specifically targets stroller design serve as design guidelines are available for manufacturers to use, there are still many strollers that are recalled, often only after many complaints and unnecessary injuries.

Stroller designs can be flawed in a number of ways. The most common reasons for recall include unintended folding or unlatching, strangulation, and pinching.

Century (now owned by Graco) has had a number of recalled due to unintended unlatching. The Century E-Z Go stroller featured an unlatching mechanism that was in position to be kicked by the stroller pusher [10]. When the mechanism is kicked sufficiently to unlatch, the stroller collapses. If the child is not injured in the collapse, there still exists the chance of hand pinching when the parent attempts to re-erect the stroller with the child still inside. Century's TraveLite Sport was designed with a latch that is weakened after repeat wheel impact and can collapse when the mechanism becomes sufficiently weakened, usually when the front wheels impact on a curb or similar solid structure. The TraveLite stroller received over 1,400 complaints from consumers on latch failure causing stroller collapse [11]. Lastly, the older Century Multi-Use travel system design allowed the car seat portion to become inadvertently detached from the stroller chassis, resulting in fall injuries [12]. Figure 7 shows the three Century strollers recalled for unintended unlatching from left to right in the order of EZ-Go, TraveLlite, Multi-Use.

Figure 7. Recalled strollers due to inadvertent unlatching (front left: Century E-Z Go, Century TraveLite, Century Multi-Use)

Another reason for recall is the possibility of strangulation due to loose-fitting restraints or large gaps within the occupant area. One stroller recalled for strangulation hazards are the Century Way-to-Go / Bilt-Rite Fold 'N Go strollers which use the same restraint setup [13]. While it is commendable to offer shoulder belts that can reduce the likelihood of falling out of the stroller, the shoulder belts could be loosely fit, introducing an unacceptable likelihood of strangulation on the shoulder belts themselves. Figure 8 shows shoulder belts that pose a strangulation hazard.

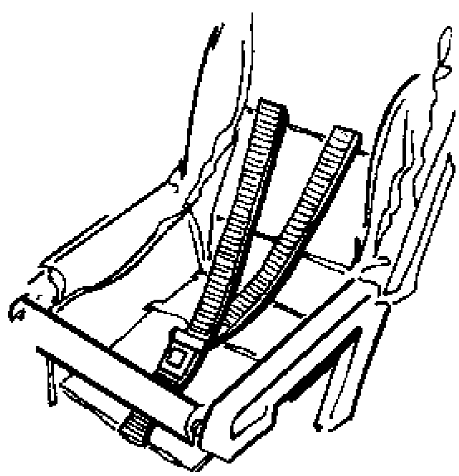


Figure 8. Loose fitting restraints pose strangulation hazard.

Finally, pinching at joints is a very common stroller injury, and it has been highlighted recently by the Maclaren stroller recall [14]. The Maclaren's folding mechanism exposed a joint that when folded leaves very little space between its members. This joint amputated a number of fingertips and highlights the need for proper covering of joints of folding members in strollers. Approximately 1,000,000 strollers were covered in this recall. The repair procedure details fitting a cloth hinge cover over the primary hinge. Figure 9 shows a typical Maclaren stroller before recall fixes have been applied (note the exposed hinge). Figure 3 shows the cloth hinge cover retrofitted in the recall.

Figure 9. Pre-retrofitted Maclaren stroller having exposed hinges

Despite the large number of recalls concerning the above failures, the most common reason for a child to become injured (though not usually critically) is from falling out of a stroller. Figure 10 shows injury types by percentage. 77% of all stroller injuries are due to falling out [15], so we would like to implement a system that assures the child is properly restrained.

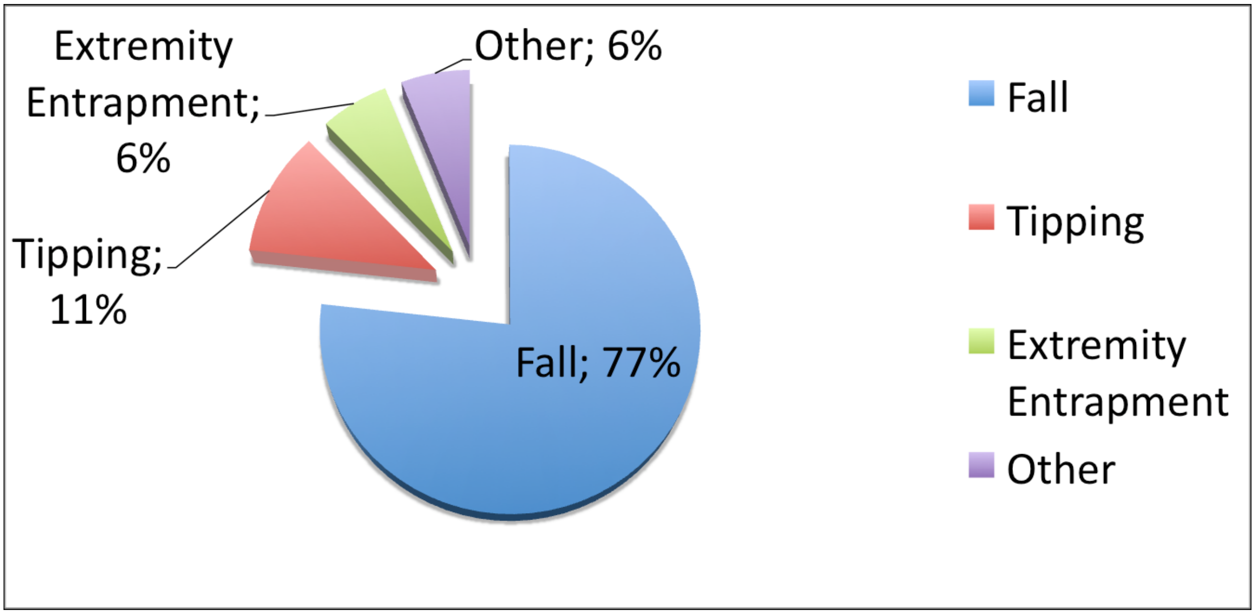


Figure 10. Stroller injuries by percentage of occurrence

BENCHMARKS

Strollers available at Toys "R" Us provided sample benchmarks. The three strollers considered were the Graco® Hamilton Travel System, the Britax® Blink stroller and the Especially for Kids® Umbrella Stroller. The Graco® stroller provided the most safety features including pinch-proof hinges and a see-through window for monitoring the child's compartment. But it was also the least affordable, costing over $200. The Especially for Kids ® Umbrella Stroller was the most affordable at $20 and is the lightest. Though it is called an "umbrella" stroller, is more closely resembles a lightweight stroller. The Especially for Kids ® stroller did not feature any safety features beyond brakes and a restraint harness, and had multiple pinch-points. The Britax® stroller sits between the other two strollers in terms of both price and weight, and featured a full-size canopy, but featured neither pinch-protection nor a see-through window. These three benchmarks are shown below in Figure 11.

Figure 11. The Graco Hamilton, Britax Blink, and Especially for Kids strollers benchmarked [16]

POTENTIAL CHALLENGES

One major area of improvement over existing designs on the market is the inclusion of an automatic braking system. However, there are many foreseeable problems associated with this new feature that hasn't been thoroughly tested in the laboratory or by consumers. Firstly, the brakes will be subject to constant use that may decrease their lifespan when compared to traditional manually-set brakes. In conjecture, if the proposed automatic braking system shares the same braking mechanism as the existing manual brakes, failure due to the increased rate of wear will result in the product failing to meet acceptable standards of safety. In order to verify lifespan of the automatic braking system, we will repeatedly apply the brakes, both manually and automatically. This will simulate the average number of brake applications over a 5-year lifespan with a safety factor of 2, and measure failures or signs of accelerated wear.

A secondary concern of the automatic braking system results from the possibility that parents may find the release system inconvenient or uncomfortable during extended use. Also, a concern is that parents may become dependent on the automatic braking system and fail to apply the manual brakes for additional safety. And, since not all strollers will feature automatic braking, parents who are accustomed to automatic braking may find themselves forgetting to set brakes at all when using a different stroller. It may be necessary to include an alarm system that activates if the delay between stroller stopping and release of the handle is less than a specified value.

Another area of engineering challenge is meeting the $60 maximum target cost while including the proposed new safety features. Often, new technologies in products result in a higher cost for early adopters. However, we must make this product affordable for most parents in order to ensure that safety is not reserved only for the financially sound. To predict cost as early as possible in the design cycle is important in keeping the product development on track both in terms of meeting the safety goals and cost goals within the specified timeframe. Cost analysis will be performed on prototype designs to determine the price of retail units.

Weight can be negatively affected by the newly-proposed safety features. While the new features do not impact major structural components, they do make the product heavier than competition and the exact increase in weight will be monitored in order to prevent design change in the later stages. Light-weight yet economical materials will be used in-so-far as possible while maintaining robust performance. During our design phase we will research parts offered by distributors and keep track of weight for the heavier parts. Further weight-reduction measures can include the removal of excess material without compromising the performance of the structure.

Two systems, namely the nighttime lighting apparatus and the restraint notification system will need a steady supply of electric energy in order to keep the systems active with the required level of output. The proposed design could use a DC generator with a single-chip solid state voltage regulator and a capacitor to ensure steady current. This system would be driven by the rotation of one of the two rear wheels. This may introduce resistance forces that could make the stroller noticeably more difficult to push, or increase the effort needed to track in a straight line. Load testing may be performed to measure the effects of the generator system.

CUSTOMER REQUIREMENTS AND ENGINEERING SPECIFICATIONS

We first determined our customer requirements by conducting market research of strollers from Toys “R” Us and collecting feedback of customers from websites of retailers such as Amazon and Wal-Mart. Based on those customer requirements, we set up our engineering specifications. With the evaluation of our benchmarks, we performed a Quality Function Deployment (QFD) to identify the most important engineering specifications.

CUSTOMER REQUIREMENTS

The customer requirements for the stroller fall into three major categories: Safe, Economical, and Comfortable & Convenient. Among those three, safety is the most important one that parents care about. Most parents can benefit from an automatic braking system to replace the manual braking system which is widely used in present strollers. A see-through window for parents' supervision and nighttime visibility are two other often mentioned customer requirements. Besides these requirements, three other required characteristics are the ability to ensure proper setup to avoid collapsing, the absence of pinching points to eliminate accidental amputation, and lastly considerations to prevent choking or suffocation. All safety customer requirements above can decrease the probability of a baby sustaining injury.

An economical stroller design is another major desire for parents. They require that a good stroller must be affordable to most families and also be durable enough to work until a baby is two years old. As the stroller may be handed down to a younger sibling, it must be able to sustain an additional two years of use. The stroller should also be versatile for different sized babies.

Additionally, most parents hope that they can operate their strollers with one hand to have a free hand for other tasks. The stroller canopy should be big enough to shade the baby from sun or rain. Also, a good stroller should be easy to fold and provide a gentle ride.

To determine the relative importance of the customer requirements, we first consulted with our sponsor Nancy Cowles, and also reviewed the feedback that we collected from Amazon and Wal-Mart. Each of the four team members ranked each customer requirement from 1-10 independently. By taking average value of our rankings and normalizing each person's results, we determined the importance weight for each of the 13 customer requirements. Our results indicated that the automatic braking system and nighttime visibility are two most important features that customers required.

ENGINEERING SPECIFICATIONS

According to these customer requirements, we created a list of engineering specifications. Our engineering specifications as well as the target values are listed in Table 1 within the appendix. Number of brakes, stopping distance and force to release brakes are three specifications that were derived from the customer requirement of an automatic braking system. Amount of lighting and brightness of lighting were derived from the customer requirement of nighttime visibility. Gap size between folding structures was derived from the customer requirement of the absence of pinching points. Finally, steps to fold, number of warning signs, stroller weight and folded length were derived from the customer requirement of being easy to fold. As for target values, we benchmarked three commercially available strollers from Toys "R" Us, of various sizes and types. We also obtained information on problematic designs from our sponsor, Kids in Danger. We used the above data to create target values for each engineering specification. These results are presented in Table 1.

Engineering Specifications	Target Values
Number of Brakes [#]	2
Stop Distance [ft]	Less than 1
Force to Release Brakes [N]	Less than 5
Amount of Lighting [deg.]	270
Brightness of Lighting [candelas]	70
Linkage Gaps size [cm]	1.25
Price [$]	60
Steps to fold [#]	2
Number of warning signs [#]	4
Weight of stroller [lbs]	20
Folded length [in.]	40
Area of window [ft^2]	0.5
Percentage of child shaded [%]	70
Hinge Cover Thickness [mm]	Over 0.085
Hinge Cover Diameter [mm]	Over 115
Hinge Cover Gap Size [mm]	Not between 5.33 and 9.53
Yield Strength of Slot Material [MPa]	Over 60 MPa
Tensile Strength of Slot Material [MPa]	Over 90 MPa

Table 1. Engineering Specifications and Target Values for Design

TARGET VALUES JUSTIFICATION

In this section, we will present our reasoning behind determining the target values for each engineering specification.

First, we determined that the target value for number of brakes is 2. Although it is not an ASTM requirement, most strollers in the markets presently have two brakes installed on their rear wheels. We believe that two rear wheel brakes will be enough to generate the deceleration force to stop the stroller in the short distance since the speed of stroller will be approximately the normal walking speed, which is about 5 miles per hour. In addition, having only one brake in the stroller will cause it to rotate around the braking wheel when stopped, a side effect we wish to avoid.

The target value for stop distance is less than 1 foot. Since we want our automatic brake system start to work sharply when the parents' hands are off of the handlebar, we did several simple tests with various strollers on various surfaces (rug, tiling) to determine how long the stop distance will be if the stroller is travelling at normal walking speed. The maximum stop distance was 1 foot, and we set this as the target value for our braking system.

For amount of lighting and brightness of lighting, we set the target value of 270 degree wrapping the stroller's front and two side face and 70 total candelas of light provided by the total LED lights, which is enough for people to observe clearly within 50 feet at night. The angle of 270 degrees ensures visibility from essentially all angles, and based on research of the value of a candela, we decided that 70 candelas was an appropriate value for our design.

We determine the minimum gap size between closing links to be 1.25 cm. The normal diameter of the finger of adult, found by measuring our own, is about 1.25 cm. Thus, the minimum gap width of 1.25 cm is safe enough for both parents and babies.

After conducting market research in Toys 'R' Us, Amazon.com, Walmart.com, and various other retailers, we set the price of our stroller to be $60, based off which is affordable for most families.

For the rest of target value of engineering specification, we just follow the standards of ASTM.

QUALITY FUNCTION DEPLOYMENT (QFD)

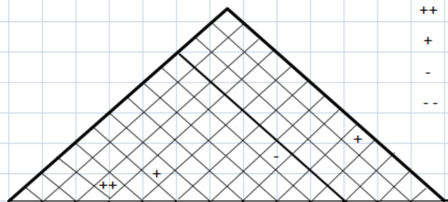
The QFD can be found in Figure 12 below. First, we listed all the customer requirements in the leftmost column. We listed the relative weight of each requirement to the right of this column ranging from "4" to "10". These factors were used later for the final weighting of the engineering specifications. Then we listed the three benchmark solutions in the rightmost columns. We listed the relative factor of their capabilities in meeting the customer requirements. All the engineering specifications were listed in the top of the QFD.

After that, we debated the relationship between the customer requirements and the engineering specifications to fill the central importance matrix. The importance matrix was filled with "0", "1", "3" or "9". A "0" indicates no relation between the related customer requirement and engineering specification, while a "9" indicate the strongest relation.

We determined the price of the stroller, the weight of the stroller, the automatic brake stop distance and the night visibility to be equally most important in our project among all the engineering specifications. This means we need to keep the materials and the manufacturing process as cheap as possible. We should choose a light material to build the stroller so that it is portable. We need to make the braking system of the baby stroller functional and reliable. We also need to work out a lighting system to make our baby stroller visible at night.

The top of the QFD is a triangle matrix which was used to determine how each engineering specification correlated with the others. We discussed together to fill out the matrix. These entries were filled with one of the four symbols (++, +, -, --) or left blank. A "++" symbol indicates a strong positive correlation between the two engineering specifications, while a "- -" symbol indicates a strong negative correlation. A blank indicates that there is no discernable correlation between the two engineering specifications. We found three important correlations after finishing this matrix. First, by increasing the amount of lights we can increase the night visibility of the stroller. However, this would have a negative effect on the price. Second, by increasing the steps to fold the stroller we can decrease the folded length of the stroller. This means we can't achieve both a minimized fold step and a minimized folded length. Third, by decreasing the weight of the stroller we can decrease the shock over specified surface. However, this would have a negative effect on the robustness and reliability of the stroller.

Quality Function Development (QFD)



Correlation between eng. Specs
- ++ Strong Positive
- \+ Medium Positive
- \- Medium Negative
- \- - Strong Negative

Benchmarks

	Weight (1-10)	Stop Distance	Force to Release Brakes	Amount of Lighting	Brightness of Lighting	Gaps size	Price	Steps to fold	# of warning signs	Weight of stroller	Folded length	Area of window	Percentage of child shade	Shock over specified surface	Greco Hamilton	Especially for Kids	Britax Blink
Automatic Braking System	10	9	1				3			3					1	1	1
Nighttime visibility	8			9	9		3			1					1	1	1
Free of pinching points	6					9	1	3							4	2	1
Affordable	7			3	3	1	9		1						1	5	3
Easy to fold	6					3		9		3	3				1	3	1
Notification of proper setup	7						3		3	1					1	1	1
One-handed operation	5		3							3					3	2	2
Avoids choking/suffocation	7								3						3	1	3
See-through window	5						1					9	3		5	2	1
Canopy shading baby	5						3			1		3	9		5	2	4
Suspension for gentle ride	5	1					1			3				9	4	3	4
Versatile for different sizes	4								3	3	3				2	3	4
Measurement Unit		ft	N	deg	cand	cm	$	#	#	lbs	in	ft^2	%	g's			
Target Value		2	10	##	70	1	60	2	4	20	40	1	70	2			
Total		95	25	93	93	79	##	72	49	98	18	60	60	45			
Normalized		0.12	0.03	0.12	0.12	0.10	0.21	0.09	0.06	0.12	0.02	0.1	0.1	0.1			

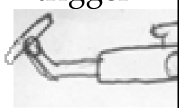
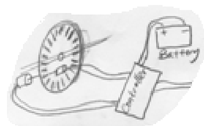
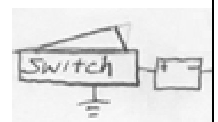
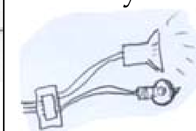
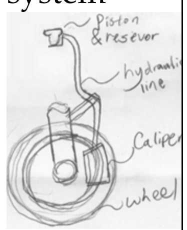
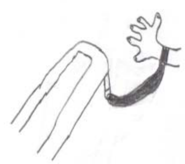
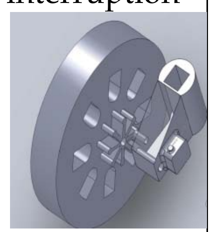
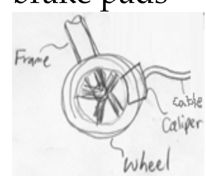
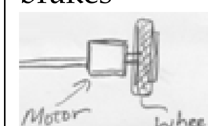
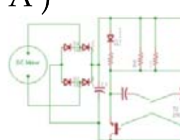
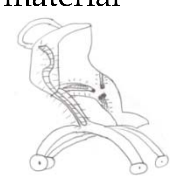
Competitive benchmarks
5 = satisfies perfectly
4 = satisfies "mostly"
3 = satisfies "somewhat"
2 = satisfies "slightly"
1 = doesn't satisfy at all

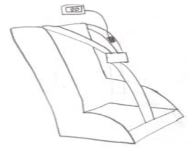
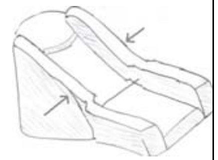
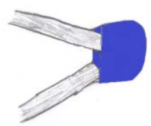
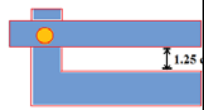
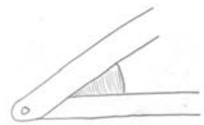
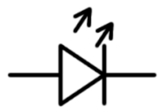
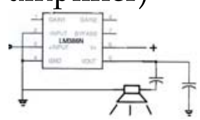
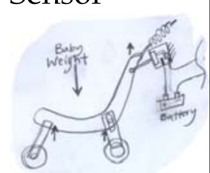
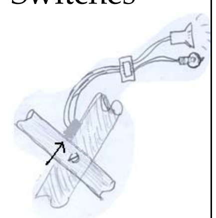
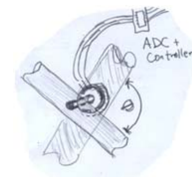
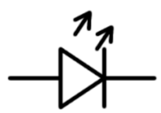
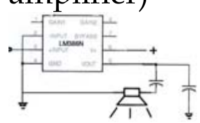
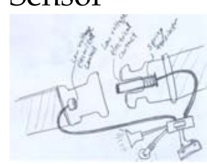
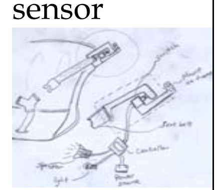
Correlation between customer reqs and eng. Specs
9 = Strong Relationship
3 = Medium Relationship
1 = Small Relationship
(blank) = Not Related

Figure 12. Quality Function Deployment Chart

CONCEPT GENERATION

From the customer requirements, we extracted a list of 11 design functions for which we need to satisfy. Multiple concepts that could be used to satisfy each of these are listed below in the morphological chart. The functions identified are the following: (1) braking trigger system, (2) braking mechanism, (3) nighttime visibility, (4) suffocation prevention, (5) pinch protection, (6) proper setup notification, (7) proper restraint notification, (8) structure strength, (9) one-handed operation, (10) parent observation, (11) folding system.

Function	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Braking trigger system	Manual locking trigger 	Mechatronic encoder with controller 	Automatic mechanical linkage at handle bar 	Automatic electric switch at handle bar 	Diagnostic warning if lever and actuator are not in sync 
Braking mechanism	Hydraulic system 	Tether 	Slot interruption 	Mechanical brake pads 	Mechatronic brakes 
Nighttime visibility	Led light (w/ generator), Appendix A) 	Reflective material 	Circular fluorescent 	Flashing wheel 	

Suffocation Prevention	Breathable material 	Heartbeat monitor 	Minimize gaps 	Adjustable side bolsters 	
Pinch Protection	Hinge Cover 	Gapped Joints 	Joint filler material 	Cloth covering 	
Proper setup notification	Light (LED) 	Sound (with amplifier) 	Baby Weight Sensor 	Limit Switches 	Potentiometer 
Proper restraint notification	Light (LED) 	Sound (with amplifier) 	Buckle Sensor 	Tension sensor 	Baby Weight Sensor 

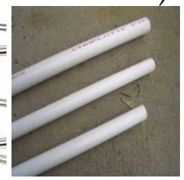
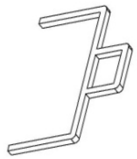
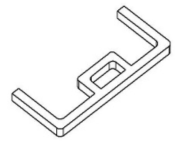
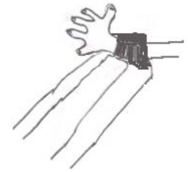
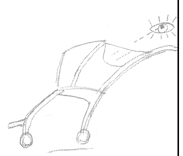
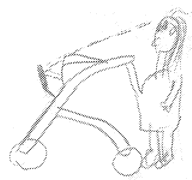
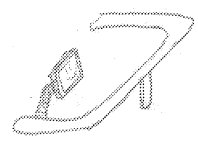
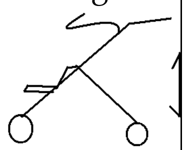
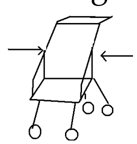
Structure Strength	Tubular aluminum 	Plastic (non-flammable) 	Titanium Alloy 	Steel Alloy 	Wood 
One-handed operation				Wrist support 	Double swivel wheels 
Parent observation	Clear Window 	Mirror 	Camera and Screen 	Clear structure 	
Folding System	Vertically folding 	Horizontally folding 			

Figure 13. Morphological chart showing generated design concepts for each function

MICROCONTROLLER INTEGRATION The re-designed stroller will incorporate a microcontroller-based Stroller Control Unit (SCU) that receives information from a variety of sensors and signal line (namely the seat weight sensor, belt tension sensor, brake lever sensor, slot interrupt pin sensor, chassis position sensor, and generator feedback line). These sensors are detailed in function descriptions below. The information will be processed by the SCU to provide a cohesive self-diagnostic and warning system to better maintain the re-designed stroller's level of safety.

FUNCTION 1: BRAKING TRIGGER SYSTEM

Brakes can be activated manually as traditional strollers do, or they can be activated automatically to increase brake usage. Five braking trigger system design concepts were generated in order to identify the most desirable way of applying stroller brakes.

MANUAL TRIGGER The manual trigger system comprises a foot lever for each lockable wheel that engages the braking mechanism. A molded mechanical groove and bump pair in the foot lever and its mounting backplate ensures that the brakes stay in the set orientation until acted upon with enough force. In the case of the slot interrupt braking mechanism, this lever acts directly on the interrupting agent to position the interrupting agent into one of the slots inside the wheel. This system can be adapted to allow hand operation by means of a mechanical cable and a remotely mounted lever on the handle bar. Another implementation that makes the manual braking system more convenient to use is a linkage that mechanically connects both left and right brakes which eliminates the need to set each wheel's brake individually.

MECHATRONIC TRIGGER Mechatronics can be used as an automatic trigger, and apply a braking force by means of a tachometer and a driver motor. The tachometer senses wheel movement and activates the driver motor to use a counter torque to keep the stroller at rest. A mechanism built into the handlebar functions to open the circuit, thus releasing the brake while the stroller is being pushed. Supporting circuits include a DC motor controller and a microcontroller with DAC capabilities to receive input from the tachometer and send the appropriate signal to the DC motor controller. A high capacity battery will be needed in order for the system to function at an acceptable level of performance. To reduce cost, the tachometer signal may be received from the DC motor. The DC motor can also be used for regenerative braking to reduce the required capacity of the battery.

AUTOMATIC MECHANICAL TRIGGER This system allows strollers to automatically apply brakes when parents take their hands off the handle bar. Many parents do not set brakes each time they let go of their strollers so the automatic trigger serves to prevent unintended stroller movement. The simplest automatic triggering system uses a spring and hinged handle bar connected to a mechanical cable that actuates on the braking mechanism. In this setup, the handle bar is normally held up by the said spring. In the case of the handle bar being in the upright position, the cable is attached such that the braking system is activated. To release the brakes, an operator must fully depress the hinged handle bar which causes movement in the cable, which in turn causes brakes to be released until the handle bar is allowed to return to its normal (raised) position.

AUTOMATIC ELECTRIC BRAKE TRIGGER Like the automatic mechanical brake trigger, the automatic electric brake trigger automatically engages the brakes whenever a lever is not held down on the handle bar. This lever is spring-loaded and operates a switch when pressed down that completes a brake release circuit. The brake release circuit utilizes a solenoid that when energized, counteracts a spring that keeps the braking system applied. This system will only consume electrical energy when the brake release lever is depressed and the brake is released.

DIAGNOSTIC WARNING NOISE As an addition to the braking system, a diagnostics system can be incorporated to alert parents of braking system failure. Traditional systems do not have sensors that help determine the true mechanical state of the brakes so that the failure condition may not be known until unexpected movement occurs. This feature is especially important in automatic braking modes as the added convenience of the automatic brakes can create a situation in which parents do not routinely check whether brakes are applied. This system uses one limit switch to send a brake handle bar position signal and another limit switch to send a slot interrupt pin position signal to the SCU (as detailed in "Microcontroller Integration" section). These signals are processed by the SCU to set a warning condition if the brake release handle is raised (in wheel lock position) but both slot interrupt pins are still retracted (wheels not actually locked). The SCU will also sound an alarm if the stroller's automatic brakes engage (brake release handle raised) while the stroller is still in motion as sensed by the generator feedback line, ensuring that parents do not develop a habit of over-reliance on the automatic braking system.

FUNCTION 2: BRAKING MECHANISM
The braking mechanism is used to stop the stroller. This is especially useful in the case of the stroller being stopped on an inclined surface, where it may otherwise roll away from the parent. The braking mechanism is an essential safety feature to keeping the stroller within control of the parent.

HYDRAULIC BRAKE MECHANISM Hydraulic fluid acts as a substitute for mechanical linkages to provide force on brake pads or actuators. In the case of disc brakes using brake pads, a caliper is used to contain and act upon brake pads. Using hydraulic fluid instead of cables or linkages reduces the friction of the system and greatly reduces chances of mechanical binding. Hydraulic systems are also less likely to be affected by freezing in severe weather, since the hydraulic fluid is in a closed system, while in braking cables, water can seep in and cause freezing.

MECHANICAL BRAKE PADS A cable actuates a two-piece mechanism that can create or reduce the gap between its two members. Brake pads are attached to the ends of the variable-gap members to create a frictional force on the wheel edges to oppose rotation. This type of braking system is widely seen on bicycles and offers a relatively low cost. However, brake pad material wears out over time and adjustment may be needed to maintain a positive braking action as the brake pads wear.

SLOT-INTERRUPT BRAKING A series of slots are molded into the inner circumference of the wheels in order to provide surfaces that can physically interact with an extendable object parallel to the axle. The mechanical interaction interrupts the rotational motion of the wheel when the extendable object is extended such that it mechanically interferes with the slots of the inside of the wheel. The system is contained from the outside environment by a housing unit, in order to prevent contamination that can fill the slots with foreign material (e.g. slots packed with snow).

ELECTRIC MOTOR/MECHATRONIC BRAKING An electric motor can be used to provide a torque to oppose wheel rotation. This setup requires a motor to be mounted, and driven by a DC motor controller with the ability to detect when the motor has stalled to prevent giving the stroller a backward motion. This arrangement, while more complex and requiring a reliable supply of electrical energy, can provide a variable amount of braking and eliminates consumables such as frictional brake pad material.

TETHER The simplest braking system is the tether system. It is a wrist cuff that physically connects the parent to the stroller via a cloth leash-like apparatus. This ensures that the parent never leaves the stroller unattended and prevents accidental stroller release.

FUNCTION 3: NIGHTTIME VISIBILITY

The lighting system is designed to make the stroller visible at night, reducing the possibility of accidents occurring while using the stroller after dark. The system must be designed so that it presents no additional hazards to the child, and does not significantly contribute to the weight or cost of the stroller. This section will show the design concepts that we have proposed for this lighting system.

LED LIGHTS Light-emitting diode (LED) lights are inexpensive, lightweight, and can provide us with the desired lighting for the stroller. Using LEDs to light the stroller, however, requires an electrical system. Using a reverse motor, the electrical power is generated from the motion of the stroller wheels. This is fed into a bridge rectifier, which ensures that power is fed through the system whether the wheels are turning forwards or backwards. The bridge rectifier system outputs power into the circuit containing the LED lights, which lines the sides and front of the stroller, ensuring maximum visibility for the stroller.

CIRCULAR FLUORESCENT Fluorescent lights have a very long lifetime, and provide a large amount of light. They do not give off very much heat, so it would not burn the child if they were to touch it. The amount of lighting could prove to be too much for the stroller however, and could hurt the child’s eyes. An additional safety hazard resides in the fact that fluorescent lamps include a small amount of mercury, which will leak out if broken.

FLASHING WHEEL Flashing wheel lights are an existing technology that can be attached to any wheels, and will light up once they begin to spin. They are battery-powered, and the lighting is provided by LEDs. These lights include an on/off switch on the back of the LEDs, so that the battery will not be drained as the stroller is pushed during the daytime, with no need for lighting. The lighting system is encased in plastic, and thus is relatively low weight. Since they are motion activated, they need to be attached to the wheels, and thus the rest of the stroller would be invisible, with just a small area around the wheels being lit. But this light will be located far away from the child's eyes, and will not introduce the issue of feeding excessive light into the child's eyes.

REFLECTIVE MATERIAL Reflective material can be simply attached to the side of the stroller. External light provides a glare on the material, providing more lighting for the system. This material is often sold as tape, so it could easily be applied to the side of the stroller with no additional materials necessary, minimizing the cost and weight of this concept. Since many nighttime stroller accidents occur due to oncoming vehicles, adding a reflective material to the side of the stroller is a sufficient method, as the headlights of the car light up reflective material, making the stroller visible. This method is very cheap and lightweight, as well as requiring much less work to manufacture this function of the stroller. But this feature is less safe, as it requires incoming light to be illuminated.

FUNCTION 4: SUFFOCATION PREVENTION

Suffocation occurs in the stroller when the child slips out of the proper position in the seat of the stroller. Injuries can occur due to the child being choked around the neck, or by having their face smothered by a fabric. Suffocation is one of the leading causes of stroller-related injuries to children.

BREATHABLE MATERIAL By using a porous material, we can decrease the chance of the child suffocating due to their face being covered by the fabric. However, this material must also be comfortable and soft for the child, as a scratchy material can cause rashes on the child if they move around too much. Different types of fabrics are listed below, with specific gravity values for each. The lower values have a lower density, and thus are more breathable materials. Other material properties such as flammability must be taken into consideration to fully evaluate the fabric, but this table provides a preliminary look at how breathable some common stroller fabrics are [17].

Material	Specific Gravity
Nylon 6	1.14
Wool	1.31
Cotton	1.52

Table 2. Table of breathable materials

HEARTBEAT MONITOR A heartbeat monitor ensures that there is no issue with the child's health, and provides notification to the parent if something is wrong. If the child slips out of position and begins to choke, this heartbeat monitor will alert the parent of the change in heartbeat, and that there is a cause for concern. The sensor is attached to the restraint strap close to the child's heart to pick up the signal. It then outputs the heart rate to a LCD device mounted on the handlebar, always being visible to the parent. This provides an instant health analysis on the baby. However, this system may alert the parent of the problem after it is too late, and so preventative mechanisms may be more desirable. In addition, this system is very expensive, especially with the addition of the LCD screen.

MINIMIZE GAPS To reduce the chance of a suffocation accident, gaps in the seating area of the stroller must be made as small as possible. Injuries have occurred as a result of children slipping into gaps and having their head stuck, particularly in models with leg holes. These gaps also include space between restraint straps, space between the seat sides and the linkages, and space between the sides of the seat. Thus, by making one solid seat, with no holes for the child's legs, the chance of suffocation occurring is reduced. This is aided by the proper restraint notification system which utilizes a tension sensor and the to ensure proper belt tightness.

ADJUSTABLE SIDE BOLSTERS Fitting the seat with cushioned side bolsters helps to keep the child in the proper position as the stroller makes sharp turns. As the stroller turns, centrifugal force pushes the child to the outside of the cart. In certain cases, this can slide the child out of the proper position, leaving them prone to injury. This is similar to seat designs in sports cars, where the side bolsters provide the same function. These side bolsters can adjust inward and outward, to properly fit the size of the child in the stroller.

FUNCTION 5: PINCH PROTECTION

As a stroller is being folded, the child may be nearby, which poses a risk as they could put their fingers in the stroller and injure themselves. Also, dangerous gaps may be present even after the stroller is setup. The child may place their fingers in these areas during use, and injure themselves. Thus, it is important to include features in the design of the stroller to avoid these pinch points at which injury can occur.

JOINT CAP In the case where a joint cannot be designed to avoid a pinch point, a joint cap is useful in eliminating the danger. The joint cap is a simple circular plastic casing that fits around the dangerous joint, making it impossible for a child to put their fingers in there during folding and sustain an injury. The joint cap must be designed so that the area is completely sealed, and the child cannot fit their fingers under the cap.

JOINTS WITH A GAP The linkage system can be altered so that there are never joints that fully close, remaining open at a 90 degree angle, with clearance of at least 1.25 centimeters, satisfying our engineering specification. This structure has a gap in which the child can stick their fingers without sustaining an injury when the structure is collapsed. This may prove to take more time and resources than reasonable, as the entire linkage structure will need to be redesigned to accommodate the changes.

FILLER MATERIAL IN JOINTS Flexible filler material added inside a joint prevents a child from putting their fingers inside, while still allowing the system to fully collapse. The material used is a soft foam, which will allow the material to be compressed for folding the stroller. The material must also provide negligible force on the joint, so that when the latches on the system are released, the structure will not quickly spring open.

CLOTH COVERING A cloth covering on dangerous joints is an easy addition to seal off these pinch points. This is a simple bag-like device that fits around the dangerous area, and is sealed shut. It has been used often in pinching point recalls, as it can be easily added to the device after manufacturing. Our design will be sealed shut, with no method for the consumer to easily remove the cover without tearing it apart, to avoid the possibility of exposing the pinching point.

FUNCTION 6: PROPER SETUP NOTIFICATION

In order to avoid incomplete setup which causes the collapse of the stroller, a proper setup notification system must be installed on the stroller. This notification system will ensure that the stroller is being setup properly and fully. The following section will present some design concepts that we generated for the proper setup notification. Some of the concepts below will be integrated into the SCU microcontroller unit to provide a cohesive diagnostic and warning system.

LIGHT A small LED light will be installed in a proper place that is easy for parents to observe. When the stroller has been properly set up, an electrical circuit will be completed at same time. The small LED light will then be illuminated to notify parents that the stroller has been completely and properly setup and is ready for use. This LED is driven by the SCU using input from the proper setup notification potentiometer or limit switch.

SOUND A small speaker will be installed along the handlebar, so the sound can easily be heard by the parent. Just like the lighting notification system, when the stroller has been properly setup, the speaker will provide a short pleasant tone to notify parents that the stroller is properly set up and ready for use. This speaker is driven by the SCU using input from the proper setup notification potentiometer or limit switch. This speaker also serves as the warning sound emitter should the SCU determine a warning condition.

BABY WEIGHT SENSOR If parents put the baby in the stroller that has not been proper setup, the baby weight sensor will trigger the alarm system which will notify parents that the stroller has not been proper setup. This device is also very important in that it will disable all of the safety notification features driven by the SCU if there is no baby present in the stroller, by opening the power supply circuit. This avoids annoyances from occurring when the parent is merely trying to transport the stroller without the baby by rolling it, instead of carrying it.

POTENTIOMETER When the stroller is fully opened and properly set up, a rotating component attached to a linkage will complete the circuit, and a light signal or sound signal will notify parents. Applying the potentiometer will require an analog-digital converter, so that the light and sound will function as either “on” or “off.” This device may be omitted, and instead be replaced by a simple limit switch that is properly adjusted at the factory. Both sensors are operated by the SCU.

FUNCTION 7: PROPER RESTRAINT NOTIFICATION

In order to make sure that safety belt is properly used, a restraint notification system must be applied. Proper restraint notification system will ensure that safety belt is properly used. This section will present some method to test this function. The SCU handles all inputs and warning conditions for this function.

LIGHT A small LED light will be installed in a proper place that is easy for parents to observe. When the restraints have been properly set up, an electrical circuit will be completed at same time. The small LED light will then be illuminated to notify parents that the stroller has been completely and properly setup and is ready for use. This LED is driven by the SCU using input from the belt tension sensor and the belt buckle sensor.

SOUND A small speaker will be installed along the handlebar, so the sound can easily be heard by the parent. Just like the lighting notification system, when the restraints have been properly setup, the completed circuit will provide enough power for speaker to produce sound to notify parents that the stroller is properly set up and ready for use. This speaker is driven by the SCU using input from the belt tension sensor and the belt buckle sensor. All auditory functions in the stroller design will served by one speaker.

BUCKLE SENSOR Spring-loaded contacts in both buckles will be pressed together when the buckle is fastened, completing the circuit. If the circuit is open while the microcontroller senses that the stroller is in motion and there is a weight detected by the weight sensor, then both auditory and visual cues will alert the parent of possible child ejection. The signal is processed by the SCU.

TENSION SENSOR When the safety belt is properly tightened so that no excessive gaps remain, a limit switch will be set so that the microcontroller detects that the restraint is properly adjusted. In the case of the strap being too loose, the limit switch will go into an unset state, in which case the auditory and visual alarms will alert the parent, if both the weight sensor is set, and wheel rotation is detected. The signal is processed by the SCU.

FUNCTION 8: STRUCTURE STRENGTH

A good stroller should be light and also maintains good strength at same time. In this section several kinds of materials will be considered as the structure materials for our safe stroller.

TUBULAR ALUMINUM Tubular aluminum is the most widely used material for a stroller’s structure. Aluminum produced as an alloy forms an oxide layer that protects against corrosion, even when scratched. This increases the material durability, as it is used through severe weather conditions. Due to its high strength-to-weight ratio and easily workability, aluminum alloys are often used as structural members.

PLASTICS Plastics are generally useful for impact toughness and light weight. For types of plastics composing the structure of the stroller, we will consider ABS, Polycarbonate and PVC. All of them are rigid, tough, and stable over a wide range of temperatures. These materials are usually used as housings, handles, helmets and light structural duty.

STEEL ALLOY Steel is the alloy of iron and carbon, whose material property (hardness, strength ductility) will change as the carbon contest varies. Steel alloys are relatively cheap and have high strength. Usually, steel alloy are used as structural members and for general housings.

TITIANIUM ALLOY Titanium alloys are metallic materials which contain a mixture of titanium and other chemical elements. This alloy has a very high tensile strength, toughness and light weight, but is usually quite expensive.

FUNCTION 9: ONE-HANDED OPERATION

The one-handed operation system should make it easy to operate the baby stroller. This will ensure that the parents can operate the stroller with only one hand, useful if the parent has one hand occupied, such as from holding a coffee or cell phone. The following section will present the design concepts for the one-handed operation system our team came up with.

DUAL BAR WITH LOOP INWARDS The loop is designed in the middle of the handlebar inwards the baby stroller. The parents can both operate the baby stroller by two hands on the large handle bar or by one hand using the loop. With the loop, it's easy for the parents to steer the baby stroller by one hand.

DUAL BAR WITH LOOP OUTWARDS The loop is designed in the middle of the handlebar outwards the baby stroller. The parents can both operate the baby stroller by two hands on the large handle bar or by one hand using the loop. The loop makes it easy to turn the stroller with one hand, as the outwards loop creates a larger torque while turning the system as compared to the inwards loop.

DUAL BAR WITH VERTICAL HANDLE The vertical handle bar is designed in the middle of the handlebar, facing downwards. The parents can both operate the baby stroller by two hands on the large handle bar or by one hand using the vertical handle bar. With the vertical handle bar, it's easier for the parents to steer the baby stroller by one hand.

WRIST SUPPORT The wrist support is placed in the middle of the horizontal handlebar. The wrist support helps the parents to steer the baby stroller easier by contouring around their wrist, so the parent can generate more turning power.

DOUBLE WHEELS ON A SWIVEL The double wheels on each swivel increase the overall stability of the steering system. Adding one wheel on each swivel will make the stroller more stable and the wheels have a small chance to be spinning all the way when the stroller are made to turn sharply.

FUNCTION 10: PARENT OBSERVATION

The parent observation system should be able to provide a clear angle of view from the back. This will ensure that the parents can observe their baby from behind at any time. The following section will present the design concepts for the parent observation system our team came up with.

CLEAR WINDOW The clear window can provide the parents a particular angle of view from behind. This window enables parents know the real time status of the baby. When the baby feels uncomfortable or behaves abnormally, the parents can see their motion from behind.

MIRROR The mirror can provide the parents a particular angle of view of the face of the baby. This mirror enables parents see the face of the baby easily. When the baby is choking or crying, the parents can see this through the mirror.

CAMERA AND SCREEN The camera and screen system can provide the parents a particular angle of view of the baby. The parents can simply look at the screen to know what their baby is doing. The parents can also use the control panel to obtain a zoom-in or zoom-out view of the baby.

CLEAR STRUCTURE The clear structure can provide the parents an ultimate clear view of the baby from behind. The parents can see their baby from head to foot from behind. Every move of the baby can be seen by the parents.

FUNCTION 11: FOLDING SYSTEM

The folding system should be able to make it easy to fold the baby stroller. This will ensure that the stroller folding requires no excessive strength, and has a short folded total length. The following section will present the design concepts for the folding system our team evaluated.

VERTICALLY FOLDING The vertical folding design allows the baby stroller to fold vertically. This will reduce the volume and make the baby stroller portable. It allows the stroller to be fully folded without the parent having to kneel down.

HORIZONTALLY FOLDING The horizontal folding design allows the baby stroller to fold horizontally. This will reduce the volume and make the baby stroller portable. This is the most common design currently used in strollers.

CONCEPT EVALUATION AND SELECTION

EVALUATION

We evaluated each generated concept, noting their pros and cons with respect to criteria such as cost, manufacturability, durability, safety, feasibility, and effectiveness. Many of these designs are not mutually exclusive, as more than one can be chosen and implemented into our final selected concept. As a result, each design concept was evaluated individually – not being compared to each other, but rather to the function for which it is attempting to satisfy. Tables were made to highlight these pros and cons, and then Pugh charts were created for each function, for quantitative comparison between the concepts. From the results of the Pugh chart, combined with the overall engineering intuition of the group, we selected the design concepts to be implemented in our complete alpha design.

FUNCTION 1: BRAKING TRIGGER SYSTEM Below is a table showing advantages and disadvantages of each type of braking trigger system. Cost, reliability, and ease of use are among the traits considered.

Concept	Advantages	Disadvantages
Manual Brake Trigger	• Low cost to manufacture. • Easy to understand. • Won't cause reliance on auto system. • Good tactile feedback. • Two independent systems (2 wheels). • Less parts to break.	• Many parents don't use brakes. • Won't stop run-away stroller. • Wear after repeated lock/unlock. • Easy to forget. • Unlikely to be used momentarily.
Mechatronic Brake Trigger	• Automatic operation. • Smooth braking action (comfort). • Innate diagnostics ability. • Little mechanical wear. • Speed monitor / speed limit control.	• Requires constant electric energy. • Expensive. • Reliance on automatic brakes. • Limited runtime when stopped. • Much heavier.
Automatic Mechanical Brake Trigger	• Automatic operation. • Prevents run-away stroller. • More convenient.	• Reliance on automatic brakes. • Some additional cost. • Slight additional weight. • Cable / lever system may bind.
Automatic Electronic Brake Trigger	• Automatic operation. • Prevents run-away stroller. • More convenient. • Electrical cables won't bind. • Can be combined with theft lock.	• Requires constant electric energy. • Reliance on automatic brakes. • Some additional cost. • Limited runtime.
Diagnostic Warning Noise	• Ensures that braking mechanism is set. • Especially necessary for auto brakes. • Prevents accidental movement.	• Some additional cost. • False-positives are possible.

	• Reduces liability.	

Table 3. Comparison of design concepts for braking trigger system

FUNCTION 2: BRAKING MECHANISM Below is a table showing advantages and disadvantages of each type of braking mechanism. Cost, reliability, and ease of use are among the traits considered.

Concept	Advantages	Disadvantages
Hydraulic + Caliper	• Doesn't easily bind as with cables. • Smooth operation, no friction. • Hydraulics not prone to debris. • Greatly increases force on caliper.	• Hydraulics may leak / get air. • Periodic maintenance/inspection. • Additional cost. • Not easily repaired by user.
Mechanical + Caliper	• Relatively low cost. • Can increase force on caliper. • Compact setup. • Maintenance free unless cable is bad.	• Could bind / twist and seize. • Could be contaminated and rust. • Can stretch
Slot Interrupt	• Maintenance free. • Low cost. • Easily completely sealed. • Locks brakes easily. • External linkages require little force.	• Auto brakes require extra links. • May be difficult to assemble.
Electric Motor	• Smooth operation. • Can assist with hill descent / ascent. • Relatively sealed from environment. • Easy to maintain (worn batteries)	• On hill, requires much energy. • Battery can run out quickly. • High cost. • Unreliable unless fully charged.
Tether	• Cheapest. • Easy to use. • Provides most reliability when used. • Prevents runaway stroller w/o cost.	• May not be frequently used. • Inconvenient.

Table 4. Comparison of design concepts for braking mechanism

FUNCTION 3: NIGHTTIME VISIBILITY We evaluated each of our generated designs for the lighting system, with the main considerations being price, effectiveness and feasibility. Price is a major factor in the design, as nighttime invisibility is one of the less important safety concerns for a stroller, and so the lighting system should not have excessive impact on the price of the system. The amount of light provided by each system was determined, to analyze the effectiveness of each concept. For the concepts relying on electricity, we needed to make sure that the motion of the wheels would actually generate enough electricity to power the system. If this cannot be achieved, the concept is impossible to implement, and will be dropped from consideration.

LED Lights The LED lighting system is quite feasible to implement into our system. The small motor attached to the wheel lights the LEDs whether it is moving forwards or backwards, due to the bridge rectifier components of the circuit. It is very effective, providing plenty of brightness for it to be noticed at night. The system is always active, and does not need to be turned on and off. This system can be easily integrated into our stroller design, as the electricity will be needed to activate the notification system. Thus, it is easy to attach LEDs to this circuit, and attach them to various points around the stroller. This system is not aesthetically pleasing however, as the lights look unnatural, and will be active no matter what the preference of the user.

Circular Fluorescent The major potential problem of circular fluorescent lighting is that the stroller wheel may not generate enough electricity to illuminate it. Thus, our first order of business was to analyze potential motors and fluorescent lights to see if the proper necessary power can be supplied.

Motor Model	Rated Current [mA]	Rated Voltage [V]	Max Power [W]
708-052-0075AD	200	12	2.4
708-052-0010AD	200	12	2.4
708-052-1674AD	80	6	0.48

Table 5. Comparison of different motor model [18]

Light Model	Power Rating [W]
FC6T9/CW	20
FC8T9/D/RS	22

Table 6. Comparison of different light model [19]

It is apparent from these tables that the maximum possible power that can be generated from the motor is not nearly enough to power the fluorescent lights. Even if the motors are run far beyond their rated value, they will not provide enough power. Fluorescent bulbs are typically connected to a home’s electricity provided from the grid, which is 120 volts AC. Only then is enough power generated for these lights to illuminate.

Reflective Material Using reflective material is an easy addition to the system that will provide sufficient lighting to the system if the material is illuminated. This material is cheap, and can simply be attached to the design without affecting any other of the features. However, one drawback of this concept is that light is needed to illuminate the material. Thus, other pedestrians walking in the dark, or small personal travel systems without lighting will not be able to see the stroller.

Flashing Wheels Flashing wheels, an existing technology, is effective in that they only light when the system is moving. This avoids unnecessary battery use when the system is being stored. However, the system runs on battery power, and the batteries will need to be periodically replaced, a task which is undesirable for a consumer. When the battery is out, the safety feature is inactive, and a safety hazard is present. In addition, the flashing wheels concept only provides light for the wheel area of the stroller. This accounts for a minor potion of the stroller, and will not provide sufficient lighting to fully satisfy this design requirement.

FUNCTION 4: SUFFOCATION PREVENTION We evaluated each possible design concept that we generated for suffocation prevention. Each design concept addresses possible safety hazards that could occur from an improper stroller design. The main area of concern is safety, with manufacturability, comfort, and feasibility also serving as important criteria. The chart below demonstrates the pros and cons of each device.

Suffocation Prevention	Advantages	Disadvantages
Breathable Material	• Easy addition to stroller • Cheap	• May be uncomfortable (rash-causing) • May present other safety hazards (flammable material, etc.)
Heartbeat Monitor	• Provides instant feedback on health of the child's heart	• Very expensive • Alert will occur after child is in danger • Requires extra output device to display information to parent
Minimize Gaps	• Easily implemented during stroller seat design • Holds the child in a steadier position, making for a less bumpy ride	• May compromise the comfort of the seat
Adjustable Side Bolsters	• Keeps child in position, particularly around turns • Comfortable for the child, as it contours around their body	• Adjustable component may add cost and complexity into the design

Table 7. Comparison of design concepts of suffocation prevention

FUNCTION 5: PINCH PROTECTION We evaluated each design concept for pinch-proofing the system, focusing on the safety of the system, while also concentrating on the durability and effects on other stroller components. The chart below described each possible concept for pinch-proofing the stroller, and their pros and cons.

Pinch Protection	Advantages	Disadvantages
Joint Cap	• Easy addition to avoid altering linkage system • Cheap	• Can break off, exposing the dangerous joint • Other safety hazards arise from the gap between the cap and the bar
Space Between Joints	• Safe by design, with no possibility of having a dangerous joint in the system	• Less compact stroller for folding
Filler Material	• Easy addition	• May fall off, exposing the dangerous joint • Makes the stroller more difficult to close • Causes stroller to spring open from folded position
Cloth Covering	• Easy addition • Low cost • Low weight	• Hurts aesthetics • May fall off

Table 8. Comparison of design concepts of pinch protection

FUNCTION 6: PROPER SETUP NOTIFICATION The pros and cons of each suitable proper setup notification system as described previously are summarized in the table below.

Proper Setup Notification	Advantages	Disadvantages
Light	• Easy installation • Relatively cheap	• Not easy for parents to observe •
Sound	• Easy installation • Relatively Cheap • Easy for parents to observe	• Make noise
Baby Weight Sensor	• Very sensitive • Easy for parents to observe •	• Relatively expensive • Not easy to install •
Limit Switches on	• Relative cheap	• Hard to install • Not sensitive

the Hinges		
Potentiometer	• Very sensitive	• Relatively expensive • Not easy to install • Add weight to stroller

Table 9. Comparison of design concepts of proper setup notification

FUNCTION 7: PROPER RESTRAINT NOTIFICATION The pros and cons of each suitable proper setup restraint system as described previously are summarized in the table below.

Proper Setup Notification	Advantages	Disadvantages
Light	• Easy installation • Relatively cheap	• Not easy for parents to observe
Sound	• Easy installation • Relatively Cheap • Easy for parents to observe	• May provide an annoyance if malfunctioning
Buckle Sensor	• Very sensitive	• Relatively expensive • Not easy to install • Not easy for parents to observe
Tension Sensor	• Sensitive	• Hard to install • Relative expensive

Table 10. Comparison of design concepts of proper restraint notification

FUNCTION 8: STRUCTURE STRENGTH The following table summarizes the pros and cons of the various structure material options:

Material Name	Advantages	Disadvantages
Tubular Aluminum	• High strength-to-weight ratio • Easily workable • Corrosion-resistant	• Relatively expensive • High ecological cost in production
Plastics(ABS, Polycarbonate, PVC)	• Flexible • Rigid, tough • light • relatively cheap	• Not easily workable • Not stable • Bad resist to fatigue
Steel Alloy	• Relatively cheap	• High density

	• High strength	• High carbon varieties are harder to machine
Titanium Alloy	• High tensile strength • Light weight • Good corrosion resistance	• Very expensive

Table 11. Comparison of structure materials

FUNCTION 9: ONE-HANDED OPERATION The following table summarizes the pros and cons of the various one-handed operation mechanisms:

Product Name	Advantages	Disadvantages
Dual bar with loop inwards	• No protrusions	• Difficult to steer
Dual bar with loop outwards	• Easy to steer	• Extra space needed
Dual bar with vertical handle	• Easy to steer • Low cost	• Extra length when folded
Wrist support	• Easy to steer	• Limited sizes • Complicated structure • Limited folding
Double wheels on a swivel	• Increase the stability of the stroller • Increase the ability to hold heavy babies	• Increase the cost

Table 12. Comparison of design concepts of one-handed operation

FUNCTION 10: PARENT OBSERVATION The following table lists approximate area, cost, and extra weight that each design concept would take, if built as they are currently conceived. This assisted us in visualizing what each concept would contribute to the overall stroller system.

Design	Area	Cost	Extra weight
Clear window	25 $inch^2$	$1	0.1 lb
Mirror	20 $inch^2$	$10	1 lb
Camera and Screen	30 $inch^2$	$100	3 lb
Clear structure	150 $inch^2$	$10	0 lb

Table 13. Comparison of engineering specification of parent observation

The following chart summarizes the pros and cons of each generated design concept:

Product Name	Advantages	Disadvantages
Clear window	• Easy to manufacture	• Limited view
Mirror	• View of baby's face	• Dangerous for baby • Adjustment needed to achieve the best view angle

		• Limited angle of view
Camera and Screen	• Easy to monitor	• Too much cost • Requires extra power
Clear structure	• Provide the best view angle	• Hard to find the transparent and robust material

Table 14. Comparison of design concepts of parents observation

FUNCTION 11: FOLDING SYSTEM

Product Name	Advantages	Disadvantages
Vertically folding	• Simple motion	• Relatively large folded volume
Horizontally folding	• Minimized folded volume	• Added complexity

Table 15. Comparison of design concepts of folding system

SELECTION

A Pugh chart was created for each function so that we could perform a quantitative analysis of each concept, assisting us in choosing concepts for our stroller. Since the different functions serve different roles within the stroller, we changed the specifications on which the concepts would be judged for each different function. A (+) sign indicates that the criterion was satisfied completely, a (0) was given when the criterion was only partially satisfied, and a (-) was given when the criterion was not satisfied at all.

FUNCTION 1: BRAKING TRIGGER SYSTEM The selection of the braking trigger system is presented in the Pugh chart below. The criteria for the selection of the braking trigger system are as shown in the leftmost column.

	Manual Brake Trigger	Mechatronic Brake Trigger	Automatic Mechanical Brake Trigger	Automatic Electronic Brake Trigger	Pneumatic with Diagnostic Noise
Effectiveness	-	+	+	+	-
Convenience	-	+	+	+	0
Cost	+	-	0	-	-
Reliability	0	0	+	0	-
Manufacturability	+	-	+	+	0
Total (+)	2	2	4	3	0
Total (-)	2	2	0	1	3
Total	0	0	4	2	-3

Table 16. Pugh chart for braking trigger system

As see in the Pugh chart above, the automatic mechanical brake trigger is effective, convenient, reliable and easy to manufacture. It is a feasible system, and will perform the necessary functions without introducing additional complications into the system. The automatic brake trigger can dramatically reduce the chance of an accident. Thus, we conclude that the optimal braking trigger system is the automatic mechanical brake trigger.

FUNCTION 2: BRAKING MECHANISM The selection of the braking mechanism is presented in the Pugh chart below. The criteria for the selection of the braking mechanism are as shown in the leftmost column.

	Hydraulic + Caliper	Mechanical + Caliper	Slot Interrupt	Electric Motor	Tether
Effectiveness	+	+	+	+	0
Convenience	+	+	0	+	-
Cost	-	0	+	-	+
Reliability	0	0	+	-	-
Manufacturability	-	0	+	0	+
Total (+)	2	2	4	2	2
Total (-)	2	0	0	2	2
Total	0	2	4	0	0

Table 17. Pugh chart for braking mechanism

From the Pugh chart above, the slot interrupt brake mechanism is effective, cheap, reliable and easy to manufacture. The hydraulic caliper and the electric motor introduced too many complications into the baby stroller, particularly cost. The tether is very inconvenient for the parent. The mechanical calipers are unreliable, as brake pad wear will render the system ineffective after some time. Thus, we conclude that the optimal braking mechanism is the slot interrupt brake mechanism.

FUNCTION 3: NIGHTTIME VISIBILITY The selection of the lighting system is presented in the Pugh chart below. The criteria for the selection of the lighting system are as shown in the leftmost column.

	LED Light	Reflective Material	Circular Florescent	Flashing Wheel
Aesthetics	0	0		
Brightness	+	-	+	0
Angles	+	0	+	-
Cost	0	+	-	0
Reliability	0	+	-	-
Manufacturability	0	+	-	+

Total (+)	2	3	2	1
Total (-)	0	1	3	2
Total	2	2	-1	-1

Table 18. Pugh chart for nighttime visibility

From the Pugh chart above, the circular florescent is bright but easy to break, which will be dangerous to the baby due to the mercury content and shards. The flashing wheel is too low to be seen by the drivers. Thus, we conclude that the optimal lighting system is the combination of the LED lights and reflective material.

FUNCTION 4: SUFFOCATION PREVENTION The selection of the suffocation prevention system is presented in the Pugh chart below. The criteria for the selection of the suffocation prevention system are as shown in the leftmost column.

	Breathable Material	Heartbeat monitor	Minimize Restraint Gaps	Adjustable Side Bolsters
Aesthetics	+	+	+	+
Comfort	+	+	-	+
Convenience	+	+	+	+
Cost	+	-	+	0
Reliability	0	0	+	+
Manufacturability	+	-	+	0
Total (+)	5	3	5	4
Total (-)	0	2	1	0
Total	5	1	4	4

Table 19. Pugh chart for suffocation prevention

We can quickly tell that the heartbeat monitor is far too expensive to be a feasible concept. The breathable material, minimal gaps, and adjustable side bolsters prevent the probability of suffocation occurring, without adding excessive cost to the system. Thus, we conclude that the optimal suffocation prevention system is the combination of breathable material, minimize restraint gaps and adjustable side bolsters.

FUNCTION 5: PINCH PROTECTION The selection of the pinch protection system is presented in the Pugh chart below. The criteria for the selection of the pinch protection system are as shown in the leftmost column.

	Hinge Cover	Joins that never close	Filler Material	Cloth Covering
Aesthetics	+	+	+	+
Effectiveness	0	+	-	+
Convenience	+	+	+	+
Cost	+		+	0
Reliability	0	0	+	+
Manufacturability	+	-	+	0
Total (+)	5	3	5	4
Total (-)	0	2	1	0
Total	5	1	4	4

Table 20. Pugh chart for pinch protection

The Pugh chart above shows that the filler material is not effective enough to be chosen as a design. The concept of joints that never close is too hard to design and manufacture, and limited time and resources prevents this mechanism from being a feasible chosen concept. However, the hinge cover and the cloth cover are effective, convenient, reliable and easy to manufacture. Thus, we conclude that the pinch protection system is the combination of hinge cover and cloth covering.

FUNCTION 6: PROPER SETUP NOTIFICATION The selection of the proper setup notification system is presented in the Pugh chart below. The criteria for the selection of the proper setup notification system are as shown in the leftmost column.

	Light	Sound	Baby Weight Sensor	Limit Switches on the Hinges	Potentiometer
Effectiveness	0	+	+	+	+
Convenience	+	0	+	-	+
Cost	0	0	+	-	-
Reliability	0	0	-	0	+
Manufacturability	+	+	-	-	-
Total (+)	2	2	3	1	3
Total (-)	0	0	2	3	2
Total	2	2	1	-2	1

Table 21. Pugh chart for proper setup notification

From the Pugh chart above, the sound notification is effective and easy to manufacture. The baby weight sensor is effective and cheap, and is useful in disabling safety features when they are not necessary. The limited switches on the hinges are not convenient and the manufacturing process will be too difficult. The potentiometers reliability has known issues. Thus, we conclude that the optimal proper setup notification system would be to use a combination of light and sound notifications with the baby weight sensor, to control when these safety features are active.

FUNCTION 7: PROPER RESTRAINT NOTIFICATION The selection of the proper restraint notification system is presented in the Pugh chart below. The criteria for the selection of the proper restraint notification system are as shown in the leftmost column.

	Light	Sound	Buckle Sensor	Tension Sensor
Effectiveness	0	+	+	+
Convenience	+	0	+	+
Cost	0	0	0	0
Reliability	0	0	0	0
Manufacturability	+	+	-	-
Total (+)	2	2	2	2
Total (-)	0	0	1	1
Total	2	2	1	1

Table 22. Pugh chart for proper restraint notification

From the Pugh chart above, the sound and light notifications are widely used and cheap. Although the buckle sensor and the tension sensor are hard to manufacture, they add extra safety to the whole stroller so that it reduces the chance of an accident, especially seeing as the majority of accidents occur as a result of falling from the stroller Thus, we can conclude that the optimal proper restraint notification system is the combination of the buckle sensor, the tension sensor and the light/sound notifications.

FUNCTION 8: STRUCTURE STRENGTH The selection of structure strength material is presented in the Pugh chart below. The criteria for the selection of the structure strength material are as shown in the leftmost column.

	Tubular Aluminum	Plastics	Steel Alloy	Titanium Alloy
Density	+	+	-	+
Robustness	0	-	+	+
Cost	0	+	0	-
Reliability	+	-	+	0
Manufacturability	+	+	0	-

Total (+)	3	3	2	2
Total (-)	0	2	1	2
Total	3	1	1	0

Table 23. Pugh chart for structure strength

From the Pugh chart above, the tubular aluminum is light, robust, cheap and easy to manufacture. The plastic is not robust, and could cause failure of the stroller frame. The steel alloy is too heavy, and will be difficult to manufacture. The titanium alloy is too expensive, and not worth spending the extra cost on. Thus, we conclude that the optimal structure strength material is tubular aluminum.

FUNCTION 9: ONE-HANDED OPERATION The selection of the one-handed operation system is presented in the Pugh chart below. The criteria for the selection of the one-handed operation system are as shown in the leftmost column.

	Dual Bar with Loop inwards	Dual Bar with Loop outwards	Dual Bar with Vertical Handle	Wrist Support	Dual Wheels on Each Swivel
Effectiveness	0	+	+	+	-
Convenience	+	+	+	+	0
Cost	+	-	0	-	-
Reliability	0	0	+	0	-
Manufacturability	+	-	+	+	0
Total (+)	2	2	4	3	0
Total (-)	2	2	0	1	3
Total	0	0	4	2	-3

Table 24. Pugh chart for one-handed operation

From the Pugh chart above, the dual bar with vertical handle concept is effective, convenient and cheap. It is also easy to manufacture, because of its geometry. The dual wheels will add stability to the stroller, and is easy to add to the system without excessive cost. Thus, we conclude that the optimal one-handed operation system is the dual bar with a vertical handle bar, plus using dual wheels on each swivel.

FUNCTION 10: PARENT OBSERVATION The selection of parent observation system is presented in the Pugh chart below. The criteria for the selection of the parent observation system are as shown in the leftmost column.

	Clear Window	Mirror	Camera and Screen	Clear Structure
Effectiveness	+	0	+	+
Convenience	+	0	+	+
Cost	+	0	-	-
Safety	+	-	+	-
Manufacturability	+	+	-	0
Total (+)	5	1	3	2
Total (-)	0	1	2	2
Total	5	0	1	0

Table 25. Pugh chart for parent observation

From the Pugh chart above, the clear window is effective, convenient, cheap, safe and easy to manufacture. The camera and screen device is too expensive to be a reasonable feature. Although the clear structure is transparent, allowing view of the child, the material itself is not robust enough to consider, thus damaging the structure strength. The mirror is difficult to adjust and is also dangerous to the baby if it is broken. Thus, we can conclude that the optimal parent observation system is the clear window concept.

FUNCTION 11: FOLDING SYSTEM The selection of folding system is presented in the Pugh chart below. The criteria for the selection of the folding system are as shown in the leftmost column.

	Vertical	Horizontal
Convenience	+	0
Cost	0	0
Folded Volume	0	+
Manufacturability	+	-
Total (+)	4	1
Total (-)	0	1
Total	4	0

Table 26. Pugh chart for folding system

From the Pugh chart above, we note that the vertical folding system is convenient and easy to manufacture. Though the folded volume is relatively larger than the horizontal folding system, the dimensions are still acceptable, not providing any additional concerns. Thus, we can conclude that the optimal folding system is the vertical folding system.

SELECTED CONCEPT

BRAKING TRIGGER SYSTEM

As determined from the Pugh chart, the automatic mechanical system will be used for our stroller system. We plan to include a latch on both the horizontal handlebar as well as the added one-handed operation bar. These will be connected to both activate release of the brakes. A cable will feed down from the handle to the braking mechanism for activation. The automatic braking eliminates the parental inconvenience of needing to set a manual brake upon stopping, and more importantly, makes certain that the stroller cannot roll away if left unattended and without brakes. Furthermore, the mechanical system is simpler. Electrical or mechatronic systems can fail suddenly with no warning, leaving the user bewildered. Finally, the cost of the automatic mechanical braking trigger is expected to be much lower than the competing concepts

BRAKING MECHANISM

The slot interrupt braking is the chosen mechanism for our alpha design, per the Pugh charts as well as group consensus. The cable which attaches to the automatic mechanical braking trigger will first pass into a housing unit next to the back wheels. It will then attach to the pin, which is used to fit in the spokes when the brake is activated, halting the stroller from movement. A spring will be fit between the pin and the housing unit, so that application of the brake trigger will pull the pin away from the wheel, compressing the spring while now allowing the wheel to move freely. When the trigger is released, the spring will force the pin back into the wheel, so that movement of the stroller is impeded.

NIGHTTIME VISIBILITY

We chose to implement a combination of the LED lighting system and the reflective material to satisfy the nighttime visibility function. The LED system is feasible to manufacture, and the individual components which comprise the circuit will not add excessive cost or weight to the system. We estimate the entire LED system will contribute approximately $3, based off cost values found for each component to be used [22]. The motor used primarily for the LED system will also serve to provide power for the notification systems. The reflective material will be an effective backup lighting system, in case the stroller is standing still, in which case the LEDs would not be lit. Since many nighttime stroller accidents occur due to cars, their headlights will provide the necessary light to illuminate this reflective material. In addition, the light emitted from the LEDs during motion will illuminate the reflective material, serving to provide better overall lighting.

SUFFOCATION PREVENTION

To satisfy the suffocation prevention function, we will use a combination of the breathable material, minimal gaps, and adjustable side bolsters concepts. It is important to include all three in our design, as each of them addresses different safety hazards that could arise during stroller use. We will conduct further research into fabrics to determine the best breathable material that is also comfortable and inexpensive. Using this as the default fabric for the stroller will avoid the possibility of a child’s face being smothered, resulting in suffocation. All gaps within the seat section of the stroller will be minimized in order to keep the child firmly in place, and unable to slip into a dangerous position. This includes the spaces between the restraint belts, the spaces between the side of the seat and the linkage system, and the space between the two sides of the seat. We will also ensure to not build holes for the child's legs, since this has proven to be extremely dangerous in past designs. Side bolsters will be implemented into the seat to keep the child in position during the stroller ride. This, like the minimization of the gaps, will act to keep them firmly in place, reducing the chance that they will fall out of the stroller and sustain injury.

PINCH PROTECTION

Both the hinge cover and cloth cover concepts will be used to offer pinch protection. The hinge cover will be the primary device used, as it is more rigid, and thus more effective at keeping the child from fitting an extremity into the dangerous gap. In the case where the hinge cover cannot be properly fit onto a joint without significantly altering the motion of the system, we will cover it with a fully-enclosed bag-like covering. This will be sewn into the design, with no zipper or similar mechanism available for removal, to ensure constant safety.

PROPER SETUP NOTIFICATION

For the function, a simple electric circuit will be built, operating on the power generated from the DC motor that is attached to the wheel. When the stroller is properly setup, and the baby is seated inside, the baby weight sensor will compress correctly. This will complete the circuit, activating the notification outputs, the speaker and the light. The speaker will emit a brief noise to indicate the proper setup is achieved, and the LED light will illuminate, indicating that the baby is in proper position.

PROPER RESTRAINT NOTIFICATION

A combination of the tension sensor, buckle sensor and sound notification system will meet our requirements. The electric circuit we apply here also runs off of the DC motor powered by the wheel. This circuit will include the tension sensor, the buckle sensor and a speaker and sound system. When the weight sensor is compressed, the circuit is completed, and all of the safety features are enabled. By doing this, we can prevent unnecessary alarms and battery drain if the stroller is being pushed without a child inside. If the weight sensor is compressed and the buckle sensor is not activated, the sound system beeps, notifying the user of the safety hazard. The tension sensor provides additional safety support. If the stroller is moving with the weight sensor compressed but the tension sensor does not sense a tight restraint strap, it will alert the user via noise. This serves to prevent the child from falling out of the stroller, which accounts for a major portion of stroller injuries, as previously discussed.

STRUCTURE STRENGTH

Among four different materials, we picked aluminum alloy as our structure material. It's light and has high strength. The price of aluminum alloy is also within tolerable range. Aluminum alloy is the most widely used structure material in the stroller industry. We will purchase a stroller that contains an aluminum alloy structure, as manufacturing and designing the frame ourselves takes excessive time and resources, and it out of the scope of this project.

ONE-HANDED OPERATION

For this function, we decided on a vertical handlebar for one-handed operation. Furthermore, the vertical bar will make it much easier for parents to steer the stroller when they are operating the stroller with one hand. This part will be manufactured in the shop and attached to the purchased stroller frame's horizontal handlebar.

PARENT OBSERVATION

We decided to use a clear window as our final selected concept for parents observation. Comparing with other three concepts, the clear window is cheap, safe, easy to add to the system and provide a good view for parents. To apply this concept we just need to replace some part of canopy of our purchased stroller with a transparent plastic sheet.

FOLDING SYSTEM

Among two folding system, we decided to use a vertical folding system. This mechanism will allow the baby stroller to fold vertically, which reduce the volume and make stroller portable. One major advantage of this folding mechanism, when compared with horizontal folding system, is that stroller will stay stable on the ground during folding, and cannot fall to the side, which could damage the stroller.

Finally, our 3D model is made in SOLIDWORKS 2009 SP3.0. This 3D model shows the vertical bar on the handle bar. The LED lights and reflective material are around the stroller. The slot-interrupt brake system is implemented on the rear wheels. The double wheels in front help with the steering. The stroller fabric is composed of breathable material. There are hinge covers and cloth covers over the linkages. However, the automatic braking trigger system is not shown in the 3D drawing, as the brake cable is expected to fit inside of the stroller frame, avoiding possible entanglement with the child.

Figure 14. 3D model of safe stroller with selected concepts

ENGINEERING DESIGN PARAMETER ANALYSIS

This section includes further engineering analysis to verify the performance of design concepts that may be subject to failure. Through engineering calculations, we analyze how the system will perform under expected real-life conditions. The specific conditions analyzed are the stress on the slot in our braking system, the power in the electrical components, safety issues associated with the electrical system, and durability of the hinge cover. In addition, Failure Modes and Effects Analysis (FMEA) was performed on the system, as well as a selection of materials.

SLOT STRESS ANALYSIS The most likely cause of malfunction of the automatic braking system, a very important aspect of our safe stroller design, is failure of the slot-pin mechanism. The components of this mechanism experience high stress if the stroller is stopped suddenly. First, we analyze the pin that is moved by the braking trigger and cable. This will experience significant force during braking, especially considering the large bending moment that will be applied to a long and thin pin. Thus, by undergoing material selection as described below, we determined that it is best to manufacture the pin out of aluminum, to avoid failure of the pin.

Next, we analyzed the forces acting on the slot in which the pin is inserted. Since we will be using an aluminum pin, we assumed that failure will occur due to these slots breaking, and thus conducted a stress analysis to determine if the material will fail.

We first conducted tests to determine the deceleration of the stroller from a leisurely walking speed (approximately 2 miles per hour) to stop, from which we could derive the force acting on the slot. This was conducted on a carpeted surface, with a backpack locked in, simulating a baby and increasing the overall stroller weight to approximately 40 pounds. The manual brakes were locked and the stroller was pushed up to the walking speed, then released at a specified point. Thus, all the braking was assumed to be applied by the back two wheels. The displacement of the stroller from release to stop was measured. This test was conducted five times by each of the four group members, to reduce error from various walking speeds and error from measurement. All 20 tests were averaged, obtaining a mean stopping distance of 9.4 inches. The precision error in measurement, encompassing two standard deviations, was 3.6 inches. Thus, we used a stopping distance of 5.8 inches, the minimum stopping distance that will introduce the highest force on the slot structure, so that we consider the highest possible applied force. By assuming the stroller has a constant deceleration from walking speed, we obtain an average speed of 1 mile/hour during deceleration. By using Equations (1) and (2) below, we obtain a deceleration of 2.82 m/s^2.

$$v = \frac{x}{t} \qquad \text{Eqn. (1)}$$

$$\nabla x = \frac{1}{2}at^2 \qquad \text{Eqn. (2)}$$

Now, by using Newton's Second Law (F = m a), we calculate F, the force applied to the wheels to stop the stroller, to be 51.2 Newtons. Since this force is applied from the ground, using the 3 inch wheel radius as a moment arm on the wheel, and is distributed over the two wheels, the torque acting on each wheel was calculated to be 3.9 Nm. This torque applies a force on the slot structure through the braking pin, keeping the wheels locked. Using the location of this force to be 1.6 centimeters from the center of the wheel, where the pin is acting on the slot, we obtain a force of 95.9 Newtons acting on the slot structure. Figure 1 below further clarifies the geometry of these forces.

Solid mechanics analysis was then used to obtain the stress acting on the point where the beam is attached to the wheel, σ_{zz} where failure is first likely to occur. This was obtained by using Equation (3).

$$\sigma_{zz} = \frac{My}{I} \qquad \text{Eqn. (3)}$$

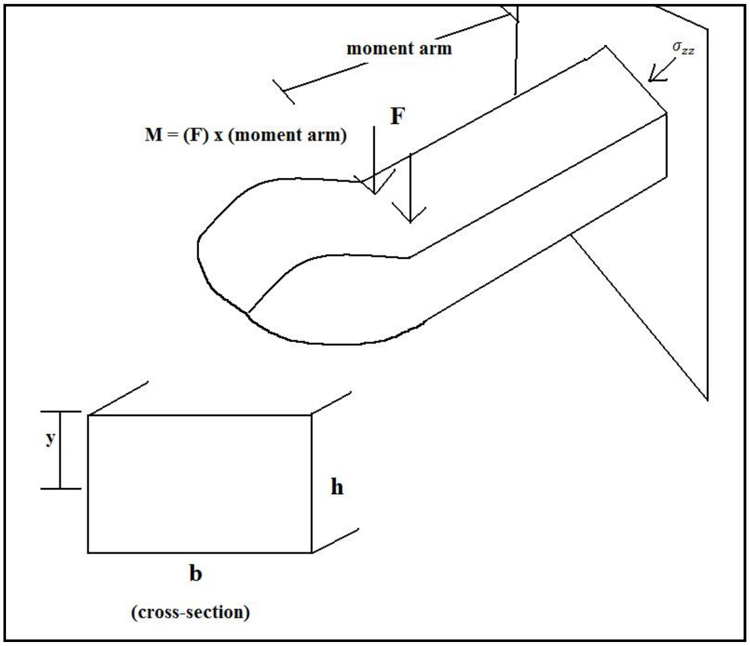


Figure 15: Drawing Used for Solid Mechanics Analysis

Note that the moment arm is obtained by multiplying the pin force by the length to the base of the slot structure, as it does not connect all the way to the center of the wheel. This distance was measured to be 1.02 cm.

The second moment of area was calculated using Equation (4).

$$I = \frac{1}{12}bh^3 \qquad \text{Eqn. (4)}$$

The stress acting on the base of the slot structure during testing was 58.0 MPa. We assumed the plastic used for the slot structure was polypropylene, and used CES EduPack 2009 find the material properties. The yield strength can range from 12-43 MPa, and the tensile stress can range from 19.7-80 MPa. Thus, our structure has yielded for all possible types of polypropylene. Since the material has not failed, we have not reached the tensile strength, and thus must be using a material with a tensile strength above the experienced 58.0 MPa, which is possible, as supported by the material properties. Close observation of the slot structure shows white marks incurred from plastic deformation, supporting the conclusion from our calculations that the material has yielded. While this stress alone will not be enough to cause failure in the pin-slot mechanism, repeated use will result in fatigue of the slot structure, causing failure after a certain amount of time. This, in order to reduce the chance of failure by fatigue, we should aim to decrease this stress as much as possible, since higher stresses will induce fatigue quicker.

Various approximations were used in order to make these calculations. For the purpose of our analysis, this is sufficient, as our calculations are just providing an estimate to the stresses experienced. In addition, we do not know the exact material properties, and can only compare the experienced stresses to the range of yield and tensile strengths provided. The walking speed used was a guess, and was inconsistent between trials. We assumed a beam structure for the slot, even though the sides were also attached, making our estimation of the applied stress higher than it actually would be. In addition, we ignored rolling resistance when the stroller was coming to a stop.

ELECTRICAL COMPONENT ANALYSIS

The following safety features are controlled by the Stroller Control Unit: 1) LED lighting, 2) Proper restraint notification, 3) Proper setup notification and 4) Brake failure warning.

The Stroller Control Unit is a PIC® 16F54 microcontroller that receives 6 separate DC 5V level sensor inputs, namely the wheel generator output signal, the tension and buckle sensor network, the proper setup notification sensors, the slot interrupt pin / brake release lever position sensors, and the seat weight sensor. To reduce cost, the microcontroller clock signal will be supplied by a supported RC circuit instead of a quartz oscillator.

Outputs from the Stroller Control Unit are the LED networks that make up the LED lighting circuit, a warning buzzer, and LED status indicators.

The Stroller Control Unit is powered by a DC wheel generator with a bridge rectifier and a current-limited capacitor.

We will first verify the feasibility of the Stroller Control Unit and its subsystems by first verifying the controller selection, then the input sensors for each of the safety features, and finally the ability to supply the total required current using a wheel-driven DC generator.

MICROCONTROLLER The PIC® 16F54 is chosen for its low cost, durability, low power usage, high source / sink current ability, GPIO count and its watchdog timer feature. It is also lead-free and RoHS certified for European export. Table 27 summarizes these key parameters.

Cost	$0.45 USD at 5,000+ units (unprogrammed)
Voltage range	2-5.5V
Current draw (4MHz mode, 2V VDD, excluding I/O)	170μA
Operating temperature range	-40 - 125^{0}C
GPIO	12
Current source / sink (total for all GPIOs)	25mA
Watchdog timer	Yes

Table 27. PIC® 16F54 key parameters.

The cost of $0.45 USD benefits the low-cost goal of the safety stroller.

The PIC® 16F54 can operate at a maximum voltage of 5.5 Volts which allows up to three LEDs to be driven in series by each GPIO at a forward voltage of 1.7 Volts per typical LED. This means 5 GPIOs can be used to drive 5 groups of 3 LEDs, to reach the 15 total LEDs specified. The PIC® 16F54 GPIO is internally current-limited to 25mA so no external components are needed to drive the groups of 3 LEDs. A flashing pattern will be programmed to flash one group of 3 LEDs at a time to provide better nighttime visibility compared to a static light source, reduce power usage, and to remain within the specified 25mA max per GPIO and 100mA max per GPIO port.

After using 5 GPIOs to drive the 15 LEDs of the lighting system, enough GPIOs remain to implement the Proper restraint notification, Proper setup notification and Brake failure warning systems. Figure 16 shows a pinout for the PDIP18 package version of the PIC®16F54. Table 28 is a listing of the GPIO assignments.

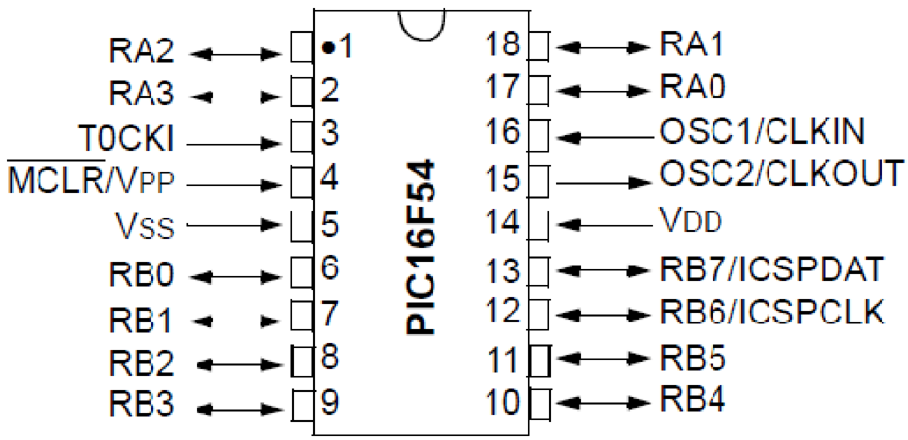


Figure 16. PIC®16F54 PDIP18 Pinout

GPIO name (number sequence out of 12 total)	Assignment (Pin direction)
RA0 (1)	LED Lighting Group 1 (Out)
RA1 (2)	LED Lighting Group 2 (Out)
RA2 (3)	LED Lighting Group 3 (Out)
RA3 (4)	LED Lighting Group 4 (Out)
RB0 (5)	LED Lighting Group 5 (Out)
RB1 (6)	Seat weight sensor (In)
RB2 (7)	Proper Restraint Notification signal (In)
RB3 (8)	Proper Setup Notification signal (In)
RB4 (9)	Brake Failure Notification signal (In)
RB5 (10)	Generator signal input (In)
RB6 (11)	Buzzer (Out)
RB7 (12)	Warning indicator LED (Out)

Table 28. GPIO Assignments

The PIC®16F54 has a 512 word program memory which is more than enough for routine stroller status checking and alerting. 25 bytes of bit-by-bit individually addressable RAM allows for software time delays and simple logic.

LED LIGHTING SYSTEM The LED Lighting System will be driven directly by the PIC® 16F54-based Stroller Control Unit in 5 groups of 3 LEDs in series. Only group of each of the 5 groups is powered at any given time to reduce power consumption as well as to create changing lighting pattern that is more visible than a static light source. Three LEDs of 1.7 Volts forward voltage each can be powered by each GPIO at 5.5 Volts. An equation for LED voltage requirements is shown in Equation 5 below. It is assumed that similar LEDs of 1.7V forward voltages are
used.

$$Supply\ voltage\ (Volts) > number\ of\ LEDs\ \times 1.7\ (Volts) \qquad \text{Eqn. (5)}$$

A 20Ohm resistor will be connected in series with each group of 3 LEDs to give the desired current of 20mA through each LED. An equation describing recommended LED resistor values is given in Equation 6. Again, we assume a 1.7 forward voltage drop per LED.

$$Resistor\ Value\ (Ohms) = \frac{Supply\ Voltage\ (Volts) - number\ of\ LEDs \times 1.7\ (Volts)}{LED\ optimal\ current\ (Amps)} \qquad \text{Eqn. (6)}$$

LEDs can typically have a halflife of 30,000 hours. When flashing in 5 groups for 12 hours a day, this translates to over 35 years of use before the LEDs fall below half of the original brightness.

SAFETY AND OTHER ELECTRICAL CONSIDERATIONS Wherever possible, the warning state will be set by a low input as to create a false positive warning biased system. It is more likely that the system fails with an open connection rather than a short so it is desirable to have a higher likelihood of false positive warnings than to have false negative warnings. The false positive warnings will also serve as a repair alert.
The current traveling through the non-lighting circuits will be limited by a 10 KOhm resistor. The current at 5.5 Volt operation will be 0.55mA which is below the perceivable current [20] even if exposed sensor wiring comes in direct contact with moist skin of no resistance. Equation 7 shows the current to resistance and voltage relationship. In this case, we assume that the wiring, switches, and PIC® 16F54 have negligible resistance compared to the 10KOhm resistor.

$$Current\ (Amps) = Voltage\ potential\ (Volts) \div total\ resistance\ (Ohms) \qquad \text{Eqn. (7)}$$

Though the PIC®16F54 microcontroller is limited to an input pin current of 0.5mA, any pin can be assigned to be either an input or an output through firmware so the input pin current limit cannot always be depended on, such as in the case of firmware corruption changing an input pin to an output.

700KOhm pull-down resistors are used at each input pin (RB1 to RB5) to keep limit switch and springed contact switches from floating to a level high signal due to capacitance and interference when they should otherwise show a level low signal. These inputs serve the Proper Restraint Notification system, Proper Setup Notification system, Brake Failure Notification system, and the weight sensor.

Mechanical switches will undoubtedly have some level of bounce as the limit switches and contact sensors are subjected to mechanical inputs during normal operation. In order to prevent bouncing, a software de-bounce routine will be added to all mechanical limit switch inputs. This is done by repeatedly detecting the input for 255 cycles after the first input change detection. If over half of the 255 additional detection cycles do not detect the change, then the program returns to the normal state and detects the same input again only after the program has completed another cycle. At 4MHz operation, the Stroller Control Unit can complete an entire program cycle with one de-bounce routine in 0.7655ms. This program cycle time gives the maximum delay experienced between impending failure / warnings conditions and the stroller entering an alarm state, since the mechanical switches will bounce before becoming steadily open. Here, we assume a full 512-instruction program with a 10-instruction delay routine, with an average of 1 clock cycle per RISC instruction. These inputs serve the Proper Restraint Notification system, Proper Setup Notification system, Brake Failure Notification system, and the weight sensor.

Equation 8 shows the program cycle time as a function of program size, frequency, and de-bounce routine loop. This gives the delay experienced between impending failure / warnings conditions and the stroller entering an alarm state, since the mechanical switches will bounce before becoming steadily open.

$$Delay\ (s) = \frac{Clocks\ per\ instruction \times (Instructions + 255 \times De\text{-}bounce\ instructions)}{Internal\ clock\ (Hz)} \qquad \text{Eqn. (8)}$$

PROPER RESTRAINT NOTIFICATION SYSTEM The proper restraint notification system is comprised of 5 tension sensors and 1 contact sensor, with all 6 sensors in series so that if any one sensor does not detect proper restraint, the circuit is broken and the Stroller Control Unit enters an alarm state.

The 5 tension sensors are placed at anchor points of each of the 5 restraint belt portions (LH shoulder, RH shoulder, LH lap, RH lap, groin). The tension sensors work by securing a point on the belt 0.5cm before the stroller anchor point to a spring-loaded limit switch mounted at the same location as the anchor point, such that when there is not sufficient tension, the switch is in the retracted position. When sufficient tension is present, the switch is extended. All loads (less the spring tension load) are reacted by the end of the belts which are securely attached by traditional means to the frame of the stroller. The spring tension is 1 pound to maintain a gap-free restraint while maintaining comfort. Since the belt is still attached to the frame by traditional means, the inclusion of this sensor only introduces a 0.5 cm gap which is not significant when compared to the gap caused by the gap introduced by clothes. The 0.5 cm tensioned gap passes a snugness test defined by the ability to pinch the belt slack between fingers[23].

The contact sensor is built into the buckle receptacle attached to the groin belt so that when all 4 buckles (LH shoulder, RH shoulder, LH lap, RH lap) are inserted, the series circuit within the buckle receptacle complete. This is done by using 4 pairs of spring-loaded electrical contacts within the buckle receptacle and a conductor on each of the four belts clips.

The above 5 switches will be connected in series with an input to RB2, so that any open switch(s) will cause the circuit to become open. Table 29 is a truth table for the sensors.

LH Should Belt Tension	RH Should Belt Tension	LH Lap Belt Tension	RH Lap Belt Tension	Crotch Belt Tension	Buckle Contact	**Proper Restraint**
1	1	1	1	1	1	**1 (OK)**
At least one cell in horizontal row contains a zero.						**0 (Alarm)**

Table 29. Truth table for Proper Restraint Notification sensors system

The two sprint-loaded contacts will be connected in series to RB3 so that if either or both latch circuit becomes open, the warning will sound.

The circuit will be current-limited to 0.55mA at 5.5V by using a 10KOhm resistor. This current is below the perceivable current even on skin with no resistance [20]. The current to voltage and resistance equation is shown in equation 7.

A more detailed analysis of a limit switch input into the Stroller Control Unit, including the user of a pull-down resistor and input debouncing, are discussed in further detail in the *Other electrical considerations* section on page 52.

PROPER SETUP NOTIFICATION SYSTEM This will use sensors similar to the buckle sensor in the Proper Restraint Notification System to detect whether the stroller is properly set up.

A pair of spring-loaded contacts will be installed in each lower latch (stationary) and the upper latches (cable operated) will feature electrical contacts that complete the circuit of the springs when it comes in full contact.

The two sprint-loaded contacts will be connected in series to RB3 so that if either or both latch circuit becomes open, the warning will sound.

The circuit will be current-limited to 0.55mA at 5.5V by using a 10KOhm resistor. This current is below the perceivable current even on skin with no resistance [20]. The current to voltage and resistance equation is shown in equation 7.

A more detailed analysis of a limit switch input into the Stroller Control Unit, including the user of a pull-down resistor and input debouncing, are discussed in further detail in the *Other electrical considerations* section on page 52.

BRAKE FAILURE NOTIFICATION SYSTEM This system uses sensors similar to the restraint tension limit switches found in the Proper Restraint Notification System to detect whether the automatic brakes have failed. The limit switches will be installed in both the slot-interrupt mechanisms at the wheels and at the three brake release levers. This system inputs into RB4 of the PIC®16F54.

A failure state occurs when at all brake release levers are released and one or more brakes are not set, and is detected when the Brake Failure Notification circuit becomes open.

The brake release lever limit switches circuit will be closed when the lever is activated in a manner to release the slot interrupt brake mechanism. Three lever limit switches are connected in parallel so that only one lever is needed to set the brake released signal portion.

The two slot interrupt brake mechanism contain limit switches that become closed when the brakes are applied (i.e. slot interruption pins are extended). Two switches (one at each wheel) are connected in series so that both brakes must be set to set the brake set signal portion.

The brake release lever limit switch circuit and the slot interrupt brake mechanism limit switch circuit are then connected in parallel so that the signal circuit becomes open when neither a Brake Released signal nor a Brake Set signal is present. This sends a level low (failure) signal to the Stroller Control Unit.

Tables 30 to 32 are truth tables of the Brake Released signal, Brake Set signal, and the detected brake system operation status by the Stroller Control Unit.

LH Release Lever	RH Release Lever	Middle Release Lever	**Brake Released Signal**
1	1	1	**1**
1	1	0	**1**
1	0	1	**1**
0	1	1	**1**
1	0	0	**1**

0	1	0	**1**
0	0	1	**1**
0	0	0	**0**

Table 30. OR Truth Table of Brake Released signal comprising three limit switches in parallel.

LH Slot Interrupt Set	RH Slot Interrupt Set	**Brake Set Signal**
1	1	**1**
1	0	**0**
0	1	**0**
0	0	**0**

Table 31. AND Truth Table of Brake Set signal comprising two limit switches in series.

Brake Released Signal	Brake Set Signal	**Brake System**
1	1	**1 Brake Stuck – No Alarm**
1	0	**1 No Alarm**
0	1	**1 No Alarm**
0	0	**0 Brake Failed – Alarm Mode**

Table 32. OR Truth table of Brake Released signal and brake system status.

The circuit will be current-limited to 0.55mA at 5.5V by using a 10KOhm resistor. This current is below the perceivable current even on skin with no resistance [20]. The current to voltage and resistance equation is shown in equation 7.

A more detailed analysis of a limit switch input into the Stroller Control Unit, including the user of a pull-down resistor and input debouncing, are discussed in further detail in the *Other electrical considerations* section on page 52.

SEAT WEIGHT SENSOR A spring-retracted limit switch will be attached to the vertical support of the stroller so that when a baby's weight is present in the seat, the seat back will be pushed to its normal position and the limit switch will be activated. This signal tells the Stroller Control Unit to turn on outputs (LED light, Proper Restraint Notification, Proper Setup Notification and Brake Failure Notification).

This feature is useful in two situations. In the first, while the stroller is being unfolded, the Proper Setup Notification and Proper Restraint Notification are suppressed to avoid annoying warning sounds before the baby is seated. In this situation, the parent has 10 seconds to securely restrain the baby after seating.

In the second situation, the stroller is being transported by push without a baby inside. In this condition, neither the lights nor the warning sounds will be active. This feature is also useful when the stroller is taken to a quiet area and the baby is removed so that the warning sounds do not continue until the stored charge is depleted.
The spring used to retract the limit switch when there is no load will have a spring constant of 2.7kg/cm in order to allow the limit switch to trip when a 5 lb baby's weight is added to the seat. The low spring constant will reduce the effects of low frequency high amplitude switch bounce, while software de-bouncing filters out high frequency low amplitude switch bounce.

WARNING BUZZER The warning buzzer draws 5mA of current at 12V at 3,600Hz. Assuming a constant resistance at this driving frequency, the buzzer will draw 2.29mA at our specified 5.5V operation.

POWER SUPPLY AND GENERATOR The maximum total current needed for the electrical systems is 22.46mA when all outputs are in operation. Because a LM317 variable linear voltage regulator plus two supporting resistors does not cost significantly more than a 7805 fixed 5V linear voltage regulator with a Zener diode, it will be used instead of a 5V regulator plus a Zener diode at the regulator ground.

A linear regulator usually requires at least 2V above output voltage in order to satisfy the output voltage. This means the stroller generator will need an output of at least 7.5V at 22.46mA. Assuming that the voltage regulator does not introduce significant resistance, the linear voltage regulator power dissipation at input voltage 2V above the output voltage is given by Equation 9. At a 22.46mA output, the linear regulator dissipates 44.94mW in our stroller application.

$$Regulator\ Dissipation\ (W) = Current\ (A) \times\ 2V \qquad \text{Eqn. (9)}$$

Total power input into the regulator to supply the needed current as a function of the output voltage and output current is given by Equation 10. In the stroller application, the generator will need to output at least 168mW.

$$LM317\ Power\ Requirement\ (W) = Current\ (A) \times\ [Output\ Voltage\ (V) + 2(V)] \qquad \text{Eqn. (10)}$$

In order to ensure that the mechanical input into the stroller in order to generate the required electrical power is within reason, we calculated the additional stroller pushing force required by the generator system at stroller speed. Stroller speed is assumed to be 2.4mph as with brake system calculations in a prior section and the efficiency is assumed to be 100% (low current). The conversion of 550 lbs × 1 (ft/s) = 745.7W is used to calculate the pounds of additional force required by the stroller pusher in order to power the generator. This conversion yields a stroller generator mechanical power requirement of .0331 lbs × 1 (ft/s). Substituting in 2.4mph as 3.52(ft/s), the resulting stroller force is 0.0094lbs.

Of course, mechanical losses are present in small wheel-powered generators, but they did not present a noticeable difference during testing.

HINGE COVER The pinch cover must be able to completely cover the pinch area from being accessible by fingers and also withstand attempts at pinch cover removal, both as specified by ASTM F-833 [6].

Figure 15 below shows the dimensions of the pinch cover. The minimum moving member gap size is 1.5cm, which is well outside the 5.33mm-9.53mm pinching gap range as defined by ASTMF-833[6]. Pinch point 1 (asterisk 1 "*1") is covered by the top enclosure (solid black curve with surface plan perpendicular to page) from top and side intrusion. Bottom intrusion of pinch point 1 is provided by the minimum of 12cm distance between the open-ended covers and the pinch location. Pinch point 2 is protected by the top enclosure (solid black curve with surface plane perpendicular to page) as well as by the moving members themselves as there exists only a 2mm gap (into the page) between the cover face and the members. Pinch point 3 is similarly protected as Pinch point 2 by both the top enclosure and the members themselves. An inner diameter of 13cm provides 1.5cm of between the pinch cover and the 11.5cm diameter semi-circular sweep of the moving latches.

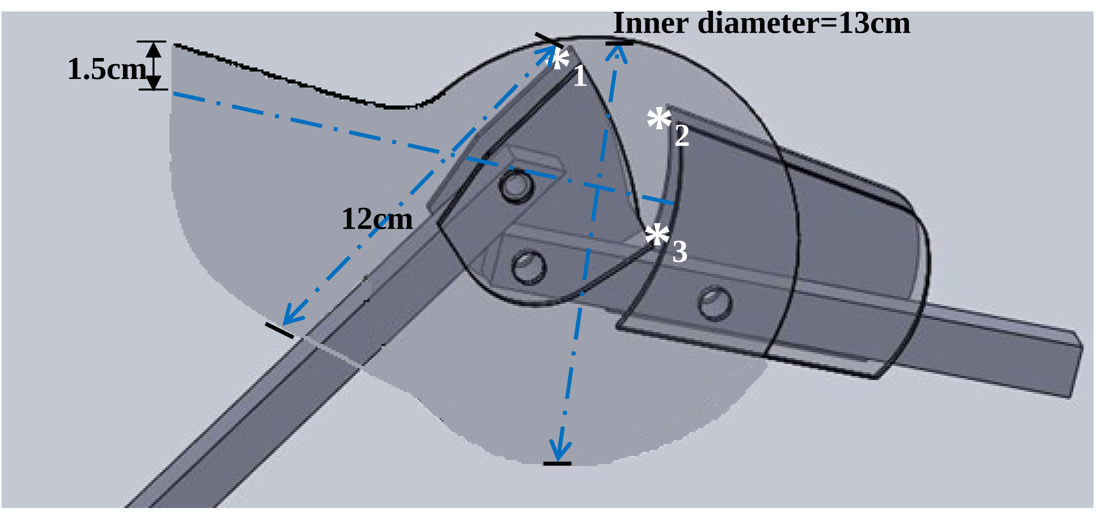


Figure 17. Pinch Protection Cover

Pinch cover removal is prevented by using a bolt that attaches the covers to the right-side member. Using 2mm-thich polypropylene material for the hinge cover in conjunction with a 1cm outer diameter washer results in a shear area of 62.8μm^2 (Eqn. 11, Fig. 18). Polypropylene has a yield stress of 20MPa, and at 2mm thick with a 1cm outer diameter washer, the cover can withstand a 1256N (282lb) normal force before yielding (Equation 12). This far exceeds the 15lb requirement of ASTM F-883[6] at a safety factor of 18. The extra pinch cover thickness minimizes denting that could cause interference with the moving latch which can lead to folding resistance and wear.

$$Shear\ Area\ (m^2) = od\ (m) \times \pi \times h(m) \qquad \text{Eqn. (11)}$$

$$Shear\ Stress\ (Pa) = Force\ (N) \div Shear\ Area\ (m^2) \qquad \text{Eqn. (12)}$$

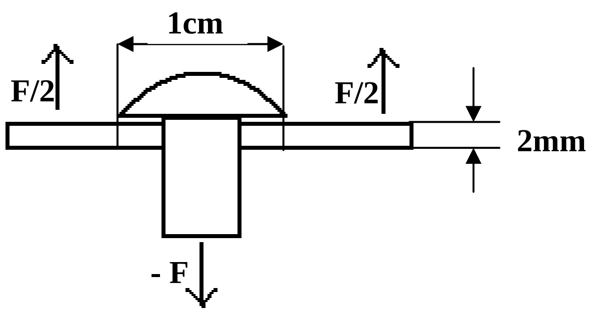


Figure 18. **Shear Stress on Pinch Cover**

CLEAR WINDOW There exist many other consumer products that offer a clear, flexible polymer window that can withstand repeated folding and unfolding – one such product is the back window found on soft top convertible vehicles. Since empirical data shows that durability under repeated folding of these flexible clear polymers such as PVC is generally not an issue [21], we will not be using a mathematical model to perform further durability analysis.

Since durability is generally not an issue, we will focus on the UV-blocking effects of the clear window to ensure protection of the child from harmful UV exposure. While a PVC window will partially block UV radiation, commercially available UV-protection films offer better protection.

BRAKE LEVER CALCULATIONS To determine the force needed to apply to the brake lever to compress the springs and release the automatic brakes, we conducted a force balance on the lever. We treated the lever as a single-support beam, as shown below in Fig. 19, and treated it as a steady state. Estimating the moment arm on the lever as 4 cm, and the moment arm between the hinge and the end to be 1 cm, we calculated that 5 N of force on the lever would exert 20 N of force on the cable. The extension of the cable was neglected, and we assumed that this 20 N was split between the two springs. Using the spring force equation (F = kx), and estimating that the pin would need to be compressed 1.25 cm to disengage the slot, we determined that a 5 N force would release the brakes if springs with constants of 0.8 kN/m are used.

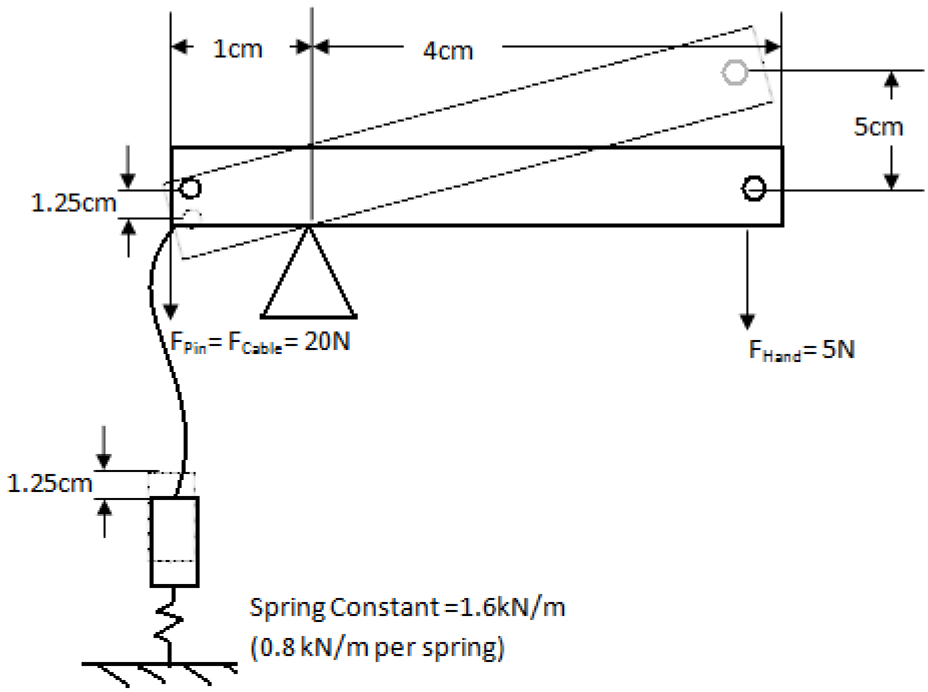


Figure 19. Drawing Used for Brake Lever Calculations

ADAMS VIEW ANALYSIS The Especially for Kids TrendSport stroller chassis purchased from Toys-R-Us is rated for up to 40lbs. This rating was verified by creating a simplified ADAMS View model of one side of the stroller. The stroller model was loaded with an approximately 40lb mass at the seat area with Earth gravity enabled in the ADAMS parameters.
The wheels were replaced with ADAMS View revolute (pin) joints having two degrees of freedom to further simply the model and eliminate the need to balance the model for stability under gravity. It is assumed that such a structure would put a downward load on both front and back wheel structures.

Forces on members were graphed with respect to time and showed constant values as expected when no spring rates were defined. The plastic parts of the stroller were examined at multiple points for high levels of forces. The highest normal force was converted to a shear stress and compared with the yield stress of polypropylene plastic by diving force by the product of the length of the smallest contact edge and the plastic thickness.

The highest force was approximately 270N. The highest resulting stress on the plastic joint is approximately 5MPa, which is within the polypropylene yield strength of 20MPa by a safety factor of 4.

The model can be seen in Figure 20. The red block has a mass of approximately 40lbs, while the green square members (representing plastic hinges) were analyzed at multiple points for forces. Figure 21 shows a force vs. time graph at three points on the lower plastic latch.

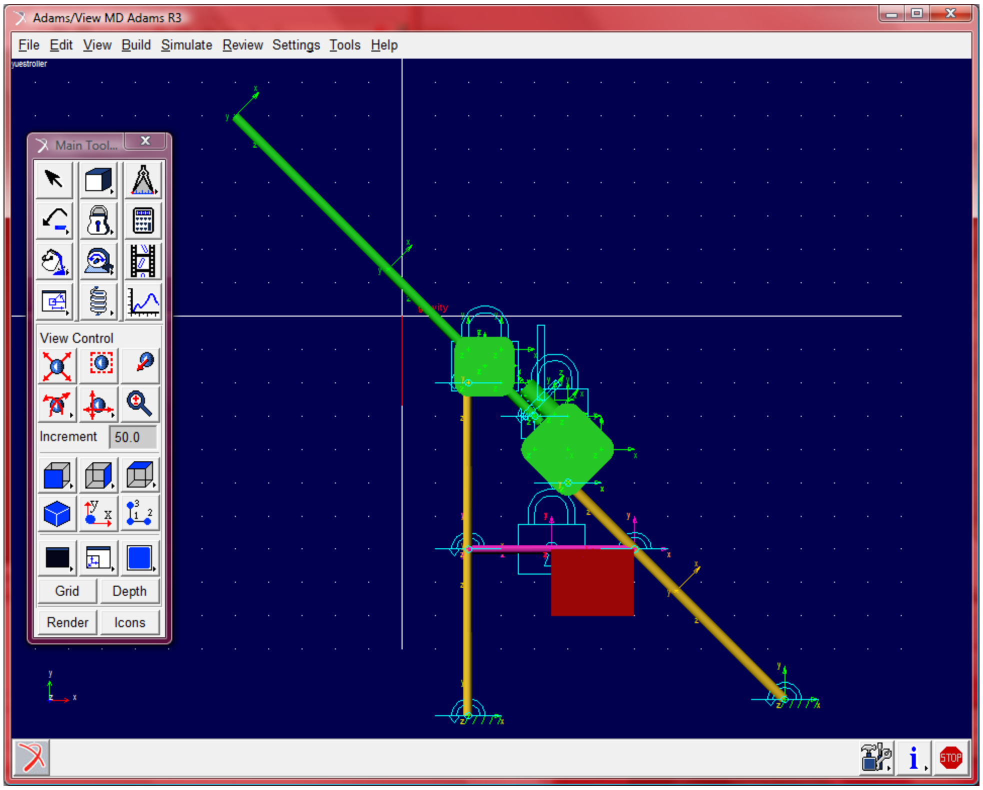


Figure 20. Simplified ADAMS View model of stroller chassis (RH side)

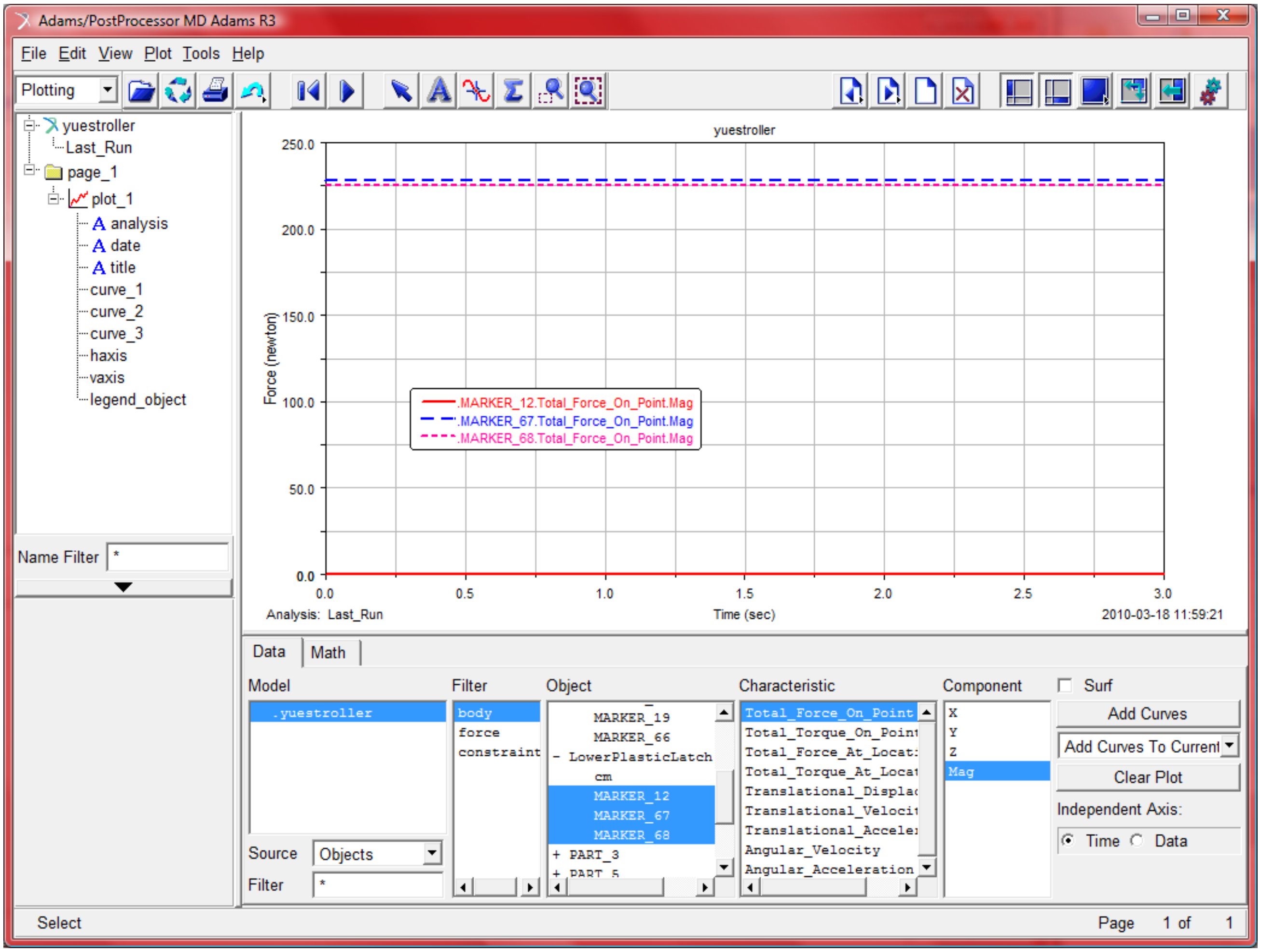


Figure 21. ADAMS forces on lower hinge vs. time graph.

FAILURE MODES AND EFFECTS ANALYSIS The table below shows the Failure Modes and Effects Analysis for the baby stroller. FMEA Analysis was performed on those components we deemed most likely to fail: manual braking system, hinge lock system and the structure. The failure of any of these systems may be very dangerous. The failure of the braking system leads to the inability to stop the stroller. The failure of hinge lock can expose the dangerous pinch points. The failure of the structure can make the stroller unable to fold, and prone to collapse, which could injure the child within. The potential risk of braking pin and braking slot fails can be reduced by using a strong metal material. The potential risk of the hinge lock can be reduced by using a tougher plastic. The potential risk of the structure can be reduced by using a tougher material. In an effort to further reduce the risk of catastrophic failure, all purchased parts can be inspected thoroughly prior to use.

Product Name: Safety Stroller			Devel. Team: Team SafeStroll			Date:			
Part# & Functions	**Potential Failure Mode**	**Potential Effect(s) of Failure**	**Severity (S)**	**Potential Causes/Mechanism (s) of Failure**	**Occurrence (O)**	**Current Design Controls/ Tests**	**Detection (D)**	**Recommended Actions**	**RPN**
Manual braking system	Inability to brake the stroller	Lose control of the stroller	3	Braking slot yields	4	Bending test	4	Use metal cover	48
			8	Braking pin yields	2	Bending test	4	Use metal pin	64
Hinge Lock System	Inability to cover pinch or prevent suffocati on	Expose the dangerou s pinch points	3	Plastic breaks	2	Bending test	3	Use tougher plastic	18
Structure	Inability to fold and unfold the stroller	Dangerou s to baby and loss of foldabilit y	6	Plastic wheel connection fractures	1	bending test	4	Use tougher material	24

Table 33. Failure modes and effects analysis for baby stroller

MATERIAL SELECTION

After researching in CES, we made decisions on material selections for our major parts including brake system, one handle bar and pinch cover.

BRAKE SYSTEM:

1. Brake Housing

We intend to use PVC to fabricate two parts of brake housing. It is cheap and light.

2. Brake Pin

We intend to use Cast Aluminum alloy to fabricate the brake pin. According to our calculation, the yield strength of Cast Al-alloy will meet our requirement.

ONE-HANDED HANDLEBAR:

We intend to use PVC after the comparison among different plastic materials.
PVC is cheap and light. Also given the consideration of easy to machine, we decide to use PVC as the materials.

HINGE COVER:

We intend to use PVC to make the Pinch cover. PVC is cheap and light.

Beside four major parts that we plan to fabricate, we also need to make some small housing to host some sensors or electrical parts. All of them will be made of Polypropylene. This plastic is cheap and light, but within good strength.

Detailed material properties are list in the table below.

	Density [lb/ft^3]	Price [USD/lb]	Yield Strength [ksi]	Machinability [-]
Polypropylene	55.6 – 56.8	0.522 – 0.574	3 - 5.4	3 - 4
Pine, across grain	27.5 – 37.5	0.32 – 0.64	0.247 – 0.377	5
Polyurethane	63.7 – 78	2.2 – 2.42	3.63 – 7.4	2 – 3
Cast Al-alloys	156 – 181	0.771 – 0.848	7.25 – 47.9	4 - 5
Stainless Steel	474 – 506	2.96 – 3.25	24.7 – 145	2 - 3

Table 34. Material selection

DESIGN ASSIGNMENTS Through multiple design assignments, we planned how we would build a prototype, mass manufacture it, and how it would impact the environment, and learned some lessons from this. In the material and manufacturing selection process, we learned that it is very important to choose the right manufacturing method for a certain material. A better manufacturing method can make the whole manufacturing process more time efficient and also reduce the waste. Using CES software, we can find the best material which meets the requirements easily. In the design for environmental sustainability process, we learned that there are huge differences between different materials in waste emission. We should always validate the waste emission before we choose a certain material. Though a single prototype won't cause much problem, there will be huge environmental issue under mass production if we didn't use environment friendly materials. Using SimaPro software, we can find the waste emission index for each material at a certain mass easily. In the design for safety process, we learned that we should plan carefully before we actually manufacture anything. There are a lot of potential hazards in the manufacturing process which could cause serious problems to the operator. However, after careful planning, we can reduce the most hazards to negligible low level. Safety is always the most important thing in manufacturing. By doing the DesginSafe report, we can find out those potential hazards, and work out the plan to reduce them before, which makes the manufacturing process safe.

FINAL DESIGN DESCRIPTION

BRAKE TRIGGER The brake trigger mechanism in the final design will operate as a comfortable, ergonomic button that contours around the user's fingertips. All three buttons are embedded in the handlebars – two in the right and left sides of the horizontal handlebar, and one in the vertical handlebar. A linkage system will be built inside each handlebar, which rotates to pull the cable up and release the brakes upon pushing the brake triggers. This avoids the parents' hands tiring from needing to push an uncomfortably hard handle for an extended period of time. This is preferred over a braking lever system – as built in the prototype – since it will be more aesthetically pleasing, and more comfortable to use. Figure 22 below illustrates the connection between the brake levers and the slot-interrupt system.

SLOT-INTERRUPT SYSTEM The slot-interrupt braking system for the final design is illustrated below in Figure 20. This design is built into both back wheels of the stroller. The housing unit attaches to the shaft that connects the wheels, and thus will not rotate with the wheels as the stroller is pushed. As long as the brake trigger is not held down, the spring pushes the pin into the slot, preventing motion of the wheel. When any of the three brake triggers are pushed down, a force is applied to the cable, and the pin is pulled back into the housing unit, compressing the spring. Thus, the pin is pulled out of the slot, and the wheel is then free to rotate. When the brake trigger is released, the spring pushes the pin back into the slot, preventing motion of the stroller. This process occurs for the brakes on both sides of the stroller to keep the stroller from spinning around one halted wheel. The slots in which the pin fits are made out of age-hardened aluminum alloy. As described above in the parameter analysis, this material is needed to withstand the force that will be applied when stopping the stroller.

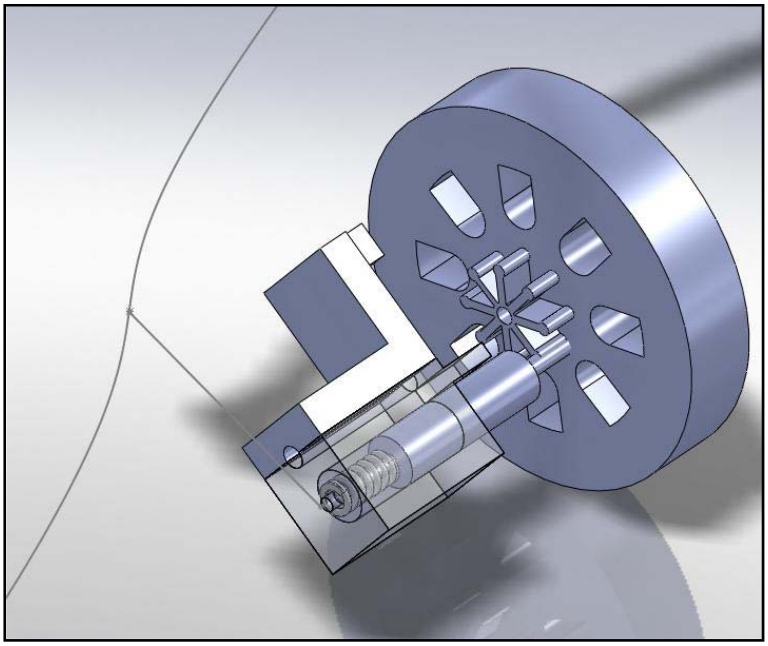


Figure 22. Final Slot-Interrupt Design

ELECTRICAL COMPONENTS The following paragraphs describe how the electrical components are integrated into the final stroller design. Refer to the parameter analysis for further detail of the technical specifications of each subsystem.

STROLLER CONTROL UNIT The Stroller Control Unit is a microcontroller that receives inputs from the various sensors to identify warning conditions. In addition, it also controls the flashing of the nighttime visibility LEDs and drives the piezo warning buzzer. It is housed inside the stroller fold handle housing and the wiring is run inside the chassis tubing along with the folding mechanism cables and brake cables. It uses 5.5VDC regulated by the power supply and generator circuit. Please refer to the Parameter Analysis section for more technical details on the microcontroller –based Stroller Control Unit.

PROPER SETUP NOTIFICATION The Proper Setup Notification system uses two springed electrical contacts within each of the two latches to determine whether the latch is set. If the latch is not set, the stroller will emit a warning sound when the stroller becomes loaded (such as in the case that a child is seated). The system is initially powered by a generator that is activated by the unfolding motion of the stroller chassis to provide ample warning before the main generator is energized by stroller forward motion. Please refer to the Parameter Analysis section for more technical details.

PROPER RESTRAINT NOTIFICATION The Proper Restraint Notification system uses 5 tension sensors and 5 springed contact sensors to determine whether the child is unbuckled or buckled loosely. An unbuckled child can fall out, while a loosely buckled child can choke on the loose belts. The system alerts the parent when either condition is present, and the stroller is in motion. The system is automatically disabled when the seat becomes unloaded so that there is no warning when the stroller is being transported alone without a child.

WEIGHT SENSOR The weight sensor is a tension sensor that detects whether or not a 5 lb (or greater) weight is present on the seat. When a child's weight is not present, the warning systems shut off to prevent annoyance.

BRAKE FAILURE NOTIFICATION This circuit warns the parent when the automatic brake system has failed, such that the brake release lever is released but the slot interrupt braking system is not set. This prevents unintended stroller movement in the case of automatic brake failure.

POWER SUPPLY AND GENERATOR The power supply and generator provide a constant 5.5VDC to the Stroller Control Unit by using mechanical energy at the stroller wheels. A secondary generator is powered by the stroller unfolding motion to provide initial warnings before the stroller is in motion.

LED LIGHTING The LED lighting system contains 5 groups of 3 LED lights, which flash at alternate times. They provide 75 candelas of lighting, and are contained within a clear tube which runs along the sides and back of the stroller.

HINGE COVER The hinge cover will be made with injection-molded PVC that will prevent fingers from being able to reach pinch points. The top is enclosed to completely cover pinch points, while the bottom and sides are open and extended to allow stroller frame member movement and increase distance to pinch points beyond finger length (12cm). PVC provides low cost and good durability. A rivet with a 1 cm head at each hinge secures the hinge covers to the top member. This combination provides pinch protection by eliminating any moving gaps that measure 5.33mm-9.53mm at any given point of the motion – gaps in this range are large enough to allow a finger to be admitted to the area, and small enough to cause pinching. It is also robust enough prevent removal by being able to withstand a 1256 N (282 lb) normal force without yielding at the rivet mounting points.

ONE-HANDED HANDLEBAR The final design for the one-handed handlebar will be much more ergonomic than the prototype design, as we have been limited by time and resources. It will have contours that the user's fingers will fit into. Most of the handlebar will be manufactured out of steel. There will be a thin polyurethane cover that is soft and comfortable for the user to hold. A model of this ergonomic final design is shown below in Figure 23.

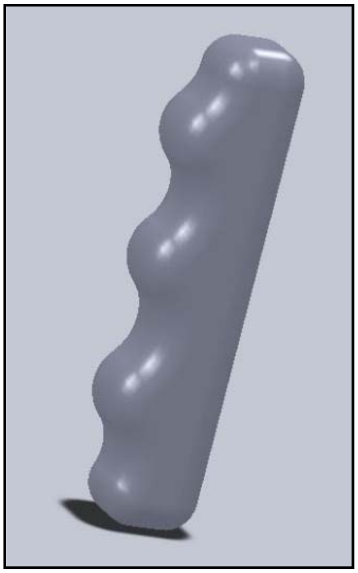


Figure 23. **One-Handed Handlebar Final Design**

CLEAR WINDOW The rectangular parent monitoring window will be a flexible UV-resistant PVC window that is sewn to a rectangular opening in the back of the stroller canopy. The stitching provides high durability and flexibility around the window perimeter. Rounded corners reduce stress concentrations. The design of the clear window is shown below in Figure 24.

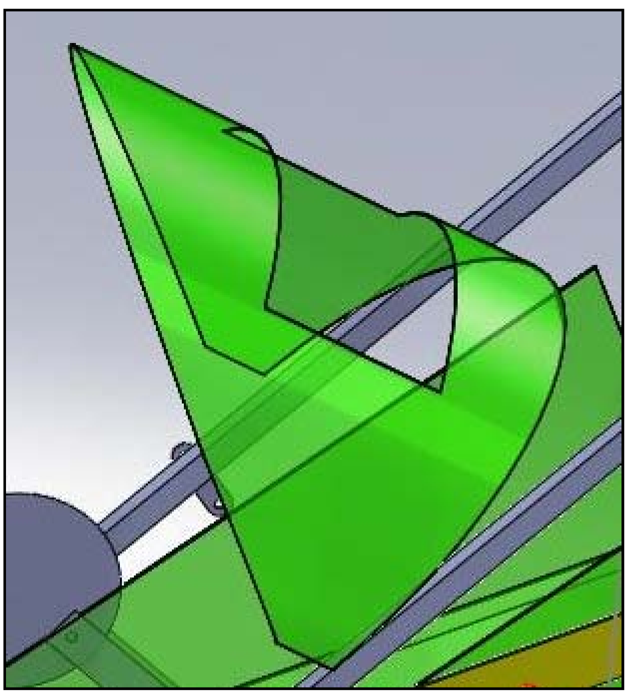


Figure 24. **Clear Window Design**

PROTOTYPE DESCRIPTION

BRAKE TRIGGER The brake trigger mechanism in the prototype will operate similar to the way a bicycle's brake trigger works. It will be in the shape of a lever, so that the user does not need to provide excessive force to release the brakes, given the large moment arm provided by the lever system. There will be three of these levers – two on the right and left sides of the horizontal handlebar, and one located on the vertical handlebar used for one-handed operation. This last trigger will be tied to both sides, so that activation will release the brakes on both the left and right wheels. The levers will be attached to a pin joint, at which they pivot about. The other end of the levers are attached to a wire cable, which then feed down to the braking mechanism, while being completely concealed within the stroller's structure as to prevent an additional suffocation hazard for the child. Figure 25 below shows the design of the prototype brake triggers, and how they connect to the slot-interrupt braking system.

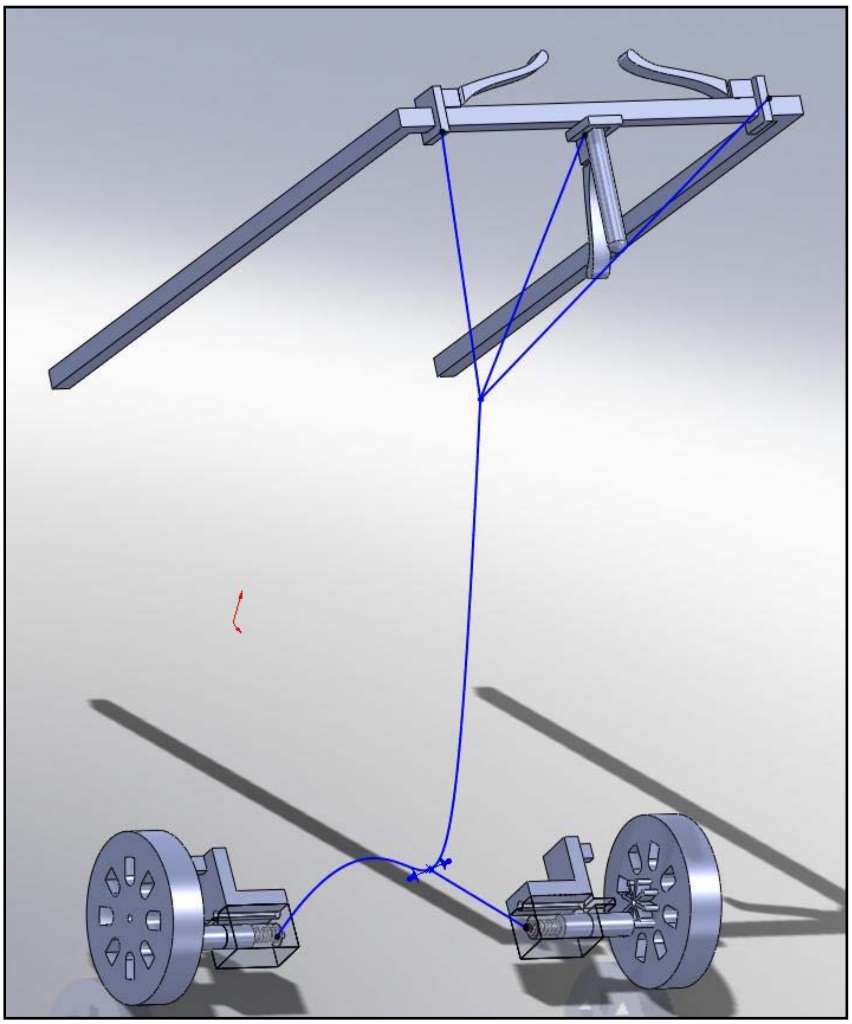


Figure 25. Prototype Braking System

SLOT-INTERRUPT SYSTEM The slot-interrupt braking system for the prototype will be geometrically the same as the final design. The major difference is in the material used for the slots. We will keep the plastic slots for the purpose of our prototype, but based on the parameter analysis, the final design will be constructed of age hardened-aluminum alloy.

The parameter analysis above showed high stresses at the slots of the slot interrupt mechanism. Analysis showed a stress higher than the prototype's polypropylene wheel's yield stress. According to the final design's specified dimensions, only metals can satisfy the stresses with a safety factor of 2.

While the prototype design's plastic wheel slots do not meet our final design safety factor, they have withstood testing thus-far and we will continue to use it for proof-of-concept of the mechanism motions until they fail. If failure does occur before the completion of mechanism motion testing, we can swap broken rear wheel with front wheels as the wheels themselves are the same (including slots), while the front wheel hubs do not contain any braking mechanisms. As casting a metal wheel will take considerable work, we will not make a prototype metal wheel but rather apply resources to prototyping other safety features instead.

The final design must use a metal wheel whose slot interrupt braking mechanism slots can withstand the stresses obtained in the Braking System Parameter Analysis at a safety factor of 2.

ELECTRICAL SYSTEMS The electrical components installed in our prototype will be the same as from the final design, with the following exception. In the prototype, we will be using a battery, as it will be too complex to integrate a wheel-powered generator into our system. However, in the final design, we will be using a generator that runs off the wheel power, making the design more durable, as the electrical features will not run the risk of failing once the battery has gone dead.

HINGE COVER The hinge cover will be made by using two semi-enclosed covers per hinge that will prevent fingers from being able to reach pinch points. The top is semi-enclosed to completely cover pinch points, while the bottom and sides are open and extended to allow stroller frame member movement and increase distance to pinch points beyond finger length (12cm). Plexiglass sheets are used because the material is easy to obtain and easy to shape. Plexiglass has a lower yield strength of 7 MPa (under the 20 MPa of polypropylene), and it is laser cut in flat sections and joined by epoxy adhesives. The joints will be the limiting factor in strength against removal. Instead of the rivet specified by the final design, the prototype design will employ a 5 mm bolt with a 1 cm outer diameter washer at each hinge. Bolts are much easier to install by hand and will allow the part to be repeatedly removed and installed until correct fitment is achieved. It will have the same shape and dimensions as the final design hinge cover and will provide the same pinch protection as the final design.

ONE-HANDED HANDLEBAR The one-handed handlebar extends vertically below the original horizontal handlebar. It is a cylindrical piece of PVC tubing with a flat, circular piece on top, through which it is attached to the horizontal handlebar by two screws. This prototype design is shown below in Figure 26.

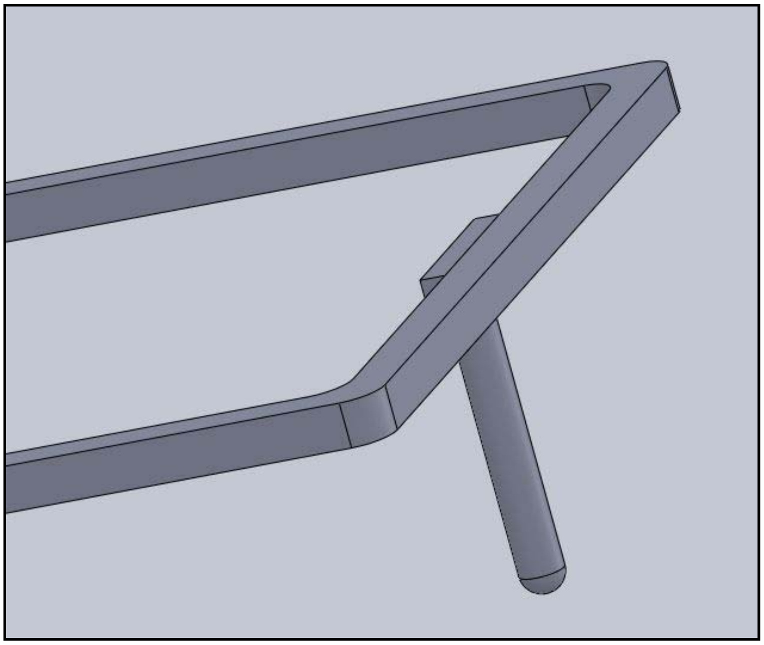


Figure 26. **Prototype Design for One-Handed Handlebar**

CLEAR WINDOW The parent monitoring window will be a flexible UV-resistant PVC window that is glued to an opening in the back of the stroller canopy. An epoxy-based glue provides good adhesion and reduces assembly time, but makes the window area difficult to fold. Rounded corners reduce stress concentrations.

FABRICATION PLAN

BRAKE TRIGGER The brake trigger system for our prototype will be mainly composed of pieces of a bicycle braking trigger system. We will purchase three existing systems for implementation in our device. By drilling holes in the existing handlebar of the stroller, plus the manufactured one-handed operation handlebar, we will screw the braking levers onto the stroller. Since the handlebar is hollow, we will fasten the screw by tightening a nut on the other end. We will use acorn nuts for this, so that the excess screw length will not be exposed and causing an additional safety hazard in the stroller. Metal braking cables will then be attached to the end of each of these levers. This can be done using the hook that is built into the brake lever system. The three wires will be tied together at the bottom of the stroller, so that activating one of the levers will release the automatic brakes on both wheels.

BRAKE PIN The braking pin will be manufactured using a lathe machine. Potential metal filing hazards can be reduced by wearing proper clothing and safety glasses. The braking housing will be manufactured using both a mill and a lathe machine. Potential cutting hazards can be reduced by operating the machine carefully and following the instructions strictly. We will use the recommending cutting speed for our metal. Potential pinch point hazards can be reduced by attaching warning labels. Potential machine instability hazards can be reduced by checking carefully before operating.

The one-handed handle bar will be manufactured using a lathe machine. Potential cutting hazards can be reduced by operating the machine carefully and following the instructions strictly. Potential machine instability hazards can be reduced by checking carefully before operating.

The hinge cover will be manufactured using a laser cutting machine. Potential cutting hazards can be reduced by operating the machine carefully and following the instructions strictly. Potential machine instability hazards can be reduced by checking carefully before operating.

The notification system will be powered by battery for our prototype. Potential overload hazards can be reduced by checking the rated voltage.

BRAKE HOUSING BOTTOM The brake housing bottom will be made out of PVC. It will be manufactured using the mill machine and the lathe machine. The detailed process is shown below:

Step	Operation	Machine	Cutting Tool	Cutting Speed	Notes
1	Generate the large cube	Mill	3/8" end mill	500 rpm	Must be well lubricated
2	Generate the small cube	Mill	3/8" end mill	500 rpm	Must be well lubricated
3	Drill the semi-cylindrical hole	Drill	5/16" drill	500 rpm	Must be well lubricated
4	Drill the big cylindrical hole	Drill	3/4" drill	500 rpm	Must be well lubricated
5	Drill the small cylindrical hole	Drill	13/64" drill	500 rpm	Must be well lubricated
6	Drill the two holes for screw	Drill	1/8" drill	500 rpm	Must be well lubricated

Table 35. Fabrication plan for brake housing bottom

BRAKE HOUSING TOP The brake housing top will be made out of PVC. The brake housing top will be manufactured using the mill machine and the lathe machine. The detailed process is shown below:

Step	Operation	Machine	Cutting Tool	Cutting Speed	Notes
1	Generate the big cube	Mill	3/8" end mill	500 rpm	Must be well lubricated
2	Generate the small cube	Mill	3/8" end mill	500 rpm	Must be well lubricated
3	Square off one corner	Mill	3/8" end mill	500 rpm	Must be well lubricated
4	Drill the semi-cylindrical hole	Drill	5/16" drill	500 rpm	Must be well lubricated
5	Drill the three holes for screw	Drill	1/8" drill	500 rpm	Must be well lubricated

Table 36. Fabrication plan for brake housing top

BRAKE PIN The braking pin will be made out of aluminum. The braking pin will be manufactured using the mill machine and the lathe machine. The detailed process of using the mill machine and the lathe machine is shown below:

Step	Operation	Machine	Cutting Tool	Cutting Speed	Notes
1	Generate the main body	Lathe	Hardened steel tooth	150-200 rpm	Use shallow cuts
2	Generate one small pin	Lathe	Hardened steel tooth	150-200 rpm	Use shallow cuts
3	Generate the other pin	Lathe	Hardened steel tooth	150-200 rpm	Use shallow cuts
4	Drill the hole for cable	Mill	#76 drill	500 rpm	Must be well lubricated
4	Drill the hole for screw	Mill	#44 drill	500 rpm	Must be well lubricated

Table 37. Fabrication plan for brake pin

ONE-HANDED HANDLEBAR The one-handed handle bar will be made out of PVC. The one-handed handle bar will be manufactured using the lathe machine. The detailed process of using a lathe machine is shown below:

Step	Operation	Machine	Cutting Tool	Cutting Speed	Notes
1	Generate the main body	Lathe	Hardened steel tooth	150-200 rpm	Use shallow cuts
2	Cut off the handle bar	Lathe	Hardened steel tooth	150-200 rpm	Use shallow cuts
3	Drill the hole for screw	Mill	1/8” drill	500 rpm	Must be well lubricated

Table 38. Fabrication plan for one-handed handle bar

HINGE COVER The hinge cover will be made out of plexiglass. The hinge cover will be manufactured using the laser cutting machine. The detailed process of using the laser cutting machine is shown below:

Step	Operation
1	Input the components into BobCAD
2	Press Start Button
3	Take the components out carefully when finished

Table 39. Fabrication plan for hinge cover

VALIDATION TESTING

In order to verify the performance of the functions in our prototype, we will conduct validation tests for each function. These are listed and described below.

BRAKING SYSTEM To test the braking system, we plan to run a variety of tests to account for all possible difficulties the braking system may encounter during regular stroller use. We will test repeated use of the stroller braking system. This will allow us to see if the components are properly in place, and will not eventually misalign and cease to work. In addition, this allows us to see if any of the components will quickly fail due to fatigue, or undergo plastic deformation that prohibits use of the braking system. To perform this test, we will push the stroller and suddenly release the levers, engaging the brake immediately to stop the stroller. This will be tested multiple times for each of the brake levers, ensuring that each can apply enough force to release the brake.

Next, we will test the stopping distance of the stroller for use on different surfaces. The surfaces tested will be rug, grass, pavement, and linoleum flooring. We will push the stroller at various speeds and carrying various baby-simulating weights. When the tires reach a certain point, the brake will be released, and thus the automatic braking system will halt the stroller. The stopping distance will then be measured from the line of brake release. This distance accounts for the time needed for the braking system to engage (the pin engaging the slot), as well as the distance the stroller will skid, which varies by surface. This testing will be used to measure our system performance versus the engineering specification of stopping within 1 foot of brake release.

Testing will be done to analyze the human fatigue associated with holding down the levers for an extended period of time. This will be done by each group member, holding down each of the levers, for time intervals of 5, 10 and 15 minutes. The test subject will then describe their hand fatigue following the time interval as either "No Fatigue", "Mild Fatigue", "Moderate Fatigue", or "Heavy Fatigue." Results will be quantified, averaged, and analyzed for a consensus fatigue factor of the design.

Other various tests on the braking system include the following. To account for debris which may get caught in the braking system and prevent proper use, we will conduct brake interference testing. We will first sprinkle sand around the braking system. Then, we will test the system stopping from normal walking speed, ensuring that the spring is able to push the pin through the debris, engage the slot, and halt the stroller. Testing will also be done on a hill. This will be to ensure that the brake will engage and hold the stroller from rolling away. This will be tested for multiple hills of varying steepness.

LED LIGHTING SYSTEM The brightness of the LED lighting system will be tested to verify it is bright enough to reduce the safety hazard associated with using a dark stroller at night. We will tests the stroller in a variety of neighborhoods, especially those with little or no street lighting. The stroller will be in constant motion, as to keep the lighting activated. An observer will be located at different distances from the stroller, estimated by being approximately a quarter of a block, half a block, three-quarters of a block, and a full block away. Tests will be conducted with the observer located on all four sides of the stroller, to ensure visibility from each. The results of these validation tests will be compared against our engineering specifications of nighttime visibility for 270 degrees around the stroller, with a brightness of at least 70 candelas.

The physical durability of the LED system will also be tested. We will ensure that the LED lights are firmly attached, and cannot be easily ripped off. This is important, as a weak attachment will allow a child to rip off the LED lights, presenting a choking hazard.

In addition, the brightness of the reflective material will be tested. This will be done by driving a car by the stroller, and observing how well it reflects the car lights, for each side of the stroller. We will also conduct this testing to see how well the reflective material reflects just the street lights of the area, and how well it couples with the LED lighting system.

SENSORS Each sensor will need to be tested for varying baby weights. We will need to verify that they are not overly sensitive, yet will be able to detect when the child has been placed in the stroller. We must ensure that the baby weight sensor covers the range of baby weights up to 40 pounds, for which our stroller is weighted. We will test that the buckle sensors work properly after extended use, and that the metal contacts will continue to touch and complete the circuit. The proper restraint sensor will be tested for varying applied tensions in the belt, ensuring that it will not give false warnings, and activate for the proper sized babies that our stroller is rated for. We will do this by using a doll simulating a baby's size. To test the brake failure sensor, we will pull on the cable to release the brake, while not pushing down any of the three brake levers. This will simulate an unwanted brake release, which the microcontroller is programmed to sound an alarm in the case of.

HINGE COVER The hinge cover will need to be tested for both absence of pinch points, and durability. The area will be closely analyzed to determine if there are any possible pinching points, using our engineering criteria as minimum gaps of 5.33 mm to quantitatively determine this. In addition, we will conduct stress testing to ensure that the hinge cover cannot be ripped off. This will be done at various points on the cover, to ensure that there are no weak spots located anywhere on the cover at which it could fail.

VALIDATION RESULTS

BRAKING SYSTEM Stop distance of the stroller, in inches, for use on different surfaces with baby weight of approximately 20 lbs. For each surface we tested 5 times:

	Test 1	Test 2	Test 3	Test 4	Test 5	Average
Rug	5	8	7	9	5	6.8
Grass	2	3	3	3	4	3
Pavement	7	5	10	9	10	8.2
Linoleum Flooring	9	8	7	13	5	8.4

Table 40: Results of testing brake stopping distance on various surfaces

The average stopping distance for all four surfaces fell below our engineering specification of stopping within one foot. We observed that the brake pin engaged the slot almost instantly after the brake levers were released, and thus almost all of the stopping distance was a result of the tires skidding.

Stop distance of the stroller for use with a heavy and light weight, approximately 20 and 40 pounds respectively, using the same surface (pavement), to determine the magnitude of the relationship between weight in the stroller, and stopping distance. For each surface we tested for 5 times:

	Test 1	Test 2	Test 3	Test 4	Test 5	Average
Light	12	9	10	11	12	10.8
Heavy	10	10	9	11	8	9.6

Table 41: Results of testing brake stopping distances for a heavy and light weight

Calculated from the difference in the average stopping distance, the heavier weight reduces the stopping distance by approximately 1.2 inches, a minimal amount, given the magnitude of error involved. This shows a minor relationship between stroller weight and stopping distance.

Stop distance of the stroller for use on up and down hill slope, an estimated grade of 25 degrees, on the same surface (pavement), at certain baby weight (20 lbs). For each surface we tested 5 times:

	Test 1	Test 2	Test 3	Test 4	Test 5	Average
Uphill	2	8	4	5	4	4.6
Downhill	13	20	11	12	12	13.6

Table 42: Results of testing brake stopping distances for uphill and downhill

Stopping uphill dropped the stopping distance significantly, but stopping downhill averaged 13.6 inches, a bit above our engineering specification, which is of some concern. As discussed previously, we noticed that almost all of the distance was from the tires skidding. The stroller we tested with was relatively new – an older, more worn stroller could slide even further. As a result of this observation, we recommend that the stroller wheels are made of better material, perhaps rubber wheels with treads.

Human Fatigue with holding down the levers for an extend period of time. For time intervals of 5, 10 and 15 minutes, each team member will hold a lever, and rate the fatigue as mild, moderate, or heavy.

	Colin	Zhekang	Yue	Yilong	Average
5min	Moderate	Mild	Mild	Mild	Mild
10min	Heavy	Moderate	Moderate	Moderate	Moderate
15min	Heavy	Moderate	Heavy	Heavy	Heavy

Table 43: Results of testing human fatigue over extended brake trigger use

The required amount of force to release the brake and hold it open is not a major fatigue issue; rather, the geometry of the brake lever is the main cause of discomfort over extended use. The lever we used in the prototype was made to be pressed down with 2-4 fingers, as used on a bicycle. In our design, we require the lever to be depressed with one's whole hand. Depending on the way that the user presses this down, the upwards curve at the end of the lever can stick into the users hand, causing discomfort over extended use. We recommend redesigning the lever shape to contour to ones entire hand to minimize fatigue and maximize comfort. Another solution to this problem would be to rotate the orientation of the brake levers, so that the user will hold down the lever with just 2-4 fingers, similar to as used in a bicycle.

LED LIGHTING SYSTEM The brightness of the LED lighting system will be tested at different distance and from three directions, and rated from among the following: Great, Good, Fair, Poor

	Front	Back	Sides
100 feet	Great	Great	Great
200 feet	Fair	Fair	Fair

250 feet	Fair	Poor	Poor
300 feet	Fair	Poor	Poor

Table 44: Results of testing LED visibility for different distances and angles

The stroller was placed in a dark corner at night (approximately 9 pm, after sunset), and observed from the estimated ranges for the three different angles. There were some streetlights around, and the lighting was similar to that of a somewhat dark area located near traffic. The stroller had great visibility from the first distance, 100 feet, but dropped off afterwards. The lighting from the front stayed fairly well lit up through 300 feet, while the lighting of the back and sides became poor when observed from farther than 250 feet away. This critical distance for visibility is quite far, and we believe that a vehicle would have time to react and avoid the stroller once they get within 150 feet and can see it.

SENSORS The sensors were tested to find out the threshold force that would be needed to press the switch and activate the system. Different objects were added to the seat, in increasing weight, to find when the beeping would activate (since the seatbelt was undone, and the tension sensors not activated). The estimated weight at which this happened was 10 pounds. Another consideration in the sensor activation is the shape of the applied load. The location of the switch is under where a baby's left leg would be. This makes it easier to be pressed, in comparison to a square-shaped load (backpack) that will not distribute its load over that location.

HINGE COVER The hinge cover was tested for presence of pinch points and durability. The full folding motion was completed many times, while placing our fingers in different locations that may be prone to pinching. The only spot in which pinching was observed was above the LED tubing, when the stroller was almost completely folded. Since we did not include the LED tubing in our CAD model, we did not predict this to happen. However, the LED tubing that caused the pinching was just excess, not covering any LED lights, as a result, we could just cut this off and avoid this hazard.

The hinge covers durability was tested by pulling and pushing with different forces. The first thing to break was the epoxy connections between the sides and top of the hinge cover. As the piece is projected to be mass manufactured by injection molding, and be manufactured in one solid piece, the durability of the final design should not be a major issue.

DISCUSSION

DESIGN CRITIQUE Upon completion of our prototype, we realized a few different aspects of our project that we would have changed if we could start again from the beginning. While we were very pleased with the outcome, and it did perform all the functions we anticipated, there were steps that could have been taken to make the process easier for us, the stroller more convenient for the parent, and the system more reliable.

There were a few weaknesses in our final design that we would eliminate if given a chance for a redesign. First of all, the hinge covers proved to have somewhat of a sharp edge facing towards the child in the seat. If the child was to drop their head low enough, they could poke themselves in the eye with this edge. For this reason, we would have redesigned the shape of the hinge covers so that this edge was cut out, and the corner was instead a smooth gradient. The entire hinge cover would be covered in padding as well. We did not completely consider the comfort of the child in the stroller initially, and these changes would improve upon this area greatly.

In addition, the method for tying the brake cables together proved to be much more difficult than expected. We needed to build an extra housing unit to tie the three cables from the handles together, and tie these to the cables attached to the brake pins. By attaching the three cables from the handles together at the top of the stroller rather than the bottom, we would only have one cable dropping down to the bottom, rather than three. This would have also decreased the amount of friction, which heavily impeded the braking mechanism from being fully reliable. We also realized that we should have built a housing unit to contain both the brake cables at the bottom and the microcontroller mounted on the back of the stroller. These exposed parts make the stroller appear more dangerous, and also expose the components to potential water damage. Also, the one-handed handlebar did not prove to significantly increase the mobility of the stroller, and would be eliminated from our next design.

On the contrary, our design had many strengths that worked much better than we imagined they would. The tension sensor worked very well and was quite reliable. If we realized this would be the case, we would have spent more of the design process focusing on integrating different sensor components into the system, such as a buckle sensor and brake failure sensor.

RECOMMENDATIONS

The prototyping process and validation tests show that all major systems are in need of design improvement in order to achieve better performance that meets or exceeds the original engineering specifications. Also, there are recommendations on how to transition from prototype to production for lower cost while maintaining or exceeding engineering specifications.

Automatic Braking System:

The automatic braking system on the prototype release levers required a higher force than desired for continued use. This is partially attributed to the use of a total of 5 sheathed cables (one to each of 3 release levers, one to each of 2 brake pin housings) which introduced an increased level of friction. On the prototype, this was done because three individual release levers were purchased off-the-shelf instead of making one unit that spans across the handle bar. The timeframe did not allow for custom fabrication of all parts. ***We recommend*** reducing the number of release lever cables in parallel from 3 to 1 to reduce the need for stronger springs in the brake pin housing and reduce the amount of force needed to release the brakes using the brake release lever. This would require that a single release bar be fitted across the stroller handle, with a middle protrusion that allows operation while using the single hand operation bar.

Brake release cables on the prototype (including release lever cables and cables to each brake pin housing) were bicycle brake cables purchased locally. They introduced friction higher than seen in their normal applications because they were bent at much greater angles when installed on the stroller. This is because the stroller is much smaller than a bicycle, and to maintain safety, the cables were routed in a path that presented the least choking danger instead of least number of bends. ***We recommend*** that in production, this increased level of brake cable friction can be reduced by using a smaller diameter cable that is less resistant to bending and produces a lower force on the brake cable sheathing. Also, injection molded plastic brackets with filled areas may be used to route the cable at smaller angles while closing the gap between the cable and the stroller chassis to eliminate choking hazards.

The brake pin housing as well as the brake cable distribution block introduced additional friction. ***We recommend*** that this additional friction be eliminated by increasing part tolerance so that a minimal gap is always maintained between moving parts. This is made easier by injection molding the entire housing as one piece, as opposed to the three-piece material removal design of the prototype.

Though validation tests were not able to produce automatic braking system failures due to foreign particle contamination such as in the case of mud or snow filling the gaps within the system, we anticipate that some strollers will be used in severe conditions that could induce contamination failures. ***We recommend*** that the lower portions of the braking system be sealed to sufficiently repel dirt and liquid from the environment. Further, a louder alarm should be implemented on the brake failure detection system to better warn against brake failure due to contamination and other causes.

Finally, the wheels of the prototype are plastic and do not provide satisfactory protection against failure. This has been detailed in the parameter analysis section before. ***We recommend*** a combination of any of the following in order to achieve a the wheel safety factor of 2.0: a)use a metallic ring that is permanently attached to the wheel using fasteners; b)increase the thickness of the interrupt slots of the wheel; c)increase the diameter of the interrupt slot portion measured from the center of the wheel; d)use a higher yield strength material for the entirety of the molded wheel.

LED Lighting System

The LED lighting system used in the prototype employed LEDs whose combined output did meet the engineering specification of 70 candelas, but appeared much dimmer because each LED contained a lens that focused the light in only one direction. Some LEDs were installed facing up, while others were installed down. The upward-facing LEDs appeared brighter to a standing person than did the downward facing LEDs. Also, the prototype routed wires outside of the tubular chassis as the chassis which increased the chance of accidental damage to the single-strand wiring. The current and voltages present do not pose a danger beyond decreased nighttime visibility. ***We recommend*** installing the LEDs perpendicular to the length of their containing tubes in order to direct the majority of the light outward from the stroller (instead of upward or downward). Care must be taken during assembly so that the LEDs are facing the outside of the stroller and not the inside where the light will be absorbed by the stroller itself. In the recommended case, it may greatly reduce assembly cost to use a pre-made flex cable strip containing SMD LEDs that is then installed in the containing tube as a whole unit rather than to individually insert each through-hole LED in the correct orientation within the containing tube. Also, the wiring should be fully enclosed in the stroller chassis and multi-strand flexible cable such as those found on headphones should be used for best reliability and durability.

Proper Restraint System

The restraint warning portion of the proper restraint system of the prototype employed only two of the 9 sensors prescribed by the final design. The signal wires used in the prototype design were single-strand wrapping wire and did not provide adequate protection against fatigue over many use cycles. In the prototype, the two installed sensors were not fully enclosed in order to demonstrate the internal parts. ***We recommend*** using all 9 sensors (5 tension, 4 contact) for the best detection of loose restraints. Also, we recommend using a soft, multi-strand wire signal cables designed for repeated bending such as those found in headphones. The tension sensors should be enclosed to prevent contamination with only one opening for the moving end of the restraint.

Weight sensor

The weight sensor in the prototype comprised of one limit switch rigidly mounted to the chassis under the seat at one point on the left side (viewing from behind the seat) of the seat. While this provided good detection in most cases, a baby whose weight is shifted to the side without the sensor may result in the proper restraint warning system being disabled since the system may not detect occupancy in this case. ***We recommend*** a wire in tension stretched across the underside of the seat connected to a limit switch so that the total downward displacement of the seat is detected. This will ensure proper detection no matter in what manner the child sits. A stretch-able section whose stretching force is greater than the limit switch's actuation force can be added to the tension wire so that neither discomfort nor limit switch damager are likely in the event of overloading. ***We recommend*** optionally a secondary limit switch that is activated when the seat weight exceeds the rated 40lbs maximum capacity – this limit switch then activates an overload warning to prevent injuries due to exceeding the maximum stroller seat capacity.

Hinge Cover

The prototype hinge cover was manufactured from laser-cut 3mm acrylic sheets which met the engineering specifications (gap size and withstanding removal force) but would not provide adequate comfort if a real child were to lean on it. It was also prone to shattering when subjected to impact during the manufacturing process and could potentially shatter if the stroller hits a hard surface. Cost was also higher than the overall $65 retail pricing point would allow when using acrylic for the hinge covers. ***We recommend*** using injection-molded ABS plastic to manufacture the hinge covers as specified by the Final Design (p.69) section. This will allow the cover to remain meet original engineering specifications while significantly increasing protection against shattering. Injection molding also allows the cover to form a more 3D shape to avoid discomfort if the baby chooses to rest beside it. ***We recommend also***, if manufacturing facilities allow, for the hinge cover to be molded along with the top hinge to which it is attached to reduce assembly time and also reduce the possibility of any attaching bolt detaching.

Proper Setup Notification

The prototype did not implement the Proper Setup Notification System in the interest of dedicating time to ensuring quality of the braking, lighting, and proper restraint notification systems. The warning system portion of the proper setup notification system passed validation by using a manually activated connection sensor to simulate the closing and opening of hinges. ***We recommend*** that the hinge sensors of the Proper Setup Notification System be installed in manufactured units and for the wiring to be hidden inside the tubular stroller structure. Dedicated sensor locations containing snap fittings should be injected molded into the hinge for ease of sensor assembly.

Additional Features

One additional feature that many parents asked for and would have been useful during validation is a bottom storage tray. This can be easily added, but the weight will have to be limited to reduce overloading of the automatic braking system. One way the weight can be limited is by the inclusion of a tension sensor that activates when the storage tray weight exceeds the portion of total stroller capacity rationed for the storage tray. ***We recommend*** adding a bottom storage tray, increasing the stroller capacity (i.e. structural capacity and automatic braking system capacity), and installing a weight sensor that activates an alarm when the storage tray's weight exceeds said increase in stroller capacity.

CONCLUSIONS

Strollers today suffer from many design flaws that negatively impact the safety of both child and parent. Kids-In-Danger sponsored ME450 Team21 at the University of Michigan to provide a safer stroller design that is affordable by the majority of families.

The requirements of the improved design are 1)Pinch protection; 2) Automatic braking; 3) Improved nighttime visibility; 4) Assurance of proper restraint; 5) Assurance of proper stroller setup.

In order to meet the above requirements, the following 5 systems were designed:

- Plastic Pinch Cover – Provides pinch protection as specified by ASTM-883 for the full range of motion when folding and unfolding the stroller. A unique shape prevents pinching at any angle.
- Automatic Braking System – Automatically applies a maintenance-free (slot and retractable pin) brake when no release levers are depressed. Brakes are applied automatically when parents take hands off handle bar / release lever area. A sensor system emits an audible warning if brake failure is detected. The warning portion is powered by a wheel generator.
- LED Lighting System – 15 LEDs grouped in 5 plastic-enclosed tubes each containing 3 LEDs provide 270-degrees of lighting and 70 candelas combined output. They flash in sequence to increase visibility. This system is powered by a wheel generator.
- Proper Restraint System – A warning sound is emitted if any of the 5 tension sensors or 4 contact sensors detect improper belt tension or missing buckle, respectively. This warning system deactivates when the stroller is unloaded to prevent unnecessary warnings. This system is powered by a wheel generator. An optional adjustable side bolster further ensures that the child is not positioned in a way that may result in suffocation.
- Proper Setup Notification System – To avoid collapsing, a pair of hinge sensors detects whether the stroller has been properly setup and emit an audible warning when the stroller is loaded but hinges are not properly set. This system activates before the stroller is in motion, when the child is first seated and activates the weight sensor. This system is powered by a secondary generator that provides temporary power as the stroller is unfolded, using the motion of the unfolding chassis – power after the initial activation is provided by a wheel generator.

A prototype stroller containing 4 of the above systems (Proper Setup Notification System was omitted) was manufactured in order to test the effectiveness of the designs.

Validation results show that all prototyped system work and provide improved safety over traditional strollers. However, there are many recommendations on improving the prototype design and are provided in the recommendations section.

ACKNOWLEDGMENTS

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BIOS

Zhekang Du

Zhekang is originally from China. He studied in Shanghai Jiaotong University in his freshman and sophomore year and then he was transferred to University of Michigan. At his junior year, he declared as a Mechanical Engineering based on the versatility of the degree and his interest in automotives, though considered EECS. He will graduate with a Bachelors of Science in Mechanical Engineering April 2010. After graduation, Zhekang plans to go to graduate school to further his study in Mechanical Engineering.

Yue Fan

Yue Fan was born in Chengde, a tourist attraction in Hebei Provence of China. He lived there until he was 7. At age 7, Yue Fan moved to Fargo, ND where he began realizing his affinity for cold weather and squirrels. In 1998, Yue Fan relocated once more to Ann Arbor, MI, and has attended school in Tree City ever since. He is due to graduate from the University of Michigan with a BSE in Mechanical Engineering in April 2010. Yue enjoys working on innovative products in his spare time, and entrepreneurial pursuits of his most prized innovations. When Yue has had a long day, he can often be found inside his garage working on his 1999 Cadillac STS, attempting to revive the car once again for another 226,000 miles.

Colin Sullivan

Colin grew up in a suburb of Boston, Massachusetts, graduating from Stoneham High School in 2006. He originally planned to study meteorology at the University of Michigan, due to his long-time interest in weather systems. During his sophomore year, he became more interested in the general engineering classes he was taking, and as a result switched his major to mechanical engineering. He will graduate with a Bachelors of Science in Mechanical Engineering in the spring, and plans to work for a few years before returning to school for a Masters degree in Biomedical Engineering.

Yilong Wen

Yilong comes from China. He was transferred to University of Michigan in Fall of 2008. After graduation, with a Bachelor’s of Science in Mechanical Engineering, Yilong will continue his enthusiasm for Mechanical Engineering, by pursuing a Master Degree of Mechanical Engineering in University of Michigan. After that, Yilong would like to work for an automotive company for some years and then go back to China to start his own business related to automotive industry. Yilong is a big fan of basketball and dream to own a basketball team one day in the future.

APPENDIX A   BILL OF MATERIALS

Item	Quantity	Source	Catalog #	Cost	Contact
1-1/4” L, 3/8” OD springs	12	McMaster-Carr	9657K155	$10.83	Mcmaster.com
330Kohm Resistor	1	Mouser	4CT52R334J	$0.05	(800) 346-6873
100Kohm Resistor	4	Mouser	4CT52R104J	$0.20	(800) 346-6873
15Ohm Resistor	5	Mouser	4CT52R150J	$0.25	(800) 346-6873
Limit Switch	3	Mouser	101-1306	$0.81	(800) 346-6873
PIC 16F628A	1	Mouser	579-PIC16F628A-I/P	$2.07	(800) 346-6873
AA Batteries	8	HarborFreight	92404-0VGA	$2.66	805-388-3000
AA Battery Holder	1	RadioShack	270-407	$1.89	800-843-7422
100 Ohm Resistor	1	Mouser	4CT52R101J	$0.05	(800) 346-6873
360 Ohm Resistor	1	Mouser	4CT52R361J	$0.05	(800) 346-6873
LM317	1	Mouser	512-LM317LZX	$0.21	(800) 346-6873
Piezo buzzer	1	Mouser	810-PS1240P02CT3	$0.43	(800) 346-6873
Wrapping wire	1	Radio Shack	278-503	$3.99	800-843-7422
Red 5mm LEDs	15	Mouser	604-WP7113LID	$2.10	(800) 346-6873
Nylon block (6”x2”x1.75”)	1	AlroMetals		$6.00	(734) 213-2727
Aluminum pin (5/8" 3')	1	AlroMetals		$9.00	(734) 213-2727
Acrylic (30”x36” .093”)	1	HomeDepot	202038044	$20.00	800-466-3337

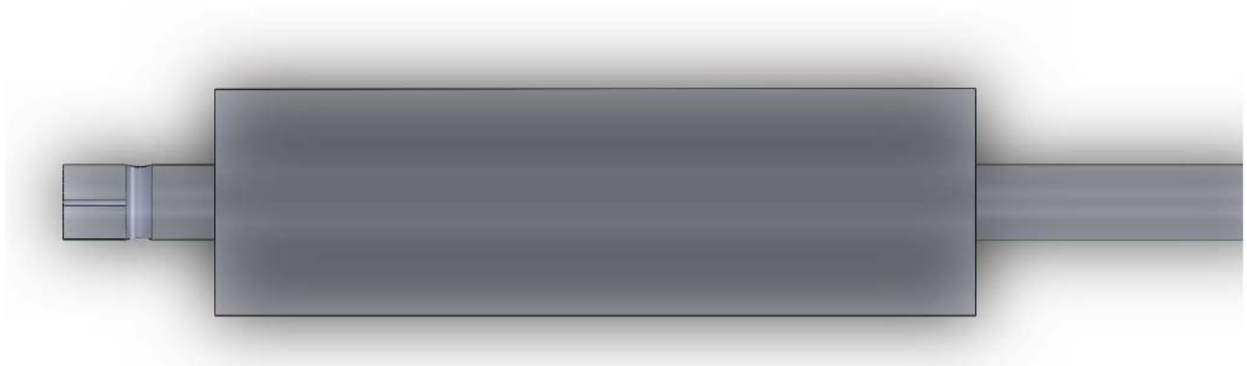
Vinyl tubing (1/4", 20')	1	Lowes	42143220	$5.72	800-445-6937
Hose clamps (3/8")	4	HomeDepot	67065	$3.92	800-466-3337
Green masking tape (roll)	1	HarborFreight	95513-0VGA	$3.48	805-388-3000
Tennis Racket Grip (roll)	3	Meijer	B001QTL0K8	$5.23	(734) 973-1200
PVC piping ¾" 10'	1	Lowes	23971	$1.73	800-445-6937
L Brackets	4	Lowes	315684	$9.88	800-445-6937
Clear Shower Curtain	1	Meijer	XDKROW008V	12.99	(734) 973-1200
Reflective Tape 3/4''X30''	2	Jack's Hardware	5022587	$6.96	(734) 995-0078
Epoxy (tube)	2	HarborFreight	92665-0VGA	$4.98	805-388-3000
Stroller	1	ToysRUS	94361	$45.00	1-800-ToysRUs
PVC tubing cap	1	Lowes	447-007HC	$0.32	800-445-6937
Brake Lever	3	Student Bike		$29.97	(734) 662-6986
Brake Cable	3	Student Bike		$14.97	(734) 662-6986
Brake Cable Cap	6	Student Bike		$0.60	(734) 662-6986
1/8" Washers (bag)	1	Home Depot	030699199815	$0.98	800-466-3337
Cable clamp	1	Home Depot	071514005560	$4.79	800-466-3337

The total cost of the prototype was **$199.14.**

APPENDIX B DESCRIPTION OF ENGINEERING CHANGES SINCE DESIGN REVIEW #3

Braking Pin

WAS:



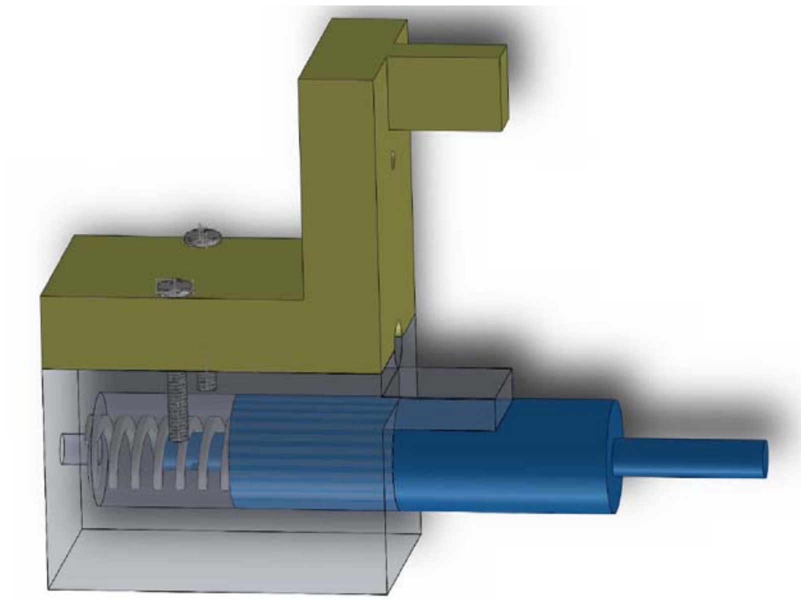
IS:

We changed the left end of brake pin for prototype. The left end of this brake pin intends to connect the brake cable to the brake pin. According to our original design, the brake cable will go through into the left end via that small cylinder hole, and then cable will be clamped tightly by two set screws from up and down side. In the actual process, it turned out that the two set screws could not hold the brake cable tightly as we expected.

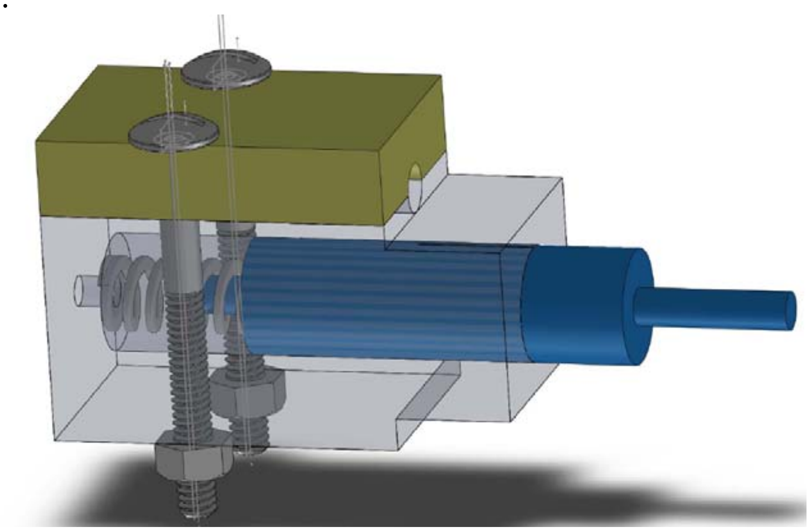
Finally, the left end of actual brake pin for prototype is like that. We made a cylinder slot in the top side of the pin. The cylinder end of brake cable will be fit into this slot and be held tightly and the cable will go out through the gap that created in the cylinder end of pin.

Brake Housing
There are three major changes made to the brake housing

WAS:



IS:



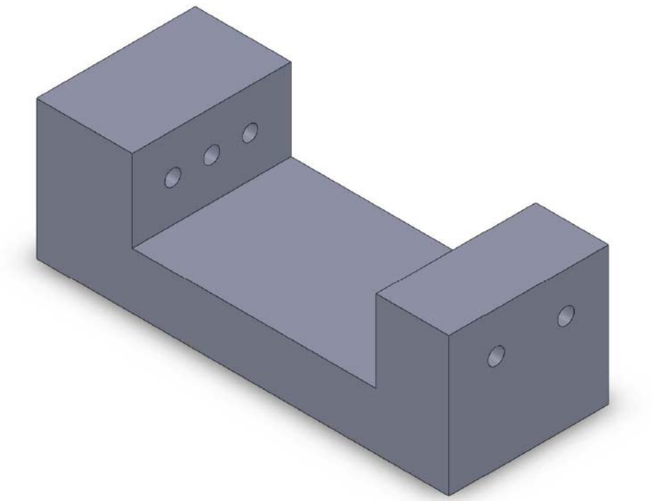
First change is the assembling of two pieces of brake housing. The original design of small screws (18-8 SS Pan Head Phillips Machine Screw 5-40 Thread, Length 1’’) is not strong enough to hold two pieces together. As a result, we changed small screws to bigger and longer screws (18-8 SS Truss Head Slotted Machine Screw ¼’’ – 20 Thread, 2-1/2’’ Length) and also at the other end we used two hex nuts to secure and tight the whole brake housing.

Second change is the modification of up part of brake housing. As first, we designed this complex up brake housing, intending to clamp the whole brake housing to the stroller. During the actual assembling process, we found out the screw s and nuts are strong enough to attach the brake housing to the stroller. So the original design seems to be redundant and useless, we simplify the original design and make it easy to fabricate.

Third change is the extending the internal cylinder hole for brake pin. During the actual fabrication process, we found out the original design is not longer enough to hold the pin plat all the time. Due to the gravity, the pin will lean to the ground when it is located in the original design. As a result, we changed the design and extend the cylinder hole.

Brake Cable Housing (did not exist before in our final design)

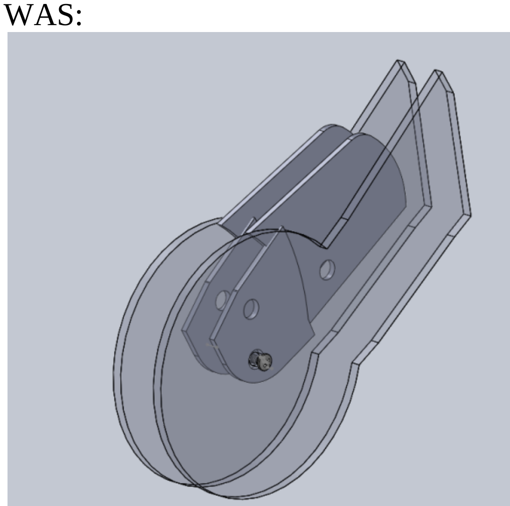
WAS: N/A
IS:



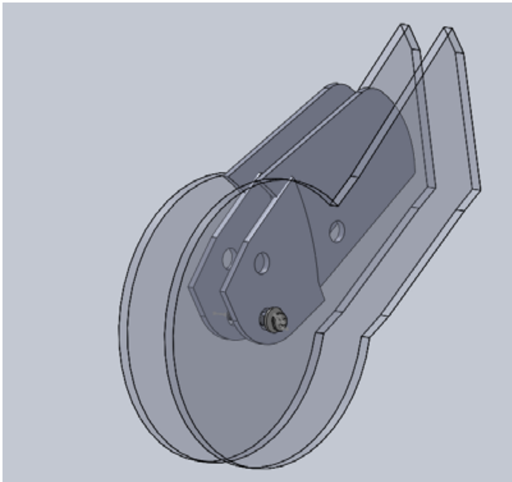
We added this part in our final prototype to hold the brake cables together. Three control cables will be set into the housing via three holes on the left side and two working cables will be set into the housing via two holes on the right side. Those cables will be connected together by a cable clamp. As a result, each control cable can control the whole system independently.

Pinch Cover

WAS:



IS:



We changed the assembling method of pinch cover to the stroller. The original assembling method is not tight enough to hold the pinch cover to stroller. We added two washers to the connection point at both sides.

APPENDIX C: DESIGN ANALYSIS ASSIGNMENT FROM LECTURE

1. Material Selection Assignment

Pinch Cover

Function: The pinch cover must be able to completely cover the pinch area from being accessible by fingers and also withstand attempts at pinch cover removal, both as specified by ASTM F-833 [6]

Objective:

Minimize price and weight of the hinge cover.

Constraints:

1) Pinch cover can't break under a force of 15lb.
2) Pinch cover must be able to completely cover pinch area from being accessible by fingers.

Appropriate Material Indices:

The objective function: m=Atρ

(m=mass, A=cross-sectional area, t=thickness, ρ=density)

Add in constraints

1) F is fixed
2) A is fixed

$\frac{F}{A} \leq \sigma_{UT}$

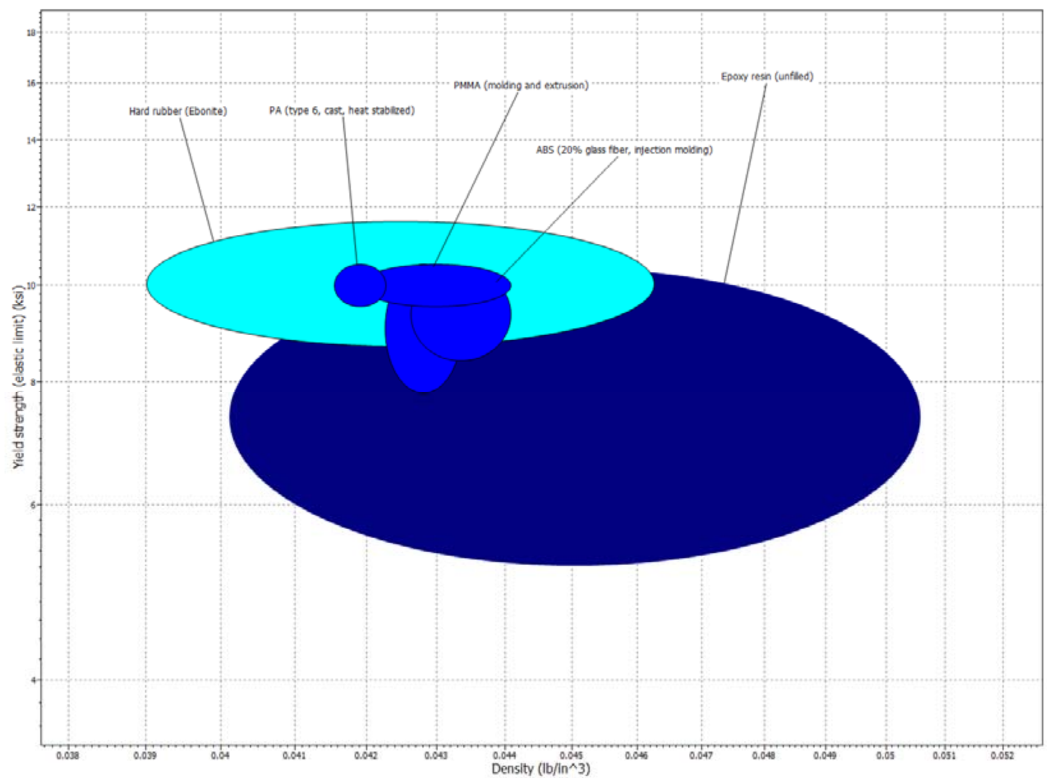
m=Atρ, $\frac{F}{A} \leq \sigma_{UT}$

m=(F)(L)($\frac{\rho}{\sigma_{UT}}$)

The material index is

M=$\frac{\sigma_{UT}}{\rho}$

	Density [lb/in^3]	Price [USD/lb]	Yield Strength [ksi]
Epoxy resin	0.0401 – 0.0506	1.16 – 1.28	5.22 – 10.4
Acrylic, PMMA	0.0423 – 0.0434	1.17 – 1.29	7.8 – 10.5
Hard rubber	0.039 – 0.0462	0.912 – 1	8.7 – 11.6
PA	0.0415 – 0.0423	1.49 – 1.64	.53 – 10.5
ABS	0.0426 – 0.0441	1.4 – 1.54	8.4 – 10.4



We finally choose ABS to make our pinch cover, because it's light, relatively cheap and has a higher yield strength. ABS also has shatter-resisting properties.

Braking Pin

Function: The mechanical interaction interrupts the rotational motion of the wheel when the extendable object is extended such that it mechanically interferes with the slots of the inside of the wheel.

Objective:

Minimize price and weight of the braking pin.

Constraints:

Braking pin can't break under a stress of 59.0 MPa.

Appropriate Material Indices:

The material index is found in the material indices chart:

Beam, minimum weight, strength prescribed

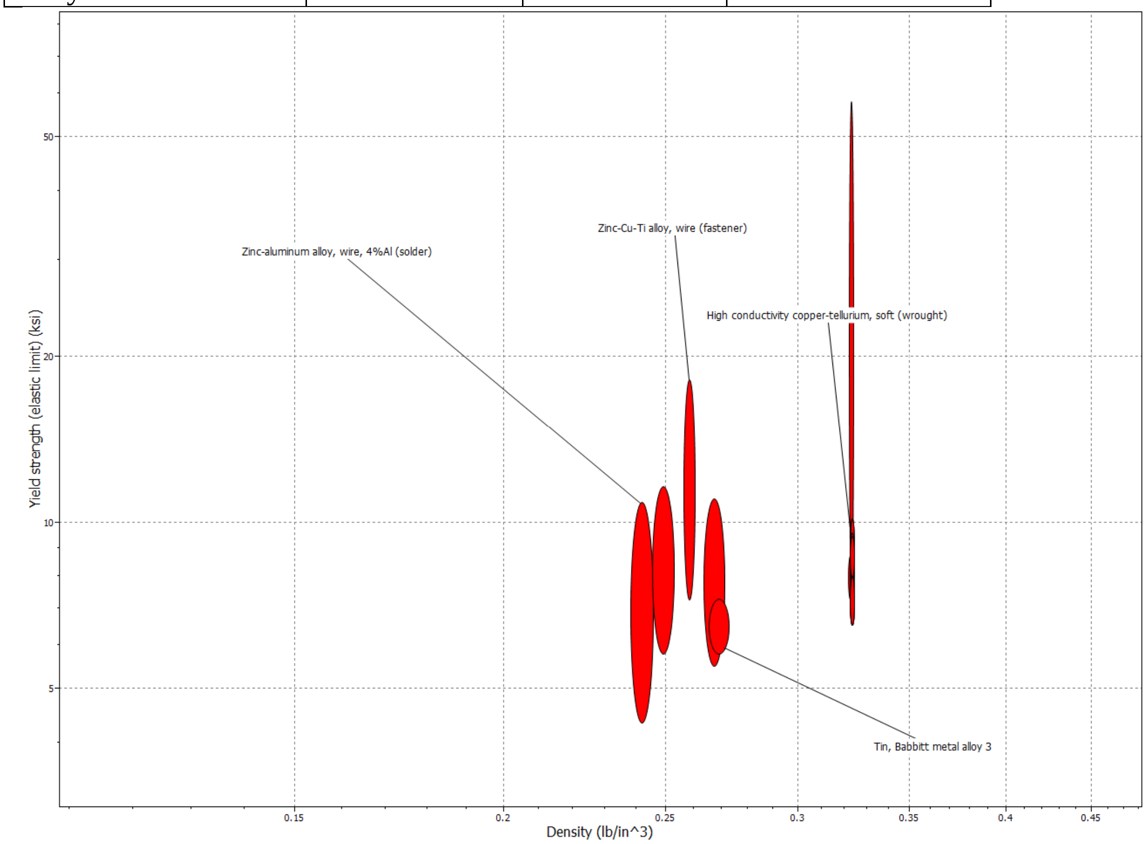
$$M=\frac{\sigma_y^{2/3}}{\rho}$$

Beam, minimum cost, strength prescribed

$M=\frac{\sigma_y^{2/3}}{C_m\rho}$

(ρ = density, σ_y = elastic limit, C_m = cost/kg)

	Density [lb/in^3]	Price [USD/lb]	Yield Strength [ksi]
Zinc-Aluminum alloy	0.238 – 0.246	0.506 – 0.557	4.35 – 10.9
Zinc-Cu-Ti alloy	0.257 – 0.26	0.519 – 0.571	7.25 – 18.1
Copper-tellurium	0.323	1.66 – 1.83	7.98 – 9.43
Tin, Babbitt metal alloy	0.266 – 0.273	4.64 – 5.1	5.8 – 7.25

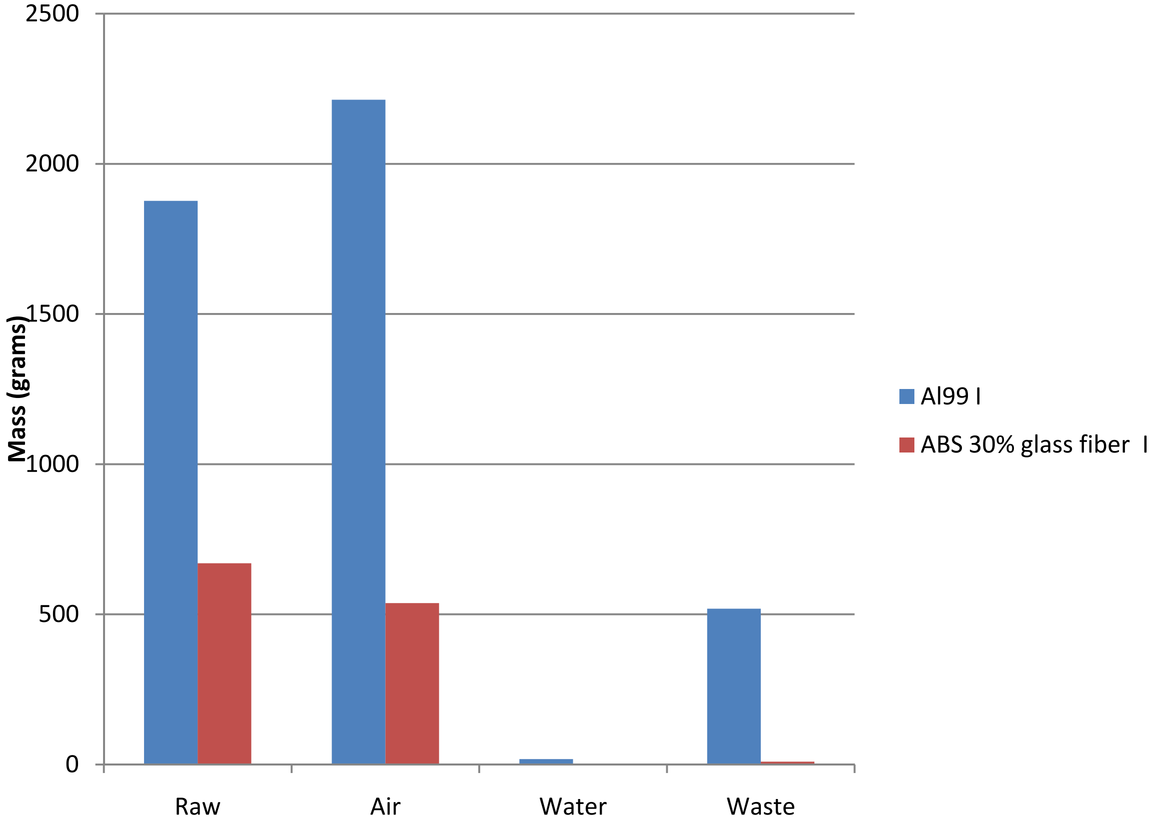


We finally choose aluminum alloy to make our braking pin, because it is cheap and light.

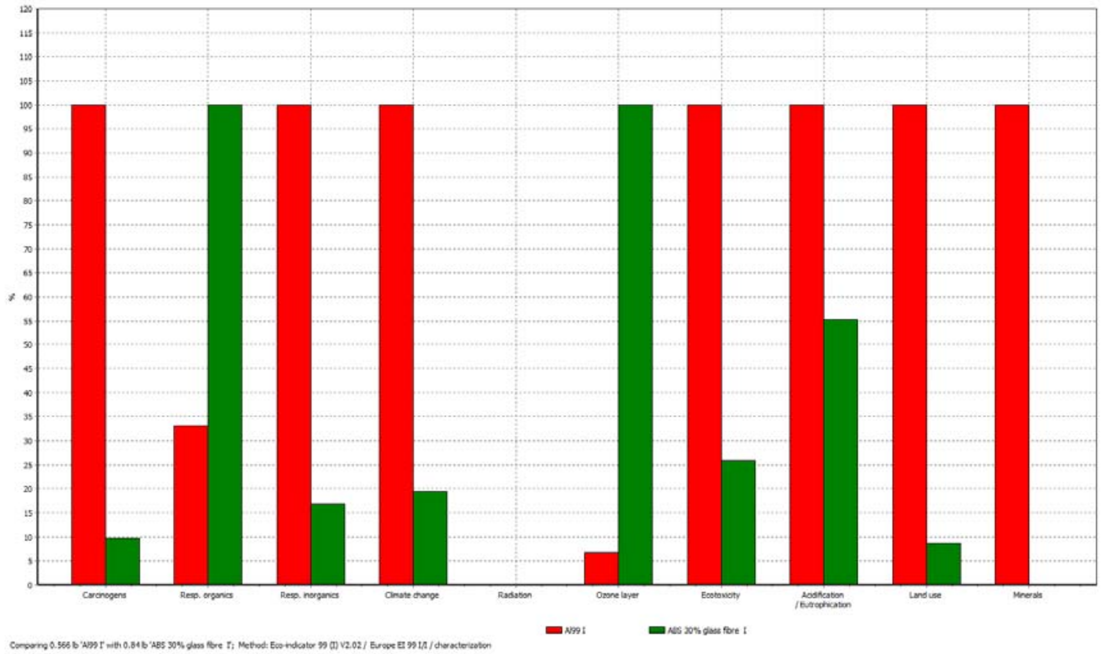
2. Material Selection Assignment (Environmental Performance)

- Materials and masses used in final design parts: Aluminum (0.5664lb) and ABS 20% fiber (0.84lb).
- Closest materials in SimaPro: Al99 and ABS 30% fiber (Used for analysis)

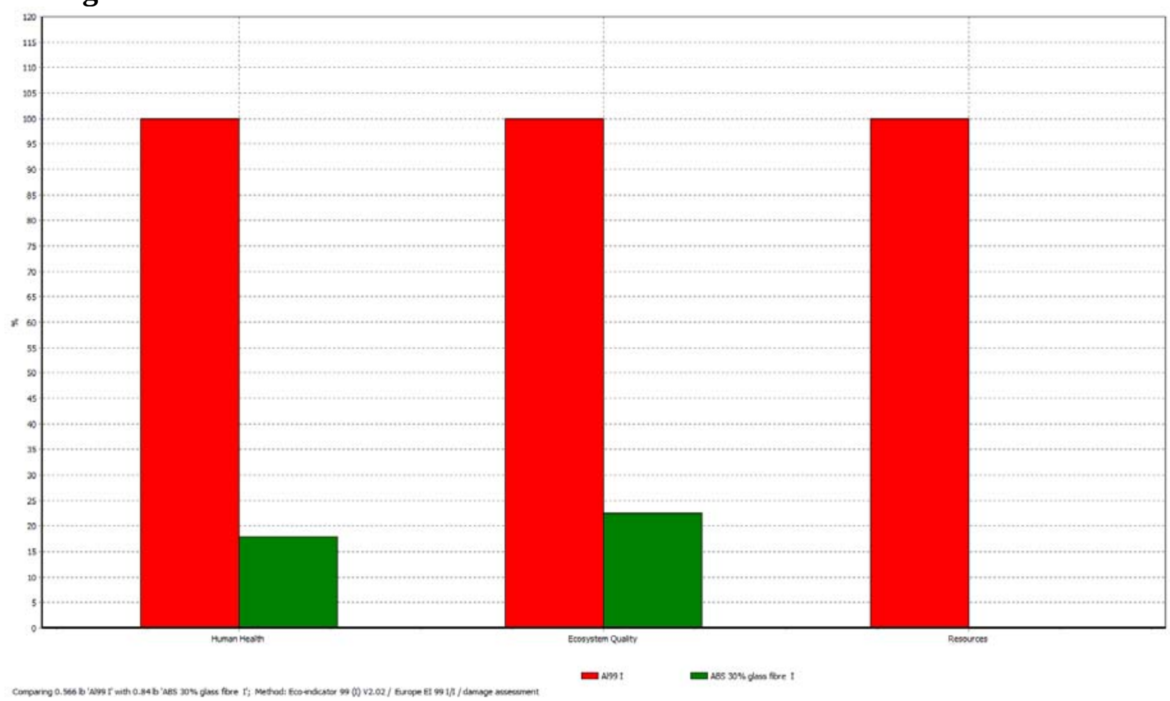
Excel graph of total emissions:



Characterization



Damage Assessment

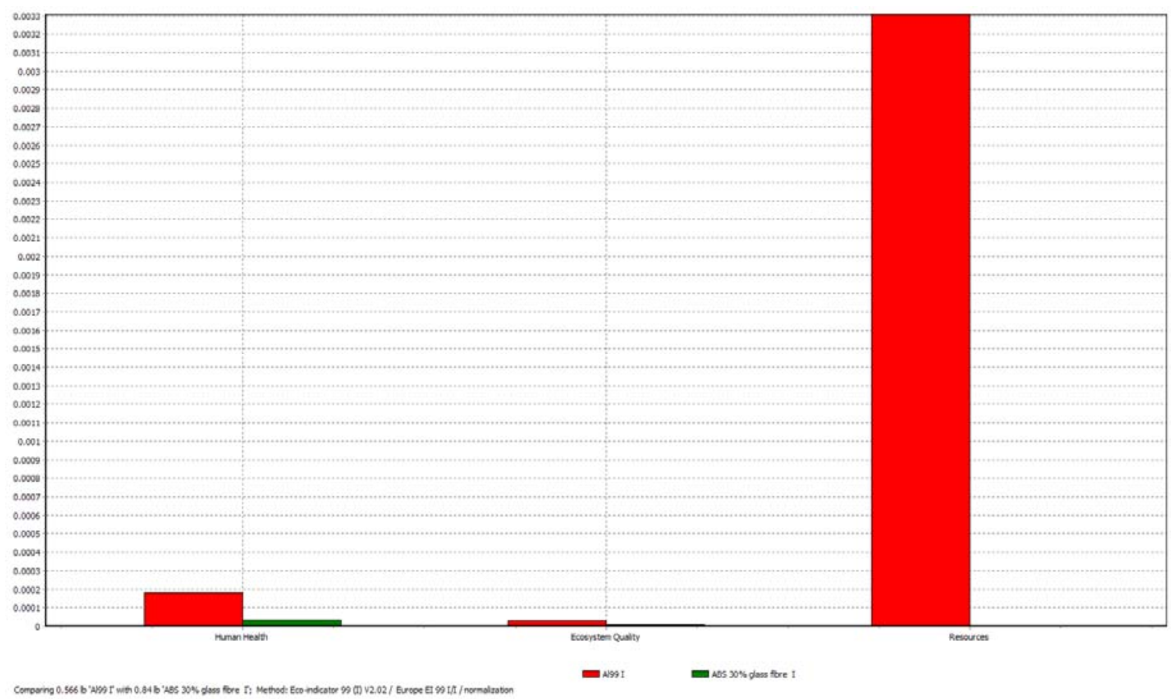


The aluminum has higher damage ratings for all three EI99 damage categories. Since the baby stroller will be in close proximity of young children and our engineering goal is first and foremost the safety of people, human health is the most important to us.

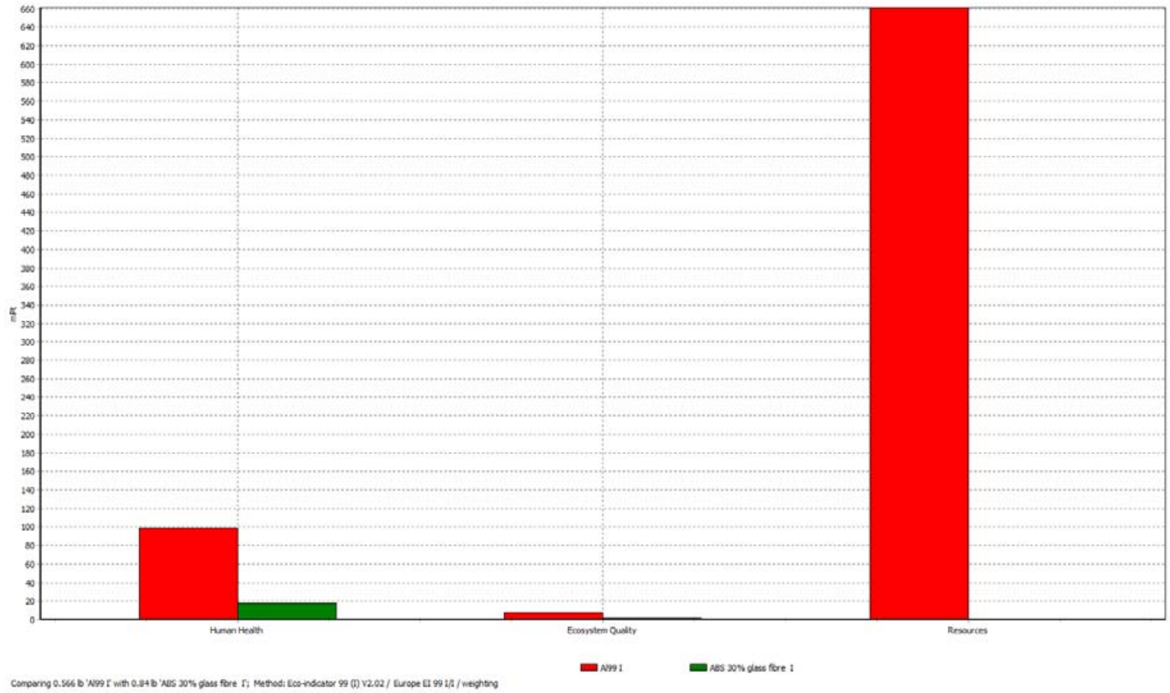
Since we don't use these materials elsewhere in the stroller, the above values can be taken as absolute. Therefore, it still stands that the aluminum brake pins create more damage than do the hinge covers.

When considering the life cycle of the aluminum pin and the PVC hinge covers, it can be estimated that the aluminum pins will be much easier to recycle. In this regard, the aluminum braking pin is much more eco-friendly than the PVC hinge covers. Also, if the brake pin is made of recycled aluminum, it has already lowered its environmental impact from the beginning. Based on these results, we will not change aluminum as the braking pin material because it is fully recyclable. We may consider polypropylene for the hinge cover and adapt the design to be able to use that. However, currently household items such as strollers and appliances are not normally fully recycled at the end of their useful lives so choosing the material with the lowest initial impact may prove to be the best for the environment, at least in the foreseeable future without changes to the way people recycle.

Normalization



Weighting



Single Score

3. Manufacturing Process Selection Assignment

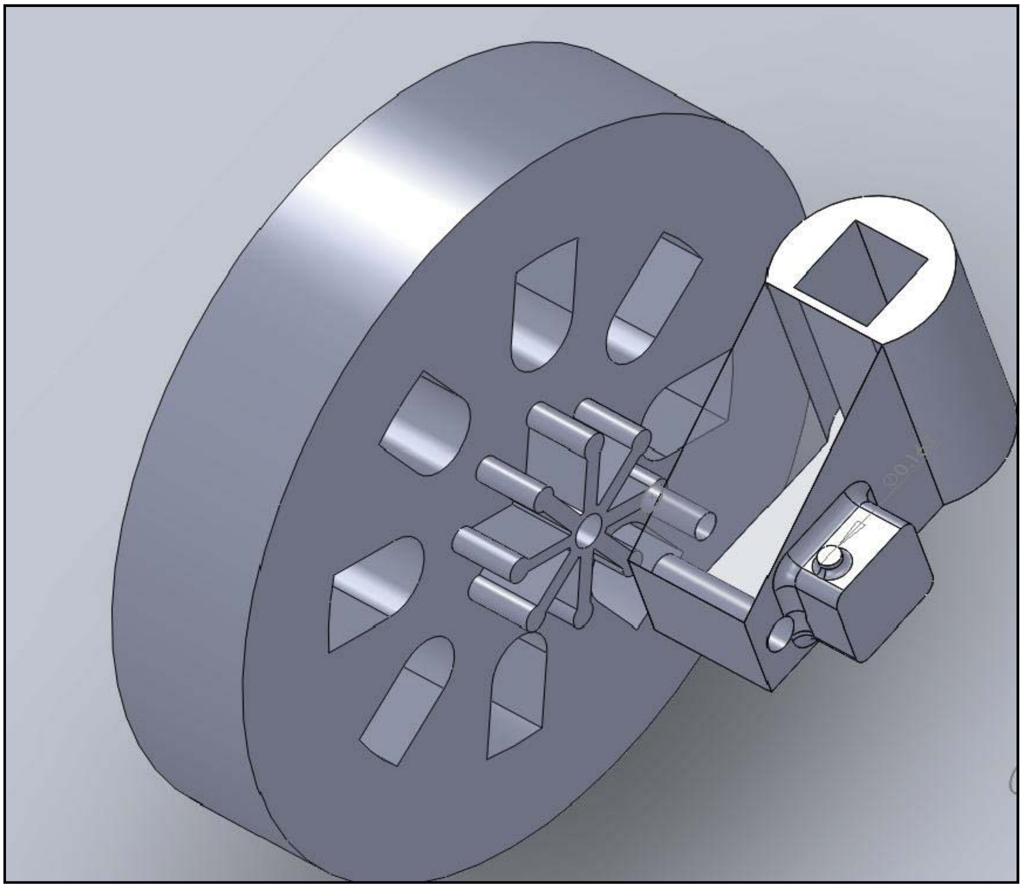
1. A real world production value for our stroller would be approximately 1,000 strollers. While there is a great demand for strollers, as every toddler needs one to be pushed around, there is much less of a demand for such an unorthodox stroller with unique features. Our stroller would primarily be used to introduce new features that are possible to increase stroller safety, and could be used by parents wishing to have safety features which aren't necessarily needed in every stroller. The figure of 1,000 is associated with our complete stroller, including all features. When the stroller is broken down into its individual components, the production value is much different. For example, many parents that wish for a hinge cover would not want LED lighting and a tension sensor on their stroller. For this reason, the following production values are estimated for our major features, as to be implemented into existing strollers: 10,000 hinge covers, 3,000 LED lighting systems, 2,000 tension/seat sensor systems, 1,500 automatic braking systems. Hinge covers are an easy addition, and could be added to many stroller without affecting the performance, and just increasing the safety. The lighting system makes the stroller aesthetically pleasing, and may be desired by a certain group of consumers who highly values that area. The tension/seat sensors can be added to the stroller easily and provide safety, yet may discourage many parents because of the annoying beeping. Finally, the automatic braking system is estimated to have the lowest production value, due to the fact that many parents would not be willing to sacrifice a great deal of comfort for an extra safety feature, when they believe they can just apply the manual brakes themselves.

2. **Hinge Covers** – The best way to mass manufacture the PVC plastic hinge covers would be by way of injection molding. This would allow for the cover to be made in one step, without requiring the assembly of the top and side pieces, as was the case with our prototype. The cover could then be slipped around the hinge, and bolted into place easily. Instead of the bolt used now, a rivet would be more effective, as it would eliminate the problem of the bolt jutting out near the child, and create a smooth finish on the hinge cover. The selection of a molding process is supported by CES, which lists the moldability of PVC as 4-5, which is very high. Also, creating a part with a thickness of 1 mm would be feasible, as injection molding can create thicknesses ranging from 0.4 mm to 6.3 mm, and the range of tolerances (0.07 mm to 1 mm) is acceptable for our design. In addition, our production value of 10,000 fits within the range of economic batch size for injection molding (10,000-1,000,000 parts).

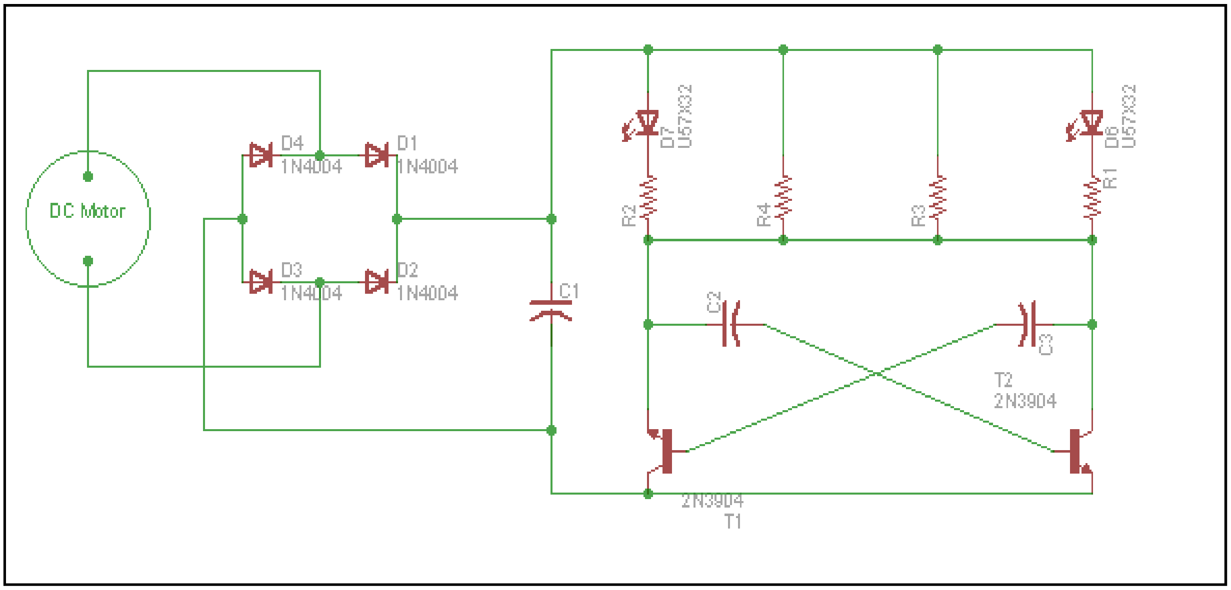
   Brake Pins – The most feasible method to manufacture the brake pins would be by sand casting. This way, a mold could be created for the brake pin, in which aluminum will be poured. This method is simple, and is preferred for the manufacture of 1,500 brake pins, as defined above to be the production value. The use of sand casting is supported by CES, which lists the castability of aluminum as 4-5, which is very high. In addition, the 19 mm diameter of the pin fits within the thickness range of 3 mm to 999 mm, the requirement for die casting. Also, our production value of 1,500 fits within the economic batch size for sand casting (1 - 100,000 parts).

APPENDIX D CLOSE-UPS OF DETAILED CHOSEN CONCEPT DRAWINGS

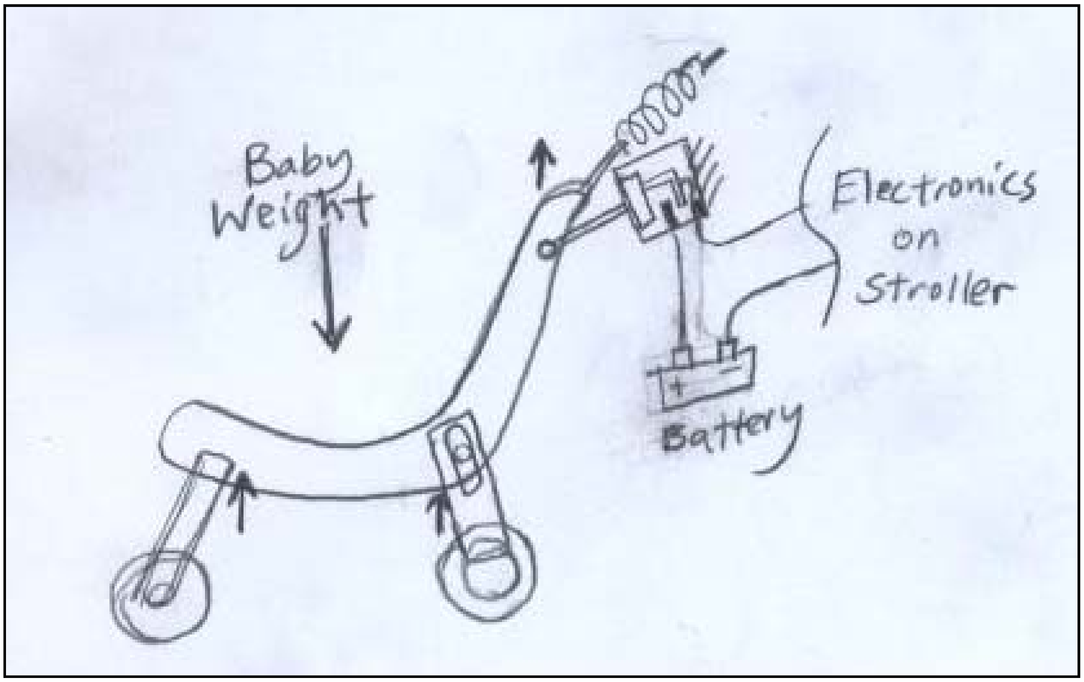
SLOT-INTERRUPT BRAKING



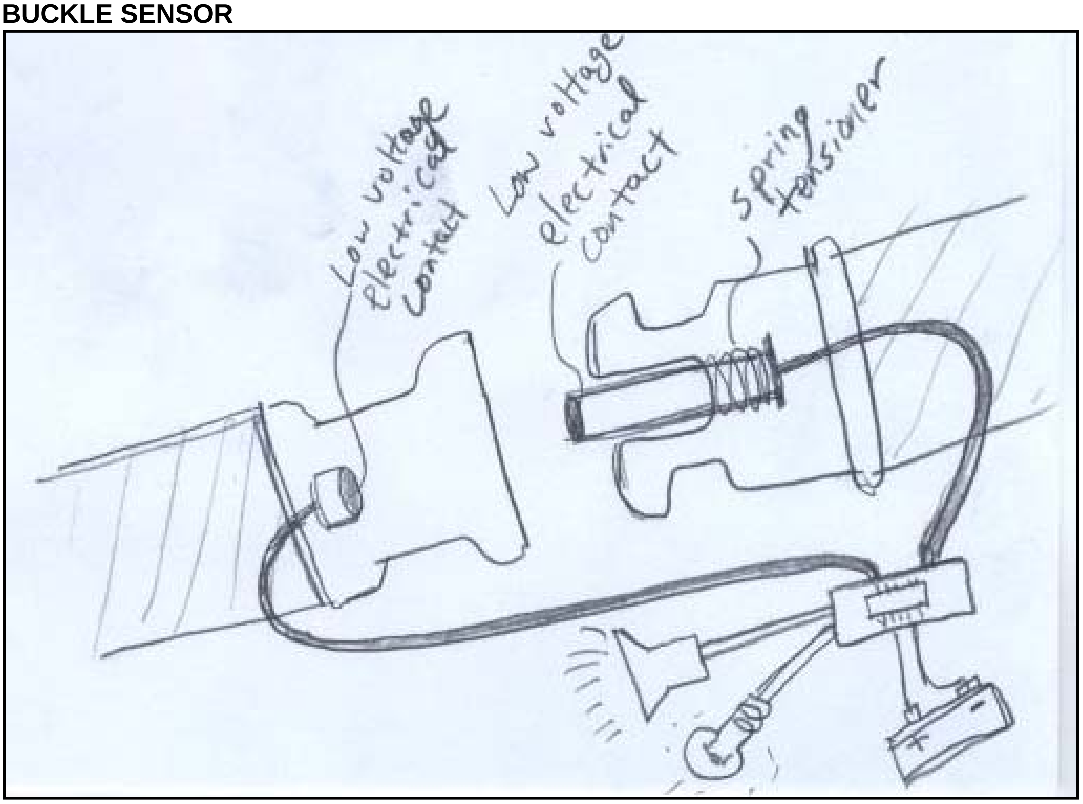
LED LIGHTING SYSTEM



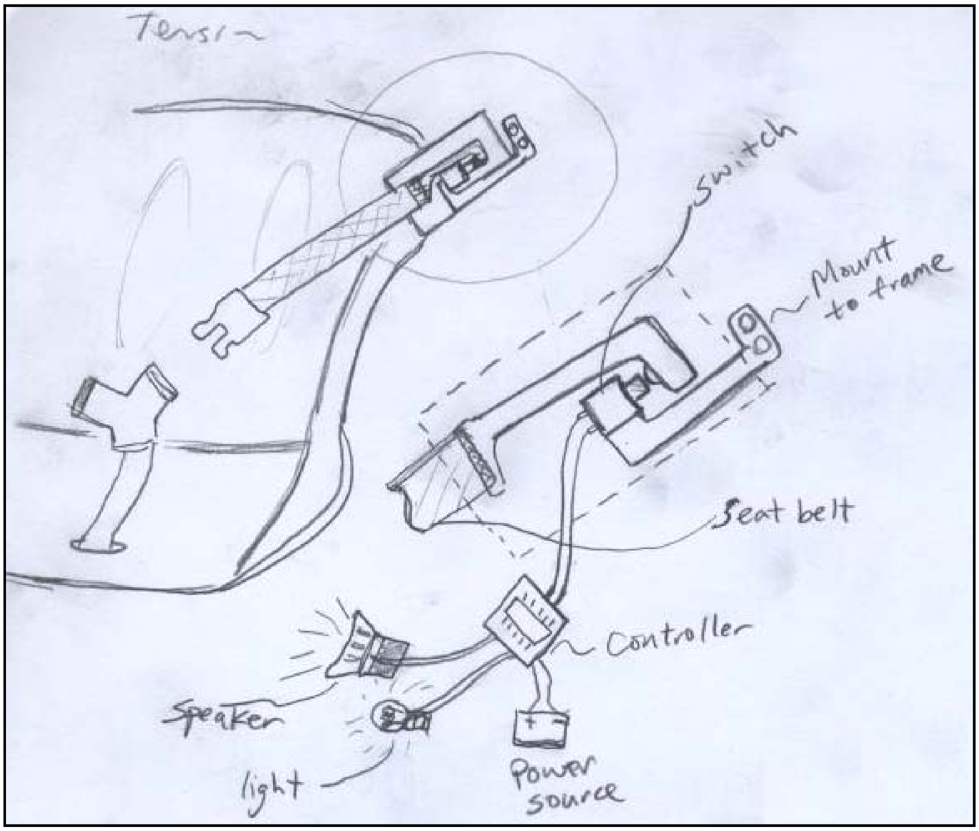
WEIGHT SENSOR



BUCKLE SENSOR

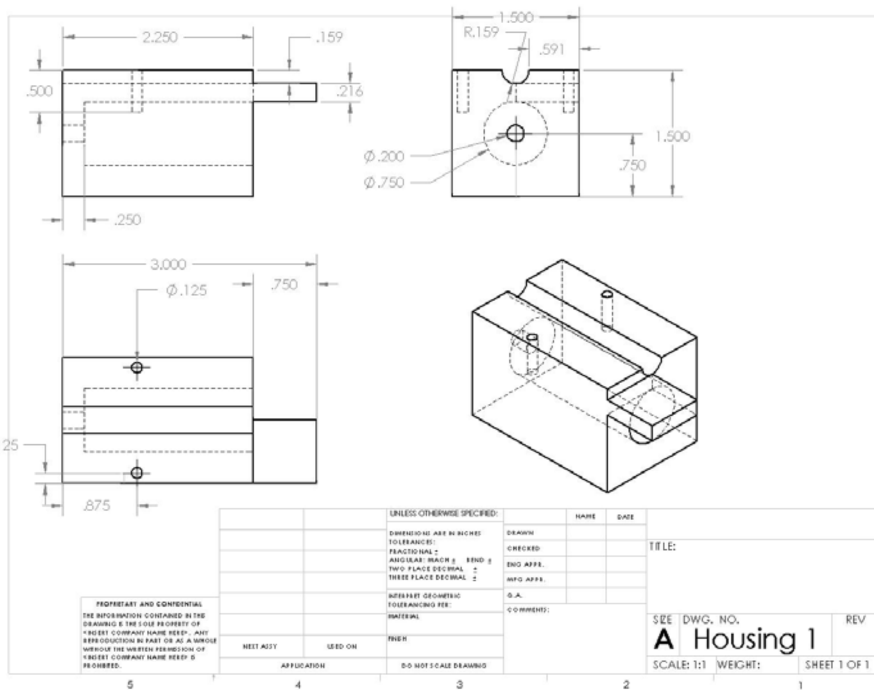


TENSION SENSOR

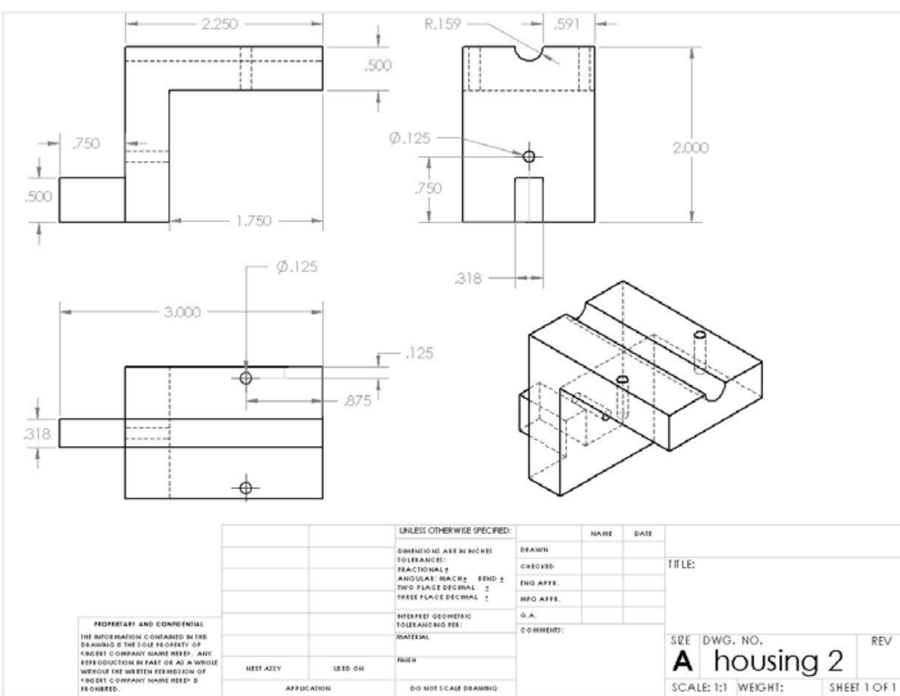


APPENDIX E DRAWINGS OF FABRICATED COMPONENTS

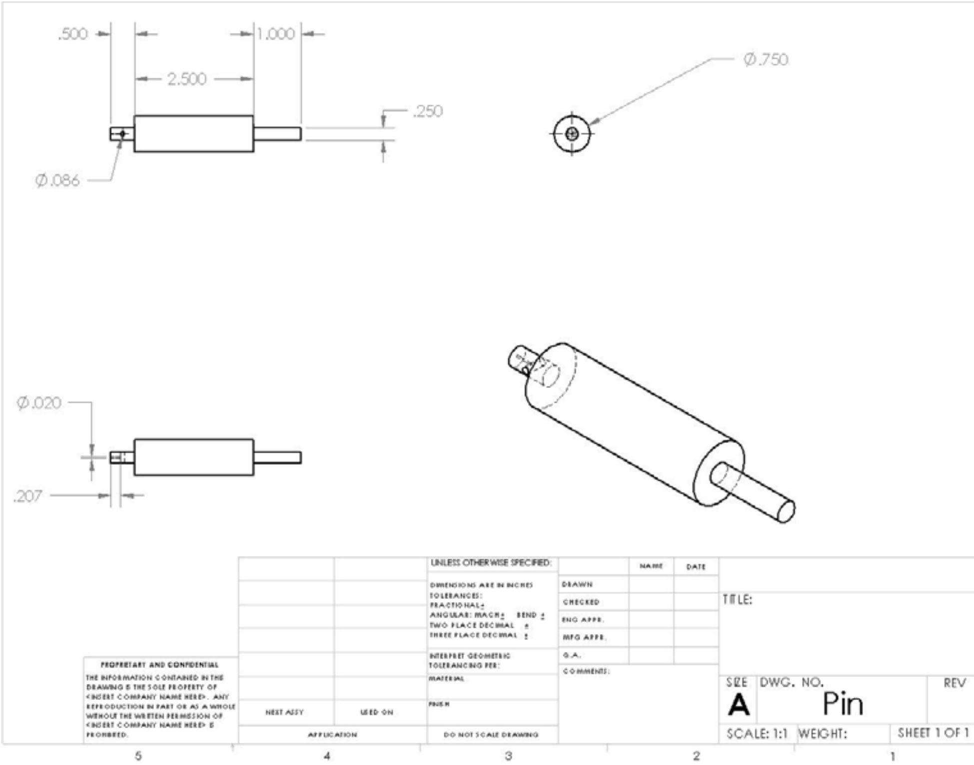
Brake Housing (Bottom)



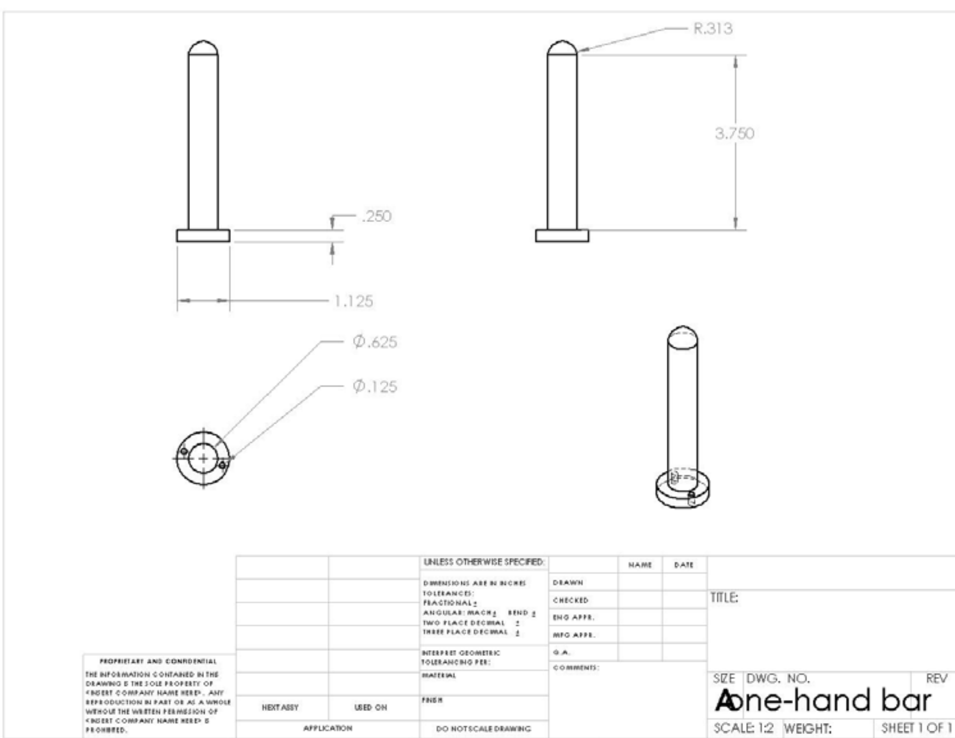
Brake Housing (Top)



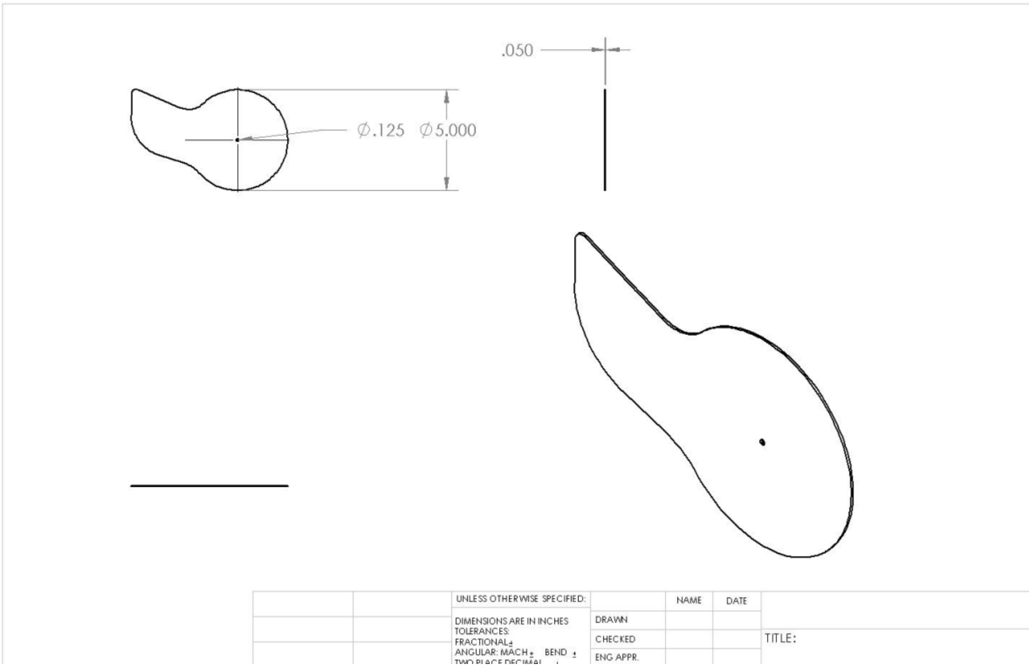
Braking Pin



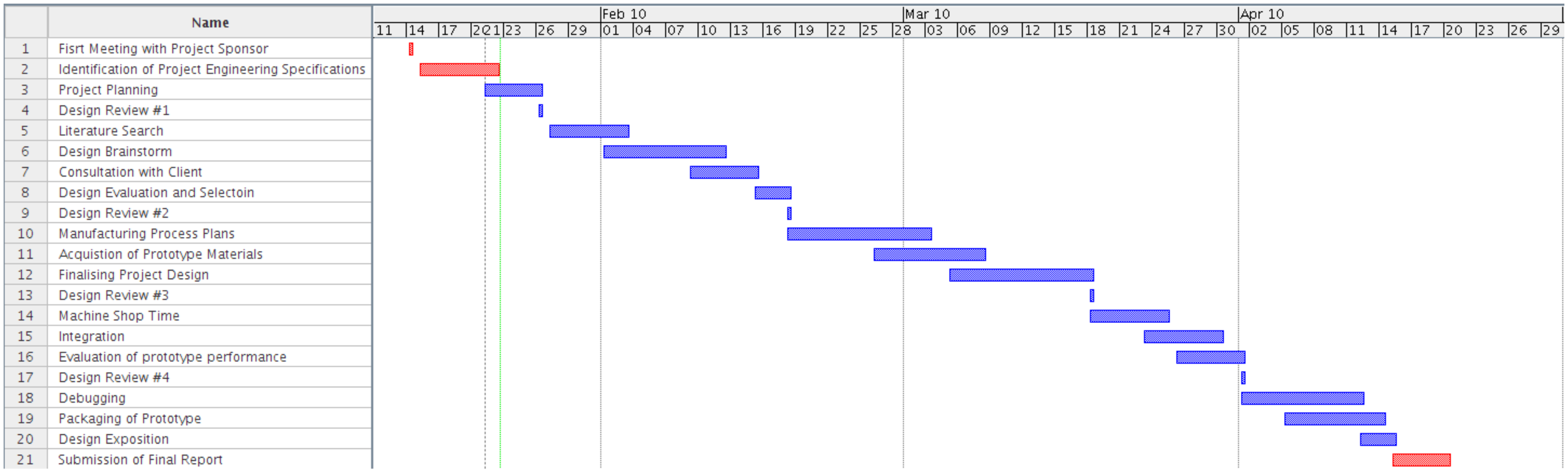
One-Handed Handlebar



Hinge Cover


.050
∅.125 ∅5.000
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH ± BEND ±
DRAWN
CHECKED
ENG APPR.
TITLE:

APPENDIX F PROJECT PLAN



Gantt Chart

APPENDIX G SOURCE CODE FOR PROGRAMMING PIC16F628A MICROCONTROLLER

```
STATUS      equ   03h
PCON equ    8Eh
CMCON       equ   1Fh
PORTA       equ   05h
PORTB       equ   06h
STCOUNT     equ   20h
COUNTMX     equ   21h

TEMP equ    27h
TEMP2       equ   28h
BTEMP       equ   2Ch
BTEMP2      equ   2Dh
BEEPPAUSE equ     29h
BEEPMULTI equ     2Ah
STNDLED     equ   2Bh
ALARMSTATE        equ   2Eh



            movlw 00h; PORTA is all output
            TRIS  PORTA
            movlw b'01011110';
            TRIS  PORTB

            MOVLW       07h; move 0x07 to W register
            MOVWF       CMCON; disable comparator module

START       clrf  PORTA; clear LEDs upon startup to prevent overloading
            bcf         PORTB,0
            bsf   PORTB,7; sets RB7 warning indicator for indicator testing
            movlw d'16'; BEEPPAUSE and BEEPMULTI should multiply to similar numbers
for each tone
            movwf BEEPPAUSE
            movlw d'110'
            movwf BEEPMULTI
            call  BEEPALM
            movlw d'12'
            movwf BEEPPAUSE
            movlw d'147'
            movwf BEEPMULTI
            call  BEEPALM
            movlw d'8'
            movwf BEEPPAUSE
            movlw d'196'
            movwf BEEPMULTI
```

```
        call    BEEPALM
        bcf     PORTB,6; sets RB7 warning indicator for indicator testing
        movlw   d'4'
        movwf   BEEPPAUSE
        movlw   d'255'
        movwf   BEEPMULTI
        call    BEEPALM

NORMAL0 clrf    PORTA; disable all lights
        bcf             PORTB,0
        bcf             PORTB,7;disable warning indicator
        bsf             PORTA,0;LED TUBE 0
        call    SCAN
        btfss   ALARMSTATE,0
        goto    ALARM
        decfsz  STCOUNT
        goto    NORMAL0
        clrwdt
NORMAL1 clrf    PORTA; disable all lights
        bcf             PORTB,0
        bcf             PORTB,7;disable warning indicator
        bsf             PORTA,1;LED TUBE 1
        call    SCAN
        btfss   ALARMSTATE,0
        goto    ALARM
        decfsz  STCOUNT
        goto    NORMAL1
        clrwdt
NORMAL2 clrf    PORTA; disable all lights
        bcf             PORTB,0
        bcf             PORTB,7;disable warning indicator
        bsf             PORTA,2;LED TUBE 2
        call    SCAN
        btfss   ALARMSTATE,0
        goto    ALARM
        decfsz  STCOUNT
        goto    NORMAL2
        clrwdt
NORMAL3 clrf    PORTA; disable all lights
        bcf             PORTB,0
        bcf             PORTB,7;disable warning indicator
        bsf             PORTA,3;LED TUBE 3
        call    SCAN
        btfss   ALARMSTATE,0
        goto    ALARM
        decfsz  STCOUNT
```

```
                goto    NORMAL3
                clrwdt
NORMAL4         clrf    PORTA; disable all lights
                bcf             PORTB,0
                bcf             PORTB,7;disable warning indicator
                bsf             PORTB,0;LED TUBE 4 (Tube 4, which is the 5th tube, is on
PORTB,0)
                call    SCAN
                btfss   ALARMSTATE,0
                goto    ALARM
                clrwdt
                decfsz  STCOUNT
                goto    NORMAL4
                goto    NORMAL0

SCAN bcf                ALARMSTATE,0; default to alarm state unless proven otherwise
                btfsc   PORTB,1; is weight sensor, set=no baby
                bsf             ALARMSTATE,0; if no baby, this line doesn't get skipped and
defaults to no alarm.
                btfss   PORTB,2
                return
                btfss   PORTB,3
                return
                btfss   PORTB,6
                return
                bsf             ALARMSTATE,0
                clrwdt
                return

ALARM           bsf             PORTB,7; sets RB7 warning indicator for indicator testing
                movlw d'4'
                movwf BEEPPAUSE
                movlw d'255'
                movwf BEEPMULTI
                clrwdt
                call    BEEPALM
                clrf    PORTA; disable all lights
                bcf             PORTB,0
                bcf             PORTB,7;disable warning indicator
                bsf             PORTA,0;LED TUBE 0
                movlw d'12'
                movwf BEEPPAUSE
                movlw d'100'
                movwf BEEPMULTI
                clrwdt
                call    BEEPALM
```

```
bcf             PORTB,7; sets RB7 warning indicator for indicator testing
movlw d'4'
movwf BEEPPAUSE
movlw d'255'
movwf BEEPMULTI
clrwdt
call    BEEPALM
clrf    PORTA; disable all lights
bcf             PORTB,0
bcf             PORTB,7;disable warning indicator
bsf             PORTA,1;LED TUBE 1
movlw d'12'
movwf BEEPPAUSE
movlw d'100'
movwf BEEPMULTI
clrwdt
call    BEEPALM

bsf             PORTB,7; sets RB7 warning indicator for indicator testing
movlw d'4'
movwf BEEPPAUSE
movlw d'255'
movwf BEEPMULTI
clrwdt
call    BEEPALM
clrf    PORTA; disable all lights
bcf             PORTB,0
bcf             PORTB,7;disable warning indicator
bsf             PORTA,2;LED TUBE 2
movlw d'12'
movwf BEEPPAUSE
movlw d'100'
movwf BEEPMULTI
clrwdt
call    BEEPALM

bcf             PORTB,7; sets RB7 warning indicator for indicator testing
movlw d'4'
movwf BEEPPAUSE
movlw d'255'
movwf BEEPMULTI
clrwdt
call    BEEPALM
clrf    PORTA; disable all lights
bcf             PORTB,0
```

```
                bcf     PORTB,7;disable warning indicator
                bsf     PORTA,3;LED TUBE 3
                movlw   d'12'
                movwf   BEEPPAUSE
                movlw   d'100'
                movwf   BEEPMULTI
                clrwdt
                call    BEEPALM

                bsf     PORTB,7; sets RB7 warning indicator for indicator testing
                movlw   d'4'
                movwf   BEEPPAUSE
                movlw   d'255'
                movwf   BEEPMULTI
                clrwdt
                call    BEEPALM
                clrf    PORTA; disable all lights
                bcf     PORTB,0
                bcf     PORTB,7;disable warning indicator
                bsf     PORTB,0;LED TUBE 4
                movlw   d'12'
                movwf   BEEPPAUSE
                movlw   d'100'
                movwf   BEEPMULTI
                clrwdt
                call    BEEPALM
                call    SCAN
                btfss   ALARMSTATE,0
                goto    ALARM
                goto    NORMAL0

BEEPALM         movlw   d'1'; this makes the beeps go without turning alarm off temporarily.
                movwf   COUNTMX
BEEPL3          movf    BEEPMULTI,0
                movwf   BTEMP2
BEEPL2          movf    BEEPPAUSE,0
                movwf   BTEMP
BEEPL1          bcf     PORTB,5; putting this up here instead of right after bsf makes
BEEPL1 longer and the overhead shorter, makes tones more accurate, it also doubles as a bunch
of NOPs after BSF to avoid a possible R-M-W error.
                ;clrf   PORTB
                decfsz  BTEMP
                goto    BEEPL1
                bsf     PORTB,5
                ;movlw  b'00100000'
                ;movwf  PORTB
```

```
        decfsz  BTEMP2
        goto    BEEPL2
        decfsz  COUNTMX
        goto    BEEPL3 ;always skipped if COUNTMX is d'1'
        bcf             PORTB,5
        return

end
```