INCREASING THE INDEPENDENCE OF CHILDREN WITH SPINA BIFIDA THROUGH THE DESIGNING AND BUILDING OF A MECHANICAL AIDE

by

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Abstract

In order to assist Silas Hopper, a child with spina bifida, with getting into his wheelchair independently when being on the ground, the senior project team set out to construct a device that would fulfill that purpose. They did this through coming up with a strict definition of the problem to be solved, designing a number of potential solutions for the problem, prototyping to determine the feasibility of the solutions, making design modifications after testing the prototype, and building the final device.

The end product was a device that was able to operate mechanically, with a design that considered safety and ergonomic standards. The estimated material cost of the device was $265, not counting labor or machinery. Testing yielded that Silas was able to use the device independently and successfully to move from the ground to his wheelchair seat. This had great implications for the lives of both Silas and his parents. After completing further modifications like adding a motor, dual button system to control the motor, and safety coverings to the device, it will be given to Silas permanently. The team hoped that awareness would be brought to spina bifida through the completion of this project, so future senior project groups or companies could use some of the lessons learned during this project and apply them to further improving the lives of those affected with spina bifida.

Introduction

Spina bifida is the most common permanently disabling birth defect, affecting 8 babies being born in the United States everyday ("What is Spinda Bifida?" 2014). Since this defect removes the feeling in the legs of the affected persons, it leaves tens of thousands of people unable to easily move from one surface to another, especially when they are at different heights. Needless to say, the need for a safe and effective transfer method going in and out of a wheelchair is dire.

Upon forming the senior project group, one member had contact with a child affected by spina bifida. Silas Hopper seemed to be the perfect candidate to model a project around. Each team member loved the idea when it was presented to them. When his parents were asked if they were alright with Silas being at the center of the project, they expressed interest and agreed to let Silas participate.

Simply put, Silas is an awesome little four year old. In many ways he is like a typical boy his age, loving airplanes and playing with toys whenever he could, but also noticeably smart and inquisitive for someone so young. As a child with spina bifida, there are many daily unique challenges that both he and his parents go through in order for Silas to be able to function properly. Some of these daily rituals include carrying Silas from his bed into his wheelchair (and vice-versa), getting him clothed and bathed, relieving urinary and gastrointestinal issues every four hours, and moving him around whenever he wants to do an activity without his wheelchair.

As an attempt to ease the process of moving Silas from the floor into his wheelchair, the senior project team set out to design and build a device that would enable Silas to perform this task independently. The end product should be a device that is fully functional, easy and safe to use, and something that Silas would actually want to use. The idea would be to leave this device at his home or preschool, the two places where he would need it the most, so he would have more freedom to do things like play with toys or grab objects on the floor. Even though this project is aimed at assisting Silas' situation specifically, many of the same concepts can be applied to people of all ages with spina bifida.

By the end of the project, the senior project team completed a prototype, a final device, and accompanying documents such as a bill of material, in support of the device. The main tasks leading to the completion of the project were defining a problem in need of a solution, coming up with design concepts that would be possible solutions for the problem, building a prototype to test the solution, making modifications to the design as needed, building the final device, performing tests to analyze safety, and compiling accompanying documents related to the final product.

Not included in the scope of this project are design considerations for anyone other than Silas, a thorough use of test statistics as a form of analysis, and consideration of the resources and circumstances required to produce the device in a large-scale operation. Even though steps were not taken to pursue any of these potential areas of study, it is possible to use the completed objectives within the scope of this project to explore those options.

This report outlines the research completed through review of relevant literature, the process of designing and building the device with certain safety and ergonomic standards, the methods of testing used to arrive at design conclusions, how successful the final product based on the interaction between it and Silas, and applications from the results for further study. The literature review shares the initial research completed for this project, describing in detail areas of study that were consulted when going through the design process. The design section of this report walks the reader through the steps in designing along with different forms of analysis related to design: designing with safety in mind and generalized ergonomic considerations.

Background

People with disabilities often require assistance with most of their daily tasks. Help is usually found in using either other people or assistive devices. Since the goal of the project was to make Silas more independent, the solution was to create a device that would not require other people to operate it. These devices are very unique in technical design because they must perform very specific tasks to accomplish goals. For instance, there are variations of a device that must help the elderly get to a standing position from sitting down, but they all work in a similar fashion. These devices lift the elderly through a rising seat or chair that slowly increases the angle of its orientation, starting from a horizontal (0°) level. Much like this device, the device resulting from the senior project could have some variations in overall design but is likely to have very few mechanical methods as applicable options. Therefore, it is important to understand similar devices on the market and different mechanical methods used in these devices.

As one can imagine, there are numerous unique considerations that must be taken into account when designing for a child. Some include device dimensions and sizing, additional safety concerns, physical strength of the child, and simplified usability. In planning the senior project, it was theorized that children have certain unique needs that are not being widely addressed by current assistive devices. One such need is playing with toys on the ground. The scope of the project was made more difficult due to the lack of previous research done surrounding the problem to be solved. This was the intent of the senior project team as we wanted to pursue a project without much precedence. The topics sought out in literature included common devices used to transfer wheelchair-bound people from one surface to another, how to design with safety built in, considering ergonomics in both design and functionality, anthropometrics, and different lifting mechanisms appropriate for lifting a person.

Literature Review

Common Transfer Devices

Transfer devices are assistive methods designed to help move people from a wheelchair onto other surfaces like beds, toilets, chairs, and couches. Currently, the most prominent transfer methods are transfer boards, patient lifts, and gait belts. Transfer poles and pivoting discs are other devices used as well, but not as often. All transfer devices still may require assistance from a caregiver or someone who knows how to assist the patient ("Transferring Using a Transfer Board" 2014).

Transfer boards are probably the most basic transferring devices available right now. The user would transfer themselves by sliding the board underneath their buttocks, allowing them to slide across until they reach the other surface. In most cases, the user requires assistance in using the transfer board. In Figure 1, the flat wooden transfer board is placed on the wheelchair at an angle from the bed.

Source: http://wishardhealth.kramesonline.com/HealthSheets/3,S,40382

Figure 1: Using a transfer board to transfer a patient

According to *Transferring Using a Transfer Board*, transfer boards come in different designs: flat, curved, or notched, depending on user's preference. Most boards are made from hardwood, high density heavy-duty plastic, or metal to provide enough stability for the user. Transfer boards on the market usually come at specific lengths, making it impossible for the-- user to adjust the board for different surfaces of varying heights. Some redeeming qualities are notches that allow for better positioning around the wheelchair tire, more transferring flexibility based on design (i.e. curved boards allow patients to place the curve of the board to accommodate different transferring positions), and their light-weight and portable design.

Patient lifts are an assistive device that transfers patients from surfaces using hydraulic power or electric motor to function. According to *Pocket Guide for the Home Care Aide*, the patient lift was patented in 1955 by R.R. Stratton who created the sling lift design based off the floor crane, a lifting device that carries engines or heavy parts. Sling lifts can be either mobile or permanently installed, an example of the latter being overhead lifts. Overhead lifts are installed on the roof, and are used more frequently if there is limited space for transferring. Mobile sling lifts can be easily transported to different locations, and serve for multiple different transfers. Figure 2 shows an example of the mobile sling being used to transfer a patient. The user can be hoisted in a sling horizontally or vertically depending on the user's needs. The sit-to-stand lift was created to help people who have decent mobility skills but lack strength or muscle control to get into a standing position. Unlike the sling lift, the sit-to-stand lift uses straps, vests or belts when transferring patients from different surfaces.

Source: http://www.prismmedicalinc.com/patient-lifts.html

Figure 2: Using a patient lift to transfer a patient

Transfer boards and patient lifts can be used in conjunction with several types of lifts built for specific purposes; one such example being a bath lift. The Sterling 303 bath lift (pictured below in Figure 3) is described by ActiveForever, the company selling it, as having "an automatic position and recline control [along with a] large transfer area" (Sterling 303 Bath Lift 70). As one could extrapolate from looking at the device setup, some kind of transferring device is required to use this lift. In order to compensate for the transferring devices' lack of complete flexibility, devices like the bath lift are seen as necessary and act as partners with the transferring device to help disabled people with daily activities.

Source: "Sterling 303 Bath Lift"
Figure 3: Sterling 303 Bath Lift

Gait belts require significant physical effort from both the person transferring and the person assisting in the transfer. The process of using these belts to transfer begins by placing the belt across the waist of the person being transferred. The belt must be placed over the clothing and under the knees with the buckle facing forward, making sure the belt is snug on the user. The assistant must position themselves so that their knees are bent and back is straight, reducing back strain, and then lift the patient using their leg muscles. Figure 4 shows a caregiver is carefully assisting the patient using the gait belt. In most cases, people assisting users must be trained due to the physical strength and abilities required of them. According to an article titled *Evidence-*

Based Practices for Safe Patient Handling and Movement, gait belts are usually made out of cotton webbing, nylon, or leather, with a buckle located on the end (Nelson 2004). A disadvantage of using gait belts is the transferring of germs between uses. There has been history of reports a lack of cleaning gait belts after use, causing patients to get infections (Rutala 2008).

Source: http://liftvest.com/gait_belt.php

Figure 4: Using a gait belt to transfer a patient

Designing for Safety

Safety is simply a condition free from danger, injury, or loss (Hunter 1992, 1). When designing an object or system, it is essential to account for hazards that may compromise the safety of the user. Hazards are occurrences of danger that one can foresee but usually not avoid (Hunter 1992, 2). An illustration of hazards is given in Thomas Hunter's book *Engineering Design for Safety*, where he gives the example of hazardous waste as a danger that cannot be avoided, but knowledge of its nature makes it predictable and enables people to dispose of it the best way they can. The only way to avoid a hazard is to either eliminate or prevent it. Hazard prevention is crucial to safety.

The process of designing for safety begins by identifying a design problem and then coming up with multiple design solutions; the best solution is then selected. Afterwards, research must be done on existing safety requirements for the product in order to prevent potential safety hazards (Hunter 5). After identifying the remaining hazards, the severity of each hazard must be assigned. The hazards that are found to be the most critical, meaning most likely to occur and with higher severity levels, should be targeted for elimination. This entire process of hazard elimination is often called *failure mode analysis* (Hunter 1992, 6).

The next step after identifying the hazards of the device itself is identifying the potential hazards associated with the human-device interaction. This involves identifying hazards found during use, misuse, and abuse of the device. Finding these hazards usually takes place immediately after choosing the final design for the device (Hunter 1992, 6). A common method used to correct these kinds of hazards is *poka-yoke*, or to mistake-proof the device. In his book *Zero Quality Control: Source Inspection and the Poka-Yoke System*, Shigeo Shingo (the creator of poka-yoke) discusses the need for mistake-proofing devices, regardless of the user, since all people make mistakes on occasion. Poka-yoke devices practically eliminate chances of confusion, injury, or any other result of misuse. Five of the best and most basic kind of poka-yoke are guide pins of different sizes, error detection and alarms, limit switches, counters, and checklists (Magazine Factory 1989, 15).

The last step needed in designing a safe product is to test it. Some hazards may not be easily recognized in the design phase of developing a device so a thorough safety test is essential (Hunter 1992, 77).

Application of Ergonomics in Design

When someone says an object has an “ergonomic” design, a multitude of design details may come to mind. For example, some might think of how a car is designed to be safe for the user, while others might think about how comfortable the user is in the car. Ergonomics is a very broad field, shared by many disciples, that aims to design tools, equipment, and tasks to improve human capabilities (MacLeod 2000, 3). Knowing this, it is easy to see that usability (sometimes associated with user-friendliness) is an excellent consideration when designing an object ergonomically. There are several considerations when designing a device with usability in mind, such as portability, comfort ability, and effectiveness in fulfilling its purpose.

Any kind of device or system that is to have ergonomic traits must be designed around the user experience (UX). In doing so, every designer must consider four key design elements: the user, the system, the activity, and the context (Boy 2011, 324).

Within designing around the user's UX, some different human factors are explored such as anthropometry, motor (drive), perception, cognition, social aspects, cultural aspects, psychology of the user, motivation, and emotions. In order to create something that is so accommodating to the user, it is not uncommon for users to be involved in the designing process (Boy 2011, 326).

The team designing for the UX is in control of the system, or device, being established along with all of its qualities. Some of the qualities found in good interactive systems include usefulness to achieve the intended goal, reliability, security, efficiency, accessibility, compatibility with other versions and products from the same manufacturer, usability, and aesthetics (although with lesser emphasis) (Boy 2011, 327). Each of these qualities plays an essential role in how the user interacts with a device.

The intended activity that is to be completed through the device is also designed around the UX. This concept traces back to intended use by the user and making sure potential misuse is reduced or eliminated. As long as the user is able to use the device consistently without high chance of mistake, the activity design is considered successful.

The context by which the device functions or exists is important because the environment it is subject to has direct effects on the functionality. For example, if the profits from selling a product went to funding some sort of illegal or immoral activity, the public would probably be less inclined to purchase it. With less revenue, the company may be unable to put sufficient resources into product design, which directly affects the UX (Boy 2011, 329).

Anthropometric Considerations

Anthropometry is the study of the measurements and proportions of the human body corresponding with the functional capabilities of a product. Product designs that are incompatible with anthropometric measurements could result in undesired results. In the past, there have been many cases of wheelchair anthropometrics that have been exhaustively analyzed. Many different experiments, testing, and statistical analysis have been conducted to further enhance the ergonomics of the wheelchair user. For example, a study titled, *Anthropometry of Wheeled Mobility Project,* conducted at the University of Buffalo analyzed 495 human measurements to enhance the feasibility of the wheelchair. This study recorded measurements of wheelchair width and length, seat height, knee and toe clearances, maneuvering clearances, reach ranges, and grip force. The population used for the sample were recruited from assisted living facilities and daycare programs for the elderly in various locations to accommodate a diverse population. The number of participants and their locations were as follows: 351 in Buffalo suburbs, 100 in Pittsburg, and 51 in Ithaca. It is noted that only those with the ability to independently move were asked to participate, as to fulfill the requirement of being capable to complete all tasks. All testing sites were carefully instructed on proper and common measuring techniques and data collection to affirm consistent methods.

Throughout this experiment, the researchers determined 125 fixed points on the human body and wheelchair in which to measure from. A three-dimensional electromechanical probe was utilized to pinpoint a 3-D location on the body and device points. The 3-D points then recorded width, length, and depth measurements of the body and wheelchair structure with the basis to enhance its ergonomics. When measuring for wheelchair width and length, the team ultimately decided that the overall wheelchair width and length would be measured from the outermost extension of any part. Therefore, for the length, whatever object was the anterior or posterior most point of the front and back respectively were used for measurements. Similarly, width was measured across the most lateral points of both right and left sides. Measurements for occupied manual wheelchair users were gathered using the 3-D probe, finding that the mean width was 685 millimeters, while length averaged 1150 millimeters. For seat clearances, the team measured various positions on the knee for leg comfort. The research dictated the apex of the knee cap, otherwise called the apex patellae, was measured from the ground up giving the values for maximum height of the lower leg while sitting in a wheelchair. Furthermore, the knee point anterior was used as a position for multiple measurements, including; knee clearance depth, buttock-knee length, and maximum length of upper leg. Many more points were recorded with the 3-D probe and compared with the United States wheelchair standards. Findings were that seat heights from the experiment sample were greater than wheelchair heights according to the US standard. Furthermore, US standards for knee and toe clearances did not accommodate the majority of people conducted in the study and should be altered.

The team also measured the maneuverability of wheelchair users. This experiment was conducted by video recording each wheelchair user performing a 90-degree turn, 180-degree turn, 180-degree turn with center barrier, and 360-degree rotation within the space of 4 walls. Each task was performed within a wall-like barrier constructed out of cardboard, which was incremented in width by 51 millimeters (2”) each time a participant failed to complete a turn without touching the wall. 90-degree and 180-degree turns began at a minimum of 762 millimeters (30”), while the complete rotation began at 1295 millimeters (51”) of wall-to-wall separation. The team found that maneuvering clearances are not properly estimated according to the US set standards. As studied by the team, most participants could not meet the US standards for a turning radius of the 360-degree rotation.

Testing also included the determination of grip strength through analyzing four different measurements: elbows fully extended, elbows bent 90-degrees, lateral pinch and thumb-forefinger pinch. Grip strengths were recorded using dynamometers, where the participant was asked to maximize their grip force for three tries at each position. The mean of each position was then used in the data collection. Findings were that the maximum operating force, as set by US standards, is too high for most of the participants.

The research uncovers the importance of future development within this field work and the many improvements or updates that can be made to design the optimal wheelchair. Anthropometrics provide a tremendous scientific view on the quality of wheelchairs that are available on the market today, as well as the future developments pertaining to the wheelchair industry.

Lift Mechanics

While there are many patient lifts available in the current market, there are none that act as a solution for the project problem. Most lifts are assisted lifts, meaning a caregiver must be there to assist the user in operating the equipment. The most frequently used lifts are usually hydraulic or electric powered, but also require the user to have upper body strength to supplement their standing. All of these lifts are sitting-to-standing lifts, meaning they work when the user is already at an elevated surface while in the seated position (as opposed to sitting on the floor). Although there are no solutions available on the market right now, examining the current lift mechanics and power sources used in similar devices can give some insight on methods that may be useful for the proposed project design. The different types of lifting methods researched were using gear ratios, hydraulics, and electric powered motors.

Mechanical advantage is defined as the ratio of the output force from a machine to the force applied to that machine. Gears can provide mechanical advantage by being used in a gear train, or several gears with varying sizes and teeth used in series with one another (Dotson 2007). The mechanical advantage provided depends on the gear ratios within the gear train. In a simple two-gear example, gear ratio is the ratio of the number of teeth on the output gear to the number of teeth on the input gear. In a more complex gear train, this can be calculated for every input-output pairing in the gear train. The compounding result, or multiplication of each ratio, will give the total gear ratio of the train. The mechanical advantage is equal to this ratio. Although there are virtually no lifting devices that use this kind of mechanism, it is still valuable to examine its potential in way that could benefit the project.

Hydraulics also follow the concept of trading force for distance travelled. In a simple hydraulic system, force is applied to an incompressible fluid using a piston, which causes a transfer of that force over distance to then move the piston at the other side. However, by changing the sizes of input piston to output piston, the mechanical advantage provided by these forces can be changed (Brain 2015). For example, if force is applied to a piston with a surface area of 1 in^2 in order to move a piston with a surface area of 9 in^2, the applied force will be multiplied by the ratio of these areas, which is 9 times. However, the input piston will also move 9 times as far as the output piston will move.

Electric motors are much different from gears and hydraulics. These motors are built to generate mechanical energy by using an electric current. The linking factor between the electric current and mechanical energy is magnetism. The north and south poles produced by the magnetic field repel each other; a motor functions by this principle. Every electric current has a magnetic field accompanying it, but it is too weak to be useful. To amplify the effects, copper wire can be twisted around an iron bar, making an electromagnet. The most common kinds of electric motors are induction motors, universal motors, and DC motors. Induction motors are commonly used in several household appliances such as refrigerators and furnace, and come in a variety of designs to fit the function of what they are powering. DC and universal motors are found in smaller objects like power tools. Instead of inducing current with a rotating core, DC and universal motors directly send the current to the rotor physically (Henkenius 1991).

To summarize, the topics sought out in literature included common devices used to transfer wheelchair-bound people from one surface to another, how to design with safety built in, considering ergonomics in both design and functionality, anthropometrics, and different lifting mechanisms appropriate for lifting a person. It was important to understand these topics in pursuing a solution to the problem presented to the team. Using what the team learned from literature, the process of designing was able to begin.

Design

With the design phase of this project being the most exhaustive, it was necessary to spend a great deal of time brainstorming on the design concept that was ideal for Silas. The designing process began by defining the problem to be addressed, coming up with an initial design to fix the problem, building a prototype based off of that design, making conceptual modifications to the design, completing a failure mode analysis and tipping analysis to promote safety, adding ergonomic considerations to the design, and constructing the final product.

Objectives Defined

The most important part of the design process was defining the specifications of the problem to be solved. In order to establish a need that would greatly benefit Silas, the senior project team consulted Silas' parents. The initial problem presented was that Silas required assistance to get in and out of his bed. Naturally, one of his parents would have to assist him every morning and night to accomplish this. The next few weeks were devoted to brainstorming design concepts to accomplish this goal. The resulting design can be seen in Figures 5 and 6. Essentially, the idea was to modify a wheelchair so that the seat can move both vertically and horizontally. This seemed adequate in helping Silas get to a lower or higher surface easily and safely.

After creating a rough 3D model of the design concept in CAD modeling software, the team approached Silas' parents once again to gain further input. His parents decided to revise the problem. Instead of assisting Silas with getting in and out of his bed, the purpose behind the device was now to bring Silas from the floor into his wheelchair independent of assistance from other people. This seemed more plausible as Silas was able to slide out of his wheelchair onto the ground by himself but was not able to get back into his wheelchair without help. Silas would often move to the ground in order to do activities such as play with toys, both at his house and at the preschool he attends.

Figure 5: Prototype when seat is up

Figure 6: Prototype when seat is down and forward

Building and Testing the Prototype

Fundamentally changing the problem definition prompted the senior project team to drastically change the design concept. In order to even begin designing, it was necessary to understand exactly what Silas was capable of in terms of physical strength. There were many instances, both before and after building the initial prototype, where the team had to measure these capabilities. Some of the measurements took place at his weekly physical therapy visits, while the others were taken at the preschool he attends.

The first set of measurements taken tested Silas' ability to use a crank, his degree of mobility when he was in his walker, his ability to lift himself into his wheelchair by himself, his ability to independently get onto the ground from his wheelchair, and the height he could push himself up from the ground while sitting.

His ability to operate a crank was tested by the use of his crank powered tricycle. His parents explained that he would use his tricycle often when they visited the beach. The tricycle is not of conventional design; the pedals are placed towards the top of the model so that the user can pedal with their hands. This tricycle is designed for children with disabilities that affect usage of their legs. It was necessary to test this ability of his because of the crank component of the initial prototype design. The project team witnessed Silas pedaling his tricycle from one point to another, a distance of 20 feet. It was reasoned that both crank mechanisms posed similar resistances to Silas' strength.

Another ability of Silas' worth considering was the degree by which he was able to move around using his walker. Though he could walk around using his walker, Silas still had an issue getting to a standing position. Since a potential functionality concept of the initial prototype design was Silas backing up into his wheelchair and get into it that way, it was necessary to evaluate his mobility. The project team asked Silas to walk forward 5 feet, to which he succeeded. He was then asked to move backwards the same distance. It was found that Silas could not walk backwards, ultimately changing the device design. Although this was the case, it is important to note that Silas did possess the ability to get into the wheelchair by himself while in a standing position as well as to get onto the ground by sliding out of his wheelchair, which the senior project team witnessed during testing.

The last physical ability tested before building the prototype was how high Silas could push himself up from a sitting position on the ground while sitting. This was tested by placing Silas on concrete (a hard, flat surface) to push off of. The project team asked Silas to lift himself three different times, which the team measured. Each time, the height that Silas pushed himself off the ground measured to be 4.5 inches. This was important to measure since the initial prototype design required Silas to be able to lift himself onto the seat of the device, a height of an estimated 5 inches. This fact additionally required the project team to redesign the initial prototype design.

Building the initial prototype was the next step in testing the design concept. Construction took four hours and only a few days to gather the materials. The prototype (pictured below in Figure 7) consists of three wooden planks, another piece of wood that was cut into a seat, a Curt 28204 Side Wind A-Frame trailer jack, a Curt 28272 Jack Foot, and screws, nuts, bolts, and washers of various sizes. The design function was for the user to lift themselves onto the wooden seat, grab onto the jack for stability, crank themselves up using the crank arm until they reached the desired height, and scoot themselves from the seat into their wheelchair.

Figure 7: Prototype

The next step was to have Silas test the prototype. This was completed while he was in his weekly physical therapy session so that project the team could gain further input from the his physical therapist. As mentioned earlier, the height of the seat was taller than Silas' ability to push himself off of the ground, so he was lifted onto the seat by the physical therapist. Once on the seat, Silas grabbed onto the jack and began turning the crank arm. Because of the gear ratio of the trailer jack, each revolution only moved Silas a very short distance per crank. Silas began at the lowest height that the jack could go and cranked his way up to the top in roughly three minutes. Figure 8 shows Silas at the maximum height of the lift. Silas began by cranking at a moderate pace but started to slow down a minute and a half into it due to fatigue. He would often stop to rest or switch arms. Once he reached the maximum height, he began to transfer from the seat into the wheelchair. The senior project team observed that Silas pulled himself back into the wheelchair using the wheels to grab onto. Once he was in the wheelchair, Silas had to roll backwards in order to free his legs (seen in figure 9), which were placed on both sides of the seat due to scooting backwards across the seat. The testing yielded some conclusions worth noting. The team learned that the height of the seat was too high for Silas to get into by himself, that Silas was able to turn a crank arm well enough to make the lifting mechanism effective for the design, wood was not stable enough for the device base, and Silas felt safe using the device at the desired height. Of course, these conclusions led to significant design changes.

Figure 8: Maximum height of lift

Figure 9: Silas leaving the device

Design Adjustments

There were many design aspects that had to be considered in adjusting the prototype based on the issues that arose during testing. The main areas of re-design that were focused on were movability, the lift mechanism, how to power the device, getting Silas onto the seat, and stability. Major design changes were required to make the device more functional for Silas' needs.

In order for Silas to use the device, it had to be able to be moved to the wheelchair, as opposed to the wheelchair being moved closer to it. This prompted the team to add wheels to the device. In addition, the wheels had to lock simultaneously through the pulling of a single lever. The solution that seemed to fit best with this concept was adding a rolling chassis to the device. This would prove to give the device a firm base while allowing the possibility of it already containing an adequate locking mechanism. Rolling chasses usually do not have a place to grab onto for movement, so handles were considered. The handles were placed on the sides of the chassis, in three different locations per side, to account for Silas sitting in different locations on the ground. The handles would act as both a means to pull the device closer to the wheelchair and for an adult to carry the device.

The type of mechanism used to lift Silas was also a target of change. The decision was made to switch to a powered scissor lift to improve the speed of the device and reduce user fatigue. The lift would be more than strong enough to lift Silas. Instead of using gears and a crank, the team thought attaching a motor to something akin to a car jack seemed to be a better fit. An electric motor powered by a battery seemed to be the most plausible power source due to its ease of use, rechargeable nature, and easy attachment to the lift. The exact motor would be chosen by measuring how much torque it takes to operate the lift with weight on it and choosing a motor strong enough to handle the torque.

Since Silas could not lift himself up a few inches to get onto the seat, an alternative way to get him on the seat was necessary. Due to the length of the rolling chassis, it seemed possible to add a ramp to the design without making the entire device longer as a result. This addition depended on Silas being able to scoot himself up a slope, but it still seemed more plausible than him using his upper body strength to push himself up off the ground.

Seeing Silas use the prototype, it was evident that the stability of the device had to be improved for both functionality and safety reasons. Instead of the base being built out of a few planks of wood, the rolling chassis would act as the base, being more stable due to its metal composition. Welding the scissor lift to the rolling chassis would provide much more stability when the lift operates compared to bolting the lift to the chassis.

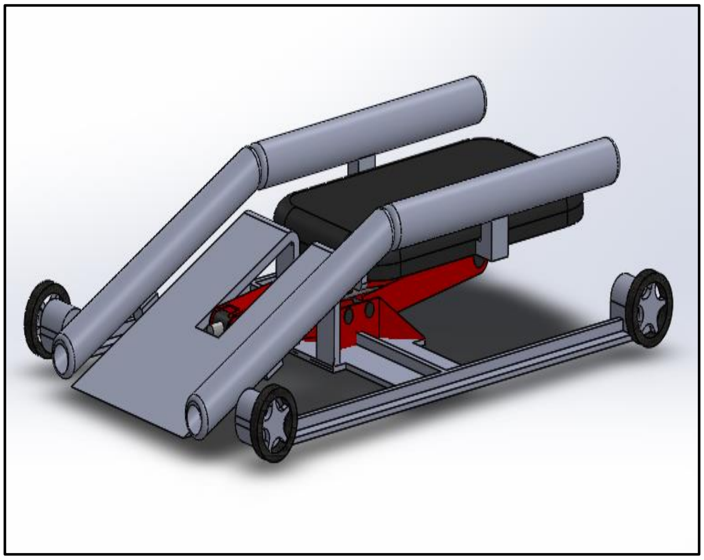


Figure 10: Idle view of new design

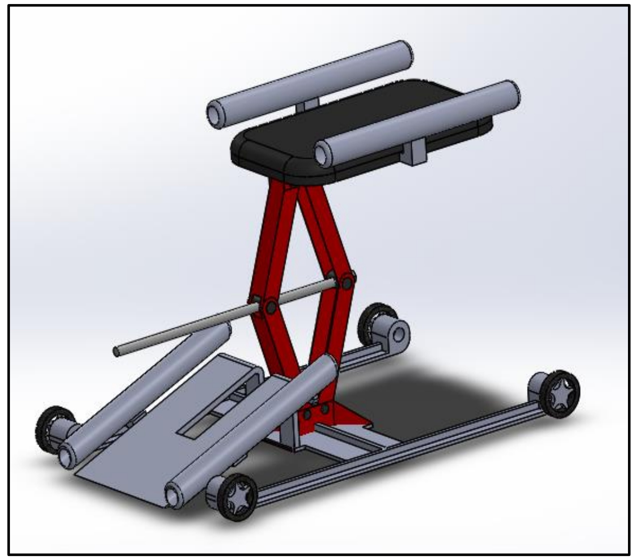


Figure 11: Action view of new design

In the end, the senior project team came up with a new design, shown in Figures 10 and 11. The design changes mentioned above are evident here, along with various other changes. A ramp was added to allow Silas access to the seat, along with handrails on both sides of the ramp and seat as support for Silas when sliding himself across the device. The motor, although not pictured above, would be attached to the end of the rod on the side opposite of the ramp, allowing it to move with the lift as the lift is changing height. Although the team felt that this design was vastly better than anything previously theorized, there were some additional design considerations that had to be added, mainly that of safety and ergonomic. Analyzing the design under these lenses would do nothing short of enhance the device the team wished to build.

In going through the process of redesign, the senior project team once again had to test some of Silas' physical capabilities as well as how he interacts with certain components of the updated design. Topics of testing included Silas' ability to walk backwards using parallel rails, move a furniture dolly to a designated position, and scoot backwards up a small ramp.

To decide between a few different design concepts for the final product, it was necessary to test Silas' ability to walk backwards using rails, as opposed to his walker tested earlier. PVC pipe of 1.5 inch diameter was used as rails to provide a smooth yet stable surface to grab onto and fit the sizing of his hand as well. Silas was helped to his feet and placed between the two pipes. When asked to try and walk backwards, he expressed disbelief in his abilities and concern for his safety, automatically eliminating the possibility of using the design concept.

The next test was to find out how well Silas could move a furniture dolly while he was sitting on the ground. The senior project team was considering using a similar object for the base of the final device, which would require Silas to move the device a few inches himself. While sitting on the ground, Silas was told to simply move the dolly to the front of his wheelchair so it would line up. Without any notable problem, Silas was able to accomplish this.

Also important for the new design was the incorporation of a ramp to accommodate for Silas not being able to scoot himself backwards onto a higher surface. To test this, the project team asked Silas to move up a wide piece of wood at approximately a 30° slope. Due to the angle, Silas was not successful in scooting backwards up the ramp. The team then placed the PVC pipes (mentioned earlier) along the sides of the ramp with the purpose of letting Silas being able to use them as a rail to help scoot backwards. The addition of rails turned out to be successful, as Silas was able to easily climb up the ramp when he was able to use accompanying rails.

Every way the senior project team tested the design concept was essential for understanding the limitations facing the device, which in turn paved the way towards finding the optimal functionality of the device. The basic measurements and observations made provided the necessary information to move forward with building the final product.

Safety as a Priority

Safety, above all else, was a priority in designing the final version of the device. When the functional and structural aspects of the final design were solidified, it was time to factor in safety. The team began by identifying potential hazards associated with using the device by completing a failure mode and effect analysis (FMEA) and then completing a tipping analysis to better understand the potential of the device to tip while in use.

The FMEA was simple and systematic in nature, and can be seen in Appendix A. The FMEA had the senior project team look at five different components of the device: the motor, brakes, lift mechanism, ramp, and seat. Each component was examined to understand its function, any ways it could potentially fail, the effects of that potential failure on the device as a whole, potential causes of the failure, frequency, severity, and difficulty in detecting it. The frequency, severity, and difficulty of detection were assigned a value from 1 to 10, with 10 being the highest value in each case. The three values were then multiplied together to make the risk priority number (RPN). The higher the RPN, the more of a priority the potential failure is in being addressed. Out of the five potential failures listed in the analysis, the seat not being stable enough for a successful transfer had the highest RPN of 800. The next highest was the user not being able to climb up the ramp with an RPN of 700. The team took note of this and put special attention on these two areas when moving forward in the design process.

To ensure the device would not tip over while Silas was using it, a tipping analysis had to be done. The analysis can be seen in Appendix B. To be on the safe side, the team placed 100 pounds of force at the very tip of the seat, knowing Silas does not even weigh half that and will never put all of his weight on the edge of the seat. The center of gravity was calculated and used as a reference point for the static analysis. Knowing the proposed weight and dimensions of the device, moments were used to calculate the normal forces being exerted on the wheels. Since neither was found to be 0N, the device should not tip. The same analysis was completed for the scenario of 100 pounds being exerted on the side of the seat, also resulting in the device not tipping.

Through further analyses, some additional design safety inputs were considered. These included the addition of handrails to reduce the chance of leaning too much to the left or right and falling over, putting protective coverings on the sharp edges and moving parts of the lift mechanism, placing markings on the device that make it clear when Silas should stop scooting backwards on the seat, and adding buttons on both sides of the seat, making it mandatory to press both for operation, to reduce the possibility of accidentally moving the seat while trying to scoot backwards.

Ergonomic Considerations

Instead of focusing on cognitive or organizational ergonomics, the scope of the project centered on solely physical ergonomics. Mainly, ergonomics were incorporated into the design by the team trying to optimize the user experience. This included taking into account the human-machine interaction taking place when Silas used the device.

Some of the design considerations that would improve the device ergonomically were determining an adequate slope of the ramp to reduce fatigue as much as possible, making the seat and ramp the correct size and material so that they are comfortable yet abrasive enough to make sliding easier, including handrails to the seat and ramp to provide appropriate grip, a braking system that locks all four wheels at the same time, and making the device easy enough for Silas to move on his own. It was important to assess Silas' physical capabilities to better understand the functional limitations of the device and figure out ways to overcome them through ergonomic design. These capabilities played a huge role in analyzing the device ergonomically.

Final Device

The final device was built with consideration of all the previously defined objectives and requirements. While the team now had an excellent layout of how they wanted to achieve these goals with their final product, they still needed to purchase or custom manufacture the intended components. Using the final CAD design discussed above as a blueprint for this task, they set out purchasing the critical components (i.e. the parts that would affect interfacing and ease-of-use with the most other components). The two components deemed most influential on the rest of the design were the rolling chassis and lifting mechanism.

The first item purchased was a Traxion 1-220 King Crawler Mechanic's Creeper with Lever-Lock Braking System. The team chose this particular crawler as a base due to its large and sturdy wheels, low-to-the-ground base, and it’s included single-lever braking system. In addition, its tube steel structure made for easy customization with welding.

The second item purchased was the lift. As discussed in the design changes, the team chose to use a standard scissor-style car jack, specifically a Torin Big Red Scissor Jack. This particular jack was chosen due to its well-reviewed ease of use and its ability to reach a height of 16 inches. When combined with the height of the King Crawler base and seat thickness, the device would be capable of exceeding the necessary 1.5 foot lift requirements to allow Silas to transfer into his wheelchair.

The padded surface from the King Crawler was removed to expose the basic rolling chassis. The Scissor Jack was then welded to this chassis, with steel stock added in key areas to prevent any deflection in this area. Then, a custom bracket was welded from steel to create a stable elongated surface for the seat to be attached to the top of the lift. In order to attach this bracket, the existing pins of the Scissor Jack had to be cut to permit disassembly. The team purchased custom steel dowel pins to replace them, which not only allowed for easy removal, but also achieved a tighter tolerance between the lift and its base, providing more stability.

Once the team was satisfied with the structure of the rolling chassis and lift, they recycled the material from the padded surface of the King Crawler to manufacture a padded seat and ramp. Wooden handrails were cut and attached via sturdy metal brackets to each. Lastly, the small circular rubber pads included with the King Crawler brake system were replaced by 6 x 1 inch rectangular rubber brake pads. This provided the proper surface area to prevent any movement in the device while the brakes were engaged.

Now that the device was finished mechanically, the team focused on the electronic, safety, and aesthetics of the device. A motor is planned to be added via a custom bracket welded to the main rear-pin of the lift, and the controls wired to their proper locations on the seat handrails so that Silas would have to be holding both rails at once in order to operate the device. This two-handed approach ensured his stability during lifting while simultaneously preventing his hands from entering any pinch-point on the device during operation.

Between all of the materials used to construct this device, the estimated cost of this device was calculated to be $264.70. This number will likely grow with additional design modifications. A detailed bill of materials can be seen in Appendix C.

All dangerously exposed surfaces are planned to be covered with accordion-style siding, which would further prevent any accidental pinching in the mechanism when in use. The screw, which would expand outward through the ramp when the lift was in use, will be covered with a hollow telescoping tube. Finally, the device was painted for a fun and clean look. It can be seen in Figure 12. With the final device nearly finished, the team began to perform tests and analyses.

Figure 12: Final Device

Methods

After coming up with a mechanically complete final device, the senior project team tested its functionality by having Silas try to complete a full cycle of using the device. Since the motor had not been purchased yet, the team used an electric drill to move the seat up and down. The team felt this provided a means for Silas to complete a full testing of the device, just without Silas pressing the buttons to move the seat up.

The first process the group observed was how Silas was able to maneuver the device. The device was light enough for Silas to maneuver, however the team noted that a handle would need to be attached for Silas to more smoothly move it. This would prevent Silas from getting his hands caught or pinched in areas he should not be placing his hands.

Next, Silas was instructed to apply the brakes by rotating the handle. Silas was able to apply the necessary rotational strength and engage the brakes when he was sitting in a proper position. If Silas was sitting too far from the device he would struggle. However upon moving closer, Silas found operating the braking mechanism to be an easy task to complete.

Following the brake application, Silas scooted up the ramp. At first, Silas experienced difficulty lifting himself off of the ground onto the ramp, but Silas overcame this obstacle with instructions to use the ground to push himself up and backwards onto the ramp. The designated handrails assisted Silas, giving him the proper grip to exert enough force to move himself up the ramp. The team thought that a more abrasive material would provide Silas better traction as he moved up the ramp.

Once Silas had scooted himself up the ramp, his next transition was moving from the ramp onto the seat of the device. With handrails cut at an angle to meet the horizontal handrails of the seat, Silas had no difficulty transferring from the ramp onto the seat. One major concern the group had was the stability of the seat, as to whether it would sway or not with Silas' weight on it. With the testing done, our group found that the seat's stability concerns were negligible, and the safety of Silas is undeterred. The groups addition of welded bar stock onto the base of the jack provided the required support to neglect any sort of deflection. Furthermore, the seat width gave Silas the proper comfort and safety to not have a lot of room to wiggle around, while also not confining him to an extremely compact space.

Finally, Silas tested his ability to transfer from the device onto his wheelchair. After Silas successfully reached wheelchair height, he was able to use the handrails to scoot himself onto his wheelchair, fasten his seatbelt, unlock the brakes, and roll backwards, completing the entire cycle. Silas proved that he is capable of using the device independently, giving the senior project group assurance that the design of the device is acceptable.

Results

The senior project group found that Silas was able to use the device independently to get from the ground into his wheelchair. Therefore, the device acts as a solution to the original problem that the team set out to address. Success of functionality came as the expected result based on the testing and various re-designs of the design concept, but Silas still seemed to struggle in a few areas. For instance, Silas seemed to be confused on where to grab onto the device when moving it to his wheelchair. This and other struggles were noted and quickly addressed so that Silas could eventually re-test to ensure that the device will best fit his needs.

Even though the testing did run smoothly, it should be noted that some of the testing conditions were not necessarily consistent with the environment that the device will most likely be used in. For example, the test took place outside on concrete flooring. Ideally, the device would be used inside on wood or tile flooring. Therefore, the brakes might operate differently based on the concrete floor and outside temperature than inside where those conditions are different. Even with these potential inconsistencies, the team felt that the results were accurate enough to extrapolate from, and not difficult to interpret.

It is important to note the need for additional modifications to the device in order for it to function normally. The plan is to attach a motor with buttons to the device so that Silas can truly operate it on his own, attach handles to the rolling chassis so Silas can easily and safely move the device, and attach safety coverings along the moving parts of the lift to lessen the chances of injury by either Silas or someone in very close proximity of the mechanism. These modifications should be completed before the end of the academic quarter, just in time to deliver the completed final product to Silas before the senior project team leaves for the summer.

Looking toward the future, Silas should be able to use this device independently and safely. The most critical issue that will arise during use will be the size of the device itself. The device is rather large and could pose issues of maneuverability in a confined space, such as a bedroom. Future senior projects at Cal Poly have the opportunity to take the current design and make it more compact and lightweight.

Conclusion

The goal of this senior project was to design and manufacture a device that would allow Silas to independently and safely transfer from the ground up to his wheelchair seat. This was completed by defining the problem, coming up with solutions to the problem, testing those solutions through prototyping, and building a final device. The results showed the senior project team how important it was to have safety as a prioritization in order for Silas to feel comfortable using the device on his own. Making a device for children of such a young age requires the device to ensure safety, as the slightest discomfort could cause the child to refuse participating in any interaction with the device. By the end of the project, all of the project objectives were completed with the exception of a few details of the final device. As mentioned earlier, plans exist to finish these details before the end of the academic quarter.

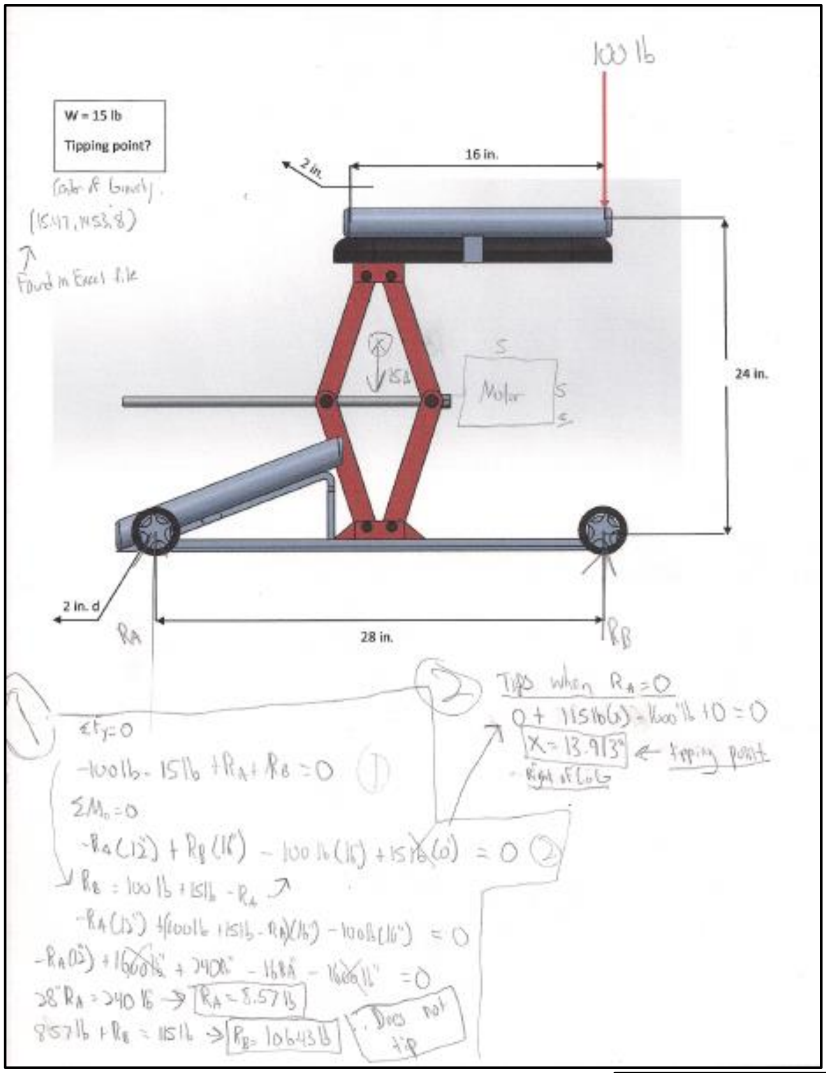
The potential social impact this project had was raising awareness for people with similar disabilities as Silas and exposing ways others can positively approach helping those with the common tasks in their lives. Through exposure to the device, others felt a connection to this senior project and its success. For instance, the volunteers and staff at the pre-school Silas attends, as well as Silas' physical therapist, were drawn to the completion of this project and the implications it would have on the Hopper family.

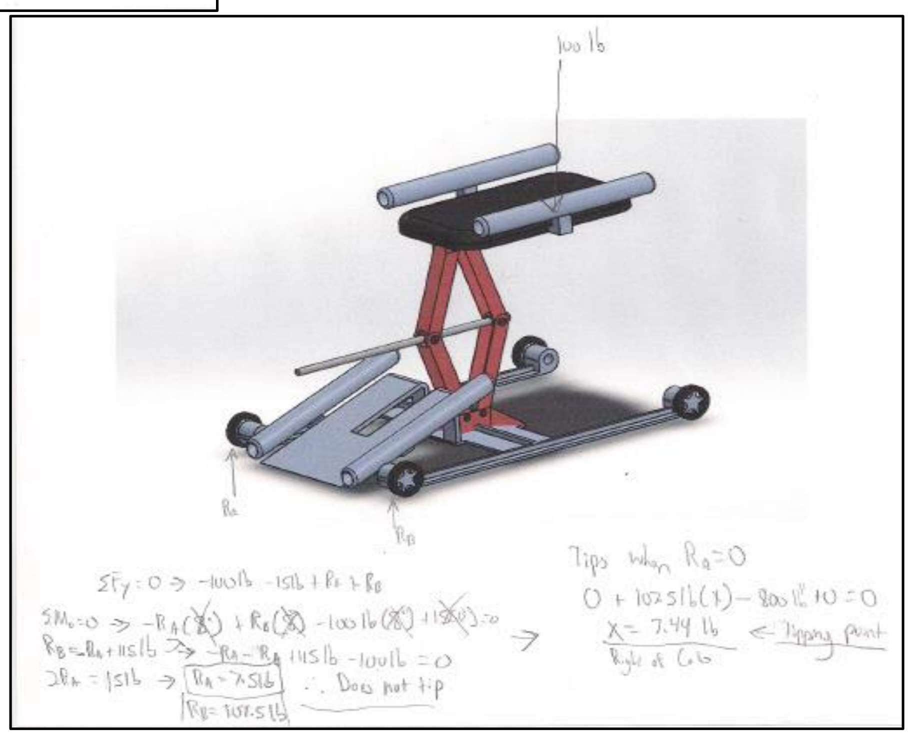
Overall, the group found that the end product was a device that was fully functional, easy to use, safe, and something that Silas would actually use. Throughout the year, this project has taught the group how to work together as a team to reach a common goal and overcome the major setbacks that inevitably occur along the way. Countless problems arose to the point where completing the project seemed impossible. However, with the dedication and hard work of every team member, all obstacles were able to be conquered resulting in a completed device on time, on budget, and of the highest quality.

Appendix A

Item Identification	Function	Potential Failure Mode	Potential Failure Effect	Potential Causes	Failure Detection Method	Frequency of Occurrence	Severity	Difficulty of Detection	Risk Priority Number	Action Recommended
Motor	Operates lift mechanism	Fails to turn on	Motor cannot operate lift mechanism	Uncharged battery	Motor not running	3	8	10	240	Charge battery after few uses or always leave plugged in
Brakes	Keeps device from rolling	Brakes switch off during use of device	Device moves further away from wheelchair	Brakes not properly secured	Brakes switch off	3	6	10	180	Try moving device after brakes are in place to test stability
Lift Mechanism	Lifts seat	Sharpness/moving parts cause injury to user or persons nearby	Injury and panic	Being in close proximity to lift mechanism	Visible injury	4	10	10	400	Cover area around mechanism with safety coverings
Ramp	Acts as path to the seat	User is unable to successfully climb ramp	User cannot climb onto seat	Material too smooth, lack of area to use as hand grip	User struggles to climb up ramp	10	7	10	700	Cover ramp with more adhesive material, add handrails for grip
Seat	Acts as path to the wheelchair	Seat is not stable enough for successful transfer	User is unable to successfully transfer into wheelchair	Weak material, unstable mounting fixture, lack of area to use as hand grip	Visible instability of the seat while in use	10	8	10	800	Make seat out of sturdy material, use stable mounting fixture, add handrails for grip

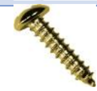
Appendix B


100 lb
W = 15 lb
Tipping point?
16 in.
2 in.
24 in.
Motor
2 in. d
28 in.
Tips when $R_A = 0$
Does not tip


100 lb
Tips when $R_A = 0$
Does not tip
Tipping point
Right of CoG

Appendix C

Name :	SiLift
Part Count :	97
Total Cost :	$264.70

Part Name	Description	Qty	Units	Picture	Unit Cost	Cost
Creeper		1	each		$ 116.00	$ 116.00
High Speed Steel Dowel Pins		2	each		$ 18.00	$ 36.00
Scissors Lift	Lifting device.	1	each		$ 30.00	$ 30.00
Rectanglular Brackets	Used for ramp.	16	each		$ 1.25	$ 20.00
Wood Dowels	Used for railings.	2	each		$ 10.00	$ 20.00
Braces	Holds ramp onto creeper.	4	each		$ 2.50	$ 10.00
Brake Pads		1	each		$ 10.00	$ 10.00
Upholstery Covering Material	Placed on seat, and ramp.	1	roll		$ 6.50	$ 6.50
L- Brackets	Used for ramp.	2	ea		$ 2.50	$ 5.00
Screws	Assemble seat to wooden dowels.	34	pack		0	$ 3.00
Adhesive	Added in between wood and brake pads.	1	each		$ 3.00	$ 3.00
Bolts		12			$ 0.20	$ 2.40
Nuts		12			$ 0.15	$ 1.80
Washers		5	pack		$ 1.00	$ 1.00
Seat	Wood was taken from creeper	1	each		$ -	$ -
Ramp	Wood was taken from creeper.	1	each		$ -	$ -
Wood Strips	Wood was taken from creeper.	1	each		$ -	$ -
Total		**97**				**$264.70**

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