Vehicular Mobility Device Lift

Senior Design Proposal submitted to the
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by

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Problem Statement
This project has been put forth to design a mobility device lift for Maple Knoll Village and to build a prototype, to be delivered by the end of Spring Semester 2020. While this project was begun by the team of Clark, Minkoff, and Zito the scope has been refocused in order to make a lift that is more universal both in terms of installation and lifting capability.

Research
Background of the Problem
Over a sixteen-year period the median age of the United States population increased to 37.9 years old in 2016 from 35.3 years old in 2000 according to the US Census Bureau (3). As a larger portion of the population achieves advanced age more people will require assistance for their daily activities and fewer persons will be available to provide it. Therefore, more devices for assisting those of advanced age will be needed in order to allow them to live independently for as long as possible.

The residents of Maple Knoll Village, as the primary customers for this project, have expressed interest in a device for their vehicles to help them load and unload their mobility devices. As it stands, many of the residents can drive, still like to travel, and can handle lifting folded walkers and, with difficulty, folding wheelchairs; however, they cannot lift and maneuver their heavier mobility devices into the trunks of their vehicles even when lighter components are removed and loaded separately. This problem will only worsen as the residents age and suffer from greater and greater loss of mobility leading to a need for heavier mobility devices as their ability to load them decreases.

A device to allow a mobility device to be loaded and unloaded from a sedan trunk would greatly assist those of advanced age with limited lifting capacity and those who take care of them. The main issues of such a device that will be addressed will be divided into two main sections: the lifting mechanism, consisting of the power supply, controls, and lifting method itself; and the attachment points, both from the lift to the vehicle and from the lift to the mobility device.

State of the Art
The State of the Art and several other sections in this report will be divided based upon the specific section of the lift being discussed.

Bruno Back Saver

Lifting Mechanism
This simple device offers storage of folding wheelchairs on the outside of the vehicle. It uses a linear actuator to directly lift the folded wheelchair into the stored position and is powered by the electrical outlet used for trailers. The whole system is activated with a single rocker switch and requires a key to operate (4). Similar devices also exist that can lift light mobility scooter with a single flat platform as opposed to the platform and wireframe of the Back Saver. This device is practical, but it can only be installed on vehicles that have a Class I, II, or III Ball-style or Square

Hitch and the necessary wiring to connect trailer hookups. This limits the vehicles to which it can be attached and blocks the license plate requiring the plate (in some states) to be moved to a holder above the lift blocking the driver's rear view. It also leaves the mobility device exposed to the elements which can leave it dirty and wet and damage mechanical and electrical components.

Container and Storage Attachment Mechanism

As it can be seen from the Bruno Back Saver (picture below) the storage is external and for a foldable, manual wheelchair. The wheelchair is attached to the carrier device by a rack and several clips via a raisable platform the wheelchair rests on. This device has a light weight capacity and is only able to lift the easiest/lightest wheelchairs or scooters. Albeit simple and easy to use, it isn't very useful due to the light capacity. The limitations of the device also deduct from the experience as it can only be installed on very specific hitches. Finally, the mobility device is left exposed to the elements and its parts might be damaged during storage/operation due to dirt and water getting into the mechanical/electrical components.

Figure: Bruno Back Saver (4)

BraunAbility Chair-Topper Wheelchair Lift and Carrier

Lifting Mechanism

This device is mounted on top of the vehicle and is actuated by the driver of the car from a single rocker switch remote in the cabin. It uses an electrical linear actuator to open the weather tight shell as the hinged base opens, most likely along a cam track. A folded bar is then lowered on two chains. This bar is then placed so that it holds the seat of the wheelchair and then lifts the wheelchair up so that it then rests on the lower half of the base. The wheelchair is then leaned over and the shell is resealed as the wheelchair is closed within (5). This is a very clever device as it allows the trunk of the car to remain open and the rear window clear of obstruction. However, installation is difficult as it must be lifted onto the roof and electrically wired to the car by trained personnel. It also is limited to lifting folding wheelchairs of 44lb or less.

Container and Storage Attachment Mechanism
The system uses a hook-like grapple to attach to the mobility device and lifts it into an enclosed storage space located on the roof of the vehicle; taking advantage of the external storage space and yet keeping the contents safe from the elements (such as dirt and water). The device is then stored in a weathertight container, keeping everything safe from harm while minimizing the space occupied in the trunk. This also allows the occupant to sit comfortably in the driver's seat during operation, which allows comfortable and convenient usage.

Figure: BraunAbility Chair-Topper Wheelchair Lift and Carrier (5)

Clark-Minkoff-Zito Device

Lifting Mechanism
The device designed by the previous year of mechanical engineering students has many good design choices for use in the limited space of a sedan. First, it has a simplified lifting mechanism that relies only on a single linear actuator powered by the 12V auxiliary power outlet (6). However, the track on which the carrier rides is solid and therefore cannot be folded into the

trunk of a sedan meaning the truck cover cannot be closed. The rack to which the wheelchair is attached is also too bulky and the overall length of the system is too long to fit within the trunk of a sedan.

Container and Storage Attachment Mechanism

As already mentioned, this system was designed by previous mechanical engineering students. The system uses a lift, similarly to the Bruno Back Saver, in the sense that it uses a platform and rack with clips/hooks to attach to the mobility device. There looks to be a closeable door, to secure the device from the elements. The internal storage is located inside of the trunk so unfortunately a lot of the space in a trunk is taken up by this system, which is not very convenient to the consumer. It also looks to be too large to fit within the space of a midsize sedan's trunk, leaving this non-usable to those in need.

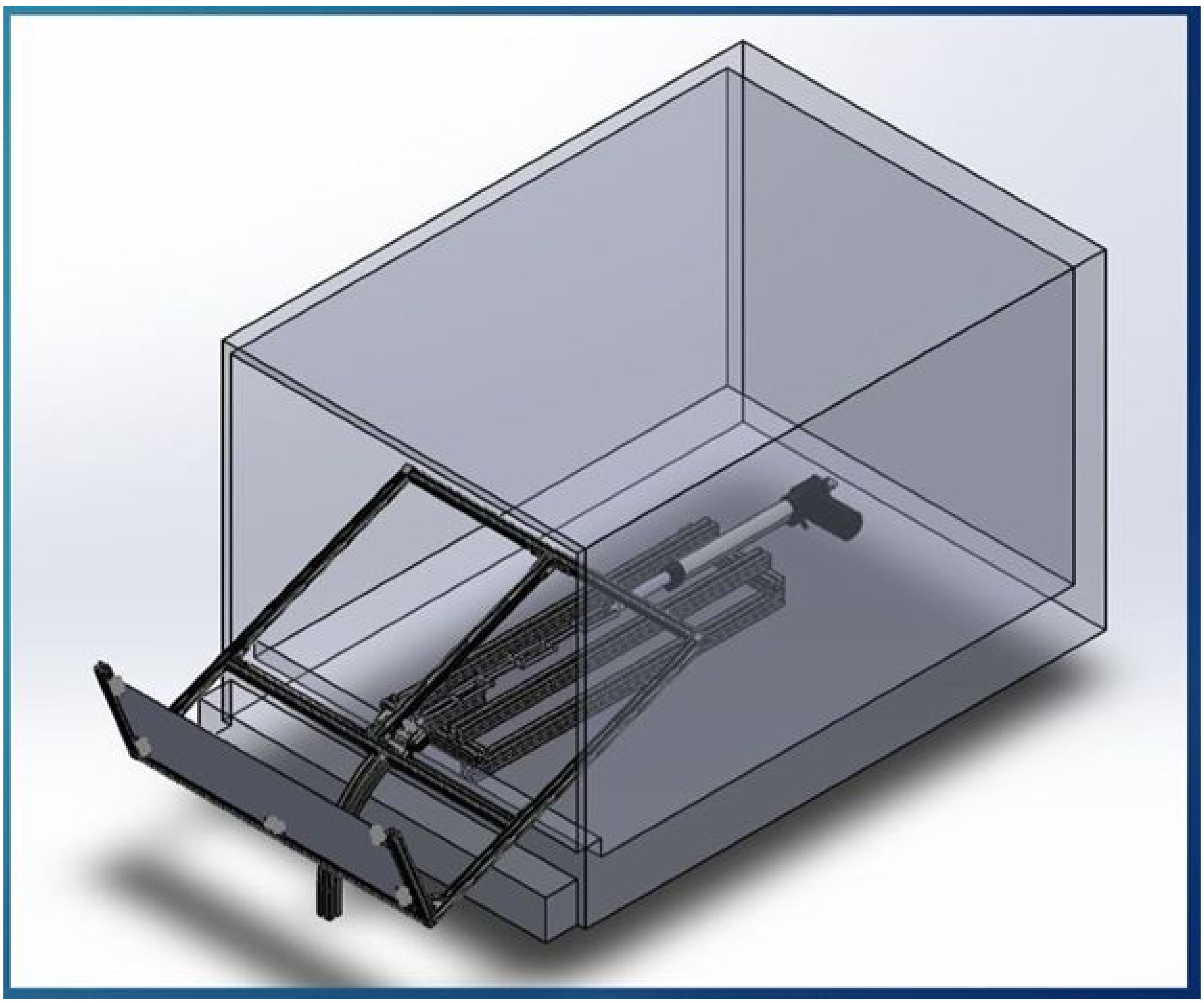


Figure: Clark-Minkoff-Zito Device (6)

Attachment Points
The points of attachment are seen in the pictures within the State of the Art section to be loosely roped or tied together. There is little mention of where or how. In the student report (previous students' project) there is no indication of where this piece attaches to the vehicle; however, it can be seen that the mobility device is attached to the lift via clips and a platform. I plan to reuse this portion of the attachment in the case that money needs to be saved to stay within budget.

End User
The end user of our device will be the residents of Maple Knoll Village and any staff that may be needed in order to set up the designed lift. The residents, from their surveys and interviews, would like to have a device that is able to lift, at most, a powered wheelchair. While the staff may be able to set up the lift, the lift will need to be able to be operated without or with minimal effort by the resident users. It is also necessary that the lift be simple to move from car to car as required by the residents. The end goal is to have a system that is universal (can be moved from vehicle to vehicle after installation), minimalistic (not bulky and occupied a small amount of space), and supplies those in need of our product with more independence (elderly consumers no longer need to rely on someone else when they want to drive).

Summary of Research
While the commercial products benefit from very efficient uses of space they still off some major drawbacks. The Back Saver can lift up to 100lbs it also leaves the device exposed to the elements. The Chair-Topper does protect the device from the elements but can only lift up to 44lbs and can only accommodate folding manual or specially designed folding power wheelchairs of a particular configuration. The Clark-Minkoff-Zito Device offers the potential of expanding its capabilities to a greater variety of mobility devices, but it currently only accommodates folding wheelchairs and possibly walkers.

The device should also be light and easy to set up if it is to be swapped from vehicle to vehicle. This will require the power to be drawn from the 12V Auxiliary power outlet (cigarette lighter) with a cable capable of reaching the trunk from the front console. It also must be able to lift at least the weight of a mobility scooter, approximately 100lbs. Finally, in order to fulfill its purpose as an aid to those who cannot lift a wheelchair it must be able to lift a mobility device from the ground.

Quality Function Deployment

Customer Features
A survey was administered to the residents of Maple Knoll Village to determine the importance of several factors of mobility device lift design. Unfortunately, some of those surveyed did not fill out their surveys. In these cases, we did not add their responses when averaging their responses. We also investigated what types of mobility devices and vehicles used by the residents and the weight of their mobility devices. We found most residents use power wheelchairs walkers to get around and most drive or ride in sedans when they travel, see

Appendix. We also received their input outside of the survey. They told us they did not need a device to lift wheelchairs specifically but instead needed a device that could lift up to the weight of a power wheelchair due to the extensive use of power wheelchairs and mobility scooters among residents.

Features Desired	Response 1	Response 2	Response 3	Response 4	Response 5	Response 6	Average
Initial Investment Cost	2	1			3	2	2
Weightlifting Capability	3	4	5		2	5	3.8
Overall Weight of Lift	3	4			2	3	3
Overall Size of Lift	5	4	4		2	3	3.6
Ease of Set-Up	5	4			5	5	4.75
Ease of Use	5	5			5	5	5
Quietness of Use	1	3	3		1	1	1.8
Time to Load/Unload	3	5	3		4	5	4
Trunk Space Used	4	0	3		4	5	3.2

Figure: The Customers Features and Weighted Importance

Engineering Characteristics

By the House of Quality found below the product objectives were found. They are, in order of importance: type of motor, lifting mechanism, motor lifting capacity, power supply, lift volume, price of materials, controller shape, and controller weight. As can be seen from this it will be most important to address the motor and its capabilities and the amount of power drawn during operation. The lifting mechanism final form and size of the lift overall will be influenced the most by the previous objectives. Next, the cost of materials will be determined, this will probably affect the choice motor and lifting mechanism the most. Finally, the controller must be considered which will be the most flexible part to design or purchase due to its low overall importance.

House of Quality

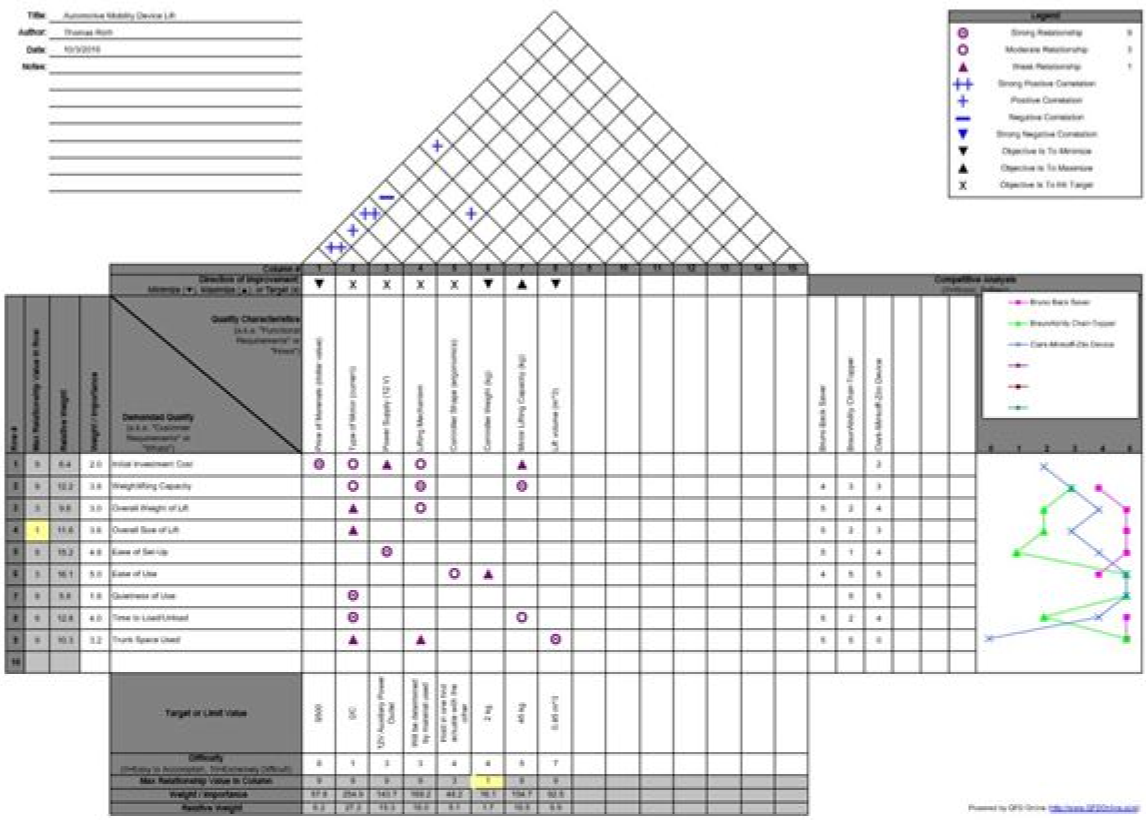


Figure: House of Quality (8)

Product Objectives

I will be addressing these customer features through the engineering characteristics of the power and lifting systems. This includes: the price of materials, type of motor, power supply, lifting mechanism, controller shape, controller weight, motor lifting capacity, and Overall Volume. These characteristics can be attributed to the characteristics of the motor, the controller, the power supply, and the final form of the lifting mechanism. In order to determine which engineering characteristics are the most important to address they must be compared against the Customer features in the House of Quality.

The product objectives along with their relative weights found through the use of the house of quality are as follows:

1. Ease of Use – 16.2
2. Ease of Set-Up – 15.2

3. Time to Load/Unload – 12.8
4. Weightlifting Capacity – 12.2
5. Overall Size of Lift – 11.6
6. Trunk Space Used – 10.3
7. Overall Weight of Lift – 9.6
8. Initial Investment Cost – 6.4
9. Quietness of Use – 5.8

Design

Lifting Mechanism

Concept Drawings

The chosen design alternative takes the motors and ropes/wires design to the furthest extent possible to minimize operating complexity, electronics complexity, design complexity, weight, and cost as much as possible. This alternative will use twin gear motors to operate two separate shafts with individual spools for a series of ropes that pass through their own individual series of pulleys. The ropes will pass over the frame and deflect off the first pulley. The rope will then pass through two adjacent pulleys. One of the two pulleys will handle the ropes while the attachment frame is inside the trunk and the other when the frame is outside the trunk. When in the trunk the attachment frame will ride on a series of tracks to lift it to a position to exit the trunk and lower it to a proper position for storage. A stand-in ramp will be used to protect the sedan’s bumper and trunk during loading and unloading and will provide a means for the mobility device to reach ground level safely. This alternative will require the operator to reverse the direction of motors’ travel mid operation and briefly guide the attachment frame into and out of the vehicle but will require no other intervention.

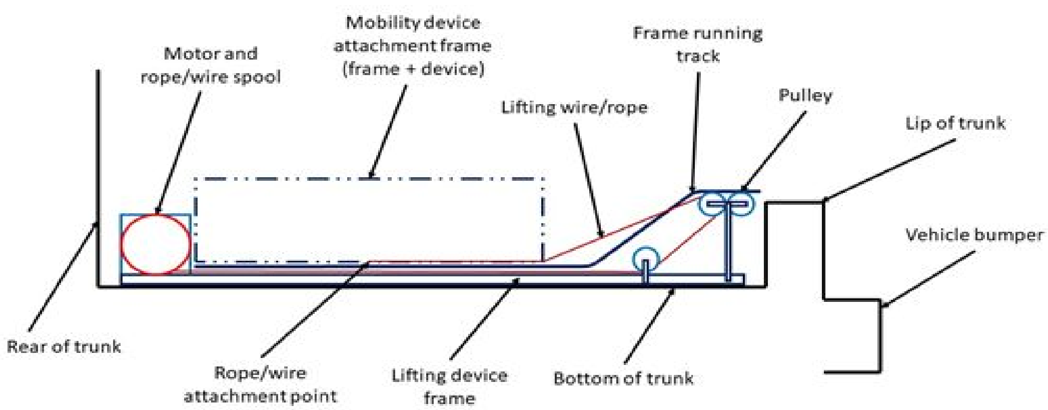


Figure: Lifting Device utilizing a single motor, several ropes/wires, and a series of pulley systems (9)

The trunks I will be designing the lift around will be the 2010 Ford Fusion and the 2012 Ford Focus. These are full-size and mid-size sedans respectively which will mean the design will be more flexible to fit into a greater variety of vehicles. The major dimensions of the two trunks are in the chart below.

Dimention	2010 Ford Fusion	2012 Ford Focus	Target
Lip Height	8"	7"	8"
Overall Depth	42"	39"	39"
Overall Narrow Width	45"	40"	40"
Overall Height	21"	20.5"	20.5"
Opening Width	31"	32"	31"
Opening Height	14"	14.5"	14"
Opening Depth	12"	10"	10"
Opening Diagonal	20"	15"	15"

Table: Trunk Dimensions of Two Sedans (1)

While the two trunks have comparable dimensions, the lift should be designed to work within the most limited dimensions. For these, only the lip height needs to have the maximum value considered. The lip height will determine the height of the rails that is needed to allow the mobility device to exit the trunk and the height of the supports for the pulleys. By these dimensions the lifting device will be limited to 36” deep and 32” wide.

The final design looks as shown below. The particulars of the design will be discussed but the evolution of the design from concept to final embodyment can be easily seen. The slides and three pulley arrangement are still present but the motor placements, number of lines, and shape of the slides have changed throughout the design

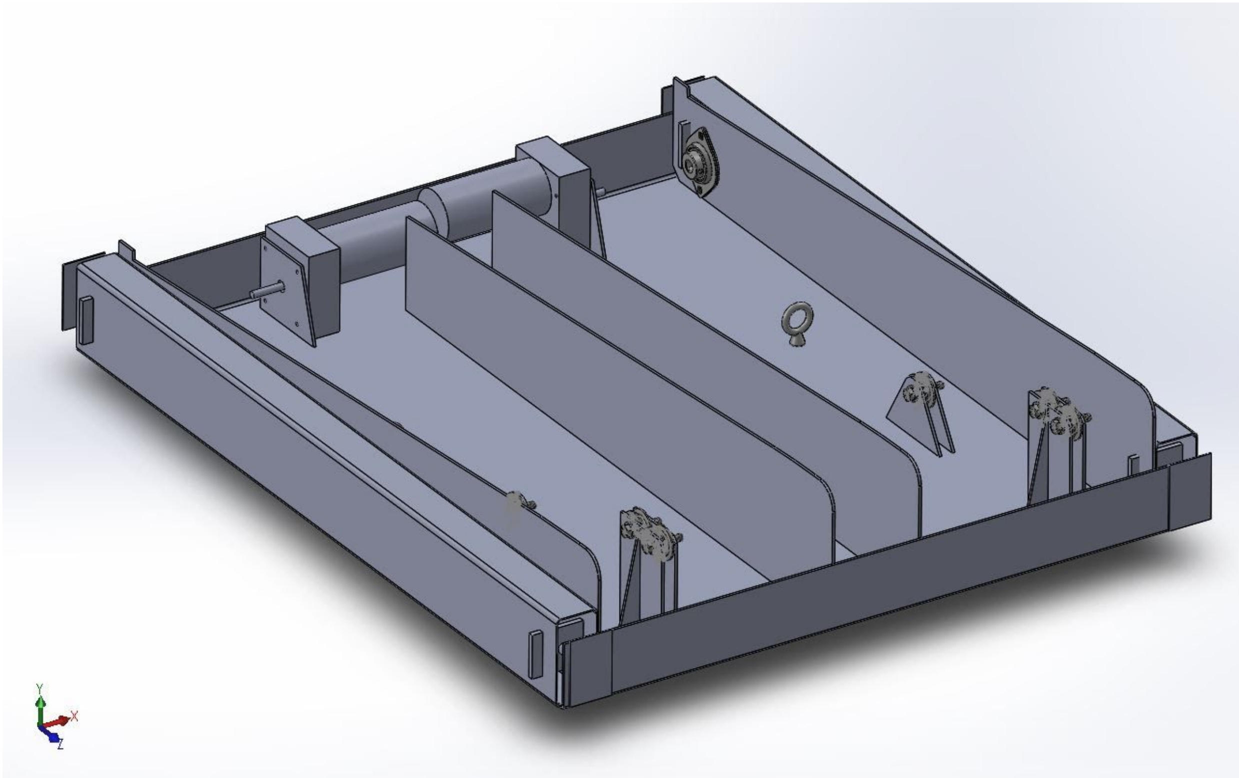


Figure: A Picture of the Final Lifting Mechanism

Loading Conditions

The lifting mechanism was designed around lifting a maximum 50lb mobility device. While a 100lb weight goal was given in the conclusion of the research, it was determined that the weight limit would need to be reduced due to budget constraints, mainly due to motor pricing. This means that we will only be functionally designing a proof-of-concept build rather than a fully capable prototype. We must also consider the weight of the fame used to attach the device. We used 25lb as a stand in for this value to ensure there is enough capacity to lift the designed attachment. This will give us a weight of 75lb to lift, with a design factor of 2 we get a 150lb weight maximum that the lift must be able to handle.

The shaft that will be used to connect the motors to the spools will be under both twisting and bending moments as the ropes used to connect the mobility device attachment to the drums will be offset from the center of the shaft. This means the shaft will need to be strong enough to be able to handle both types of stress.

The slides, used to support the mobility device attachment will provide the space and structure necessary for mounting the motor, bearings, pulleys and other components of the lifting mechanism as well as spacing the mobility device attachment at a height high enough to slide into and out of the trunk. For analysis, the slides were treated as though they were very long, thin columns with a height equal to the maximum height of the slides. By analyzing the slides at their most intense loading it should ensure that the slides will be able to cope with forces while under less strenuous loading conditions.

Design Analysis

The torque on the shaft was calculated by finding the total load, with design factor, assuming a radius for the drums around which the lifting ropes will be wound, and then calculating the torque generated.

$$\mathrm{W_{max}} = \left(\mathrm{W_{mobility\ device}} + \mathrm{W_{container,assumed}}\right) * \mathrm{DF} = (50\mathrm{lb} + 25\mathrm{lb}) * 2 = 150\mathrm{lb}$$

$$\tau_{\mathrm{input}} = \mathrm{W_{max}} * \mathrm{d_{radius,drum,assumed}} = 150\mathrm{lb} * 0.75\mathrm{in} = 112.5\ \mathrm{in.lb}$$

From the 112.5 in-lb torque a motor could be chosen to supply the necessary torque to lift the maximum weight. The nearest 12VDC motor that could supply near the necessary torque was the IronHorse 12V DC Parallel Shaft Gearmotor with 50 in-lb maximum torque, 1/16 horsepower input, 5/16” shaft diameter, and 386:1 gear ratio giving 7.9 rpm max speed. Two of these motors needed to be used bringing the total system torque up to 100in-lb. Being that this was below the maximum torque required, the maximum weight of the mobility device had to be lowered.

$$\mathrm{W_{max}} = \frac{\tau_{\mathrm{input}}}{\mathrm{d_{radius,drum,assumed}}} = \frac{100 in.lb}{0.75\mathrm{in}} = 133.3\ \mathrm{lb}$$

$$\mathrm{W_{mobility\ device}} = \frac{\mathrm{W_{max}}}{\mathrm{DF}} - \mathrm{W_{container,assumed}} = \frac{133.3 lb}{2} - 25\mathrm{lb} = 41.65\mathrm{lb} \approx 41\mathrm{lb}$$

With this lowered maximum mobility device weight of 41lb it was decided that to test the proof of concept a mobility device with a weight of or below 41;bs would need to be selected. The device chosen was the Minimus Folding Mobility Scooter by CareCo, which weighs approximately 39lb. Because the Minimus Scooter is sold by a company in the UK, costs over £1,000, and is not a model owned by any MKV residents it was decided that a mock up would be made to simulate the device. This mockup would be made of hard, pink insulation foam for safety and ease of production and weighted to approximately 40lbs.

Figure: Minimus Folding Mobility Scooter, Unfolded and Semi-folded Configurations (8)

The shaft load and proper material will be chosen by the maximum stress theory of failure. From the shaft diameter of 3/4" and a known design position of the drums, the loading on the shaft can be determined and an appropriate material chosen. For the analysis we only looked at one shaft since each motor and shaft are isolated from each other mechanically. As such, we could assume the weight on a single shaft will only be as much as half the maximum weight or 66.65lb.

Each individual shaft is designed to be 6.19" long, as present in the CAD model. Each shaft is designed such that the length of shaft between the inside face of the motor mounting plate (point A) and the center of the drum (point B) is 2.75", and between the center of the drum and the inner face of the slide mounting the bearing (point C) is 3.44". Reaction forces and moments will need to be calculated at each end shaft.

$$\tau_F = 66.65\text{in.lb}$$

$$\tau_F = F_1R_1 = F_2R_2 \ \rightarrow \tau_F = 2FR \rightarrow F = \frac{\tau_F}{2R} = \frac{66.65\text{in.lb}}{2 * 0.75\text{in}} = 44.43\text{lb}$$

$$R_A = \frac{Pb^2}{L^3}(3a+b) = \frac{44.43(3.44)^2}{6.19^3}(3 * 2.75 + 3.44) = 25.91lb$$

$$R_C = \frac{Pa^2}{L^3}(3b+a) = \frac{44.43(2.75)^2}{6.19^3}(3 * 3.44 + 2.75) = 18.51lb$$

$$M_A = -\frac{Pab^2}{L^2} = -\frac{44.43 * 2.75 * 3.44^2}{6.19^2} = -37.74inlb$$

$$M_B = \frac{2Pa^2b^2}{L^3} = \frac{2 * 44.43 * 2.75^2 * 3.44^2}{6.19^3} = 33.53inlb$$

$$M_C = -\frac{Pa^2b}{L^2} = -\frac{44.43 * 2.75^2 * 3.44}{6.19^2} = -30.17inlb$$

Using the Maximum Shear Stress Theory of Failure, the maximum shearing stress on the shaft can be determined for the given diameter and material can then be chosen.

$$T_e = \sqrt{M^2 + T^2} = \sqrt{-37.74^2 + 44.43^2} = 58.3inlb$$

$$Z_p = \frac{\pi}{16}\frac{D_o^4 - D_i^4}{D_o} = \frac{\pi}{16}\frac{0.5^4 - 0.26^4}{0.5} = 0.02275$$

$$K_t = 3.5, from\ possible\ machine\ features$$

$$\tau_{max} = \frac{T_eK_t}{Z_p} = \frac{58.3 * 3.5}{0.02275} = 8{,}969.23inlb$$

$$S_y = 2N\tau_{max} = 2 * 4 * 8{,}969.23 = 71.75ksi$$

The shaft chosen is ASTM A500 Low-carbon steel hollow structural tube with a yield strength of 75ksi. This will be more than strong enough to lift the mobility devices. The bearings have also been chosen based upon static loading as the shaft can only be rotated at a maximum of 7.9 rpm, this being slow enough to assume only static loading for specification purposes.

While the force on the four individual slides is 37.5lb from the overall desired maximum 150lb load a safety factor of 8 will be used such that 300lb will be targeted for the design. This will ensure that the material is strong enough to support the mobility device and serve as a mounting point for the other components of the lifting mechanism such as the motors, bearings, and pulleys. After analysis of several thicknesses of material of 0.125" thickness was chosen. The calculations determining that this is the right thickness of material is as follow

$$t = 0.125in$$

$$h = 1in$$

$$r_y = 0.289t = 0.289 * 0.125 = 0.036125in$$

$$r_x = 0.289h = 0.289 * 1 = 0.289in$$

$$SR = \frac{KL}{r_{min}} = \frac{2 * 6.25}{0.036125} = 346.021$$

$$Using\ ASTM\ A36\ sheet\ Steel: E = 29e^6 psi, S_y = 36.3e^3 psi$$

$$C_c = \sqrt{\frac{2\pi^2 E}{S_y}} = \sqrt{\frac{2\pi^2 * 29e^6}{36.3e^3}} = 125.58$$

$$346.021 \gg 125.58\ so\ SR \gg C_c\ so\ the\ column\ is\ long$$

$$A = ht = 1 * 0.125 = 0.125in^2$$

$$P_{cr} = \frac{\pi^2 EA}{SR^2} = \frac{\pi^2 * 29e^6 * 0.125}{346.021^2} = 298.82lb$$

$$N = \frac{P_{cr}}{P_a} = \frac{298.82}{37.5} = 7.97 \approx 8$$

Since the safety factor is approximately 8, ASTM A36 sheet steel at 0.125" thick is a suitable material.

The electrical systems were designed around the requirements of the IronHorse motors. With required power of 12VDC and a full load amperage of 1.39A for each motor it was decided that the motors would be arranged in parallel to create a 12VDC system. The first part of the analysis required that we calculate the resistance posed by the individual motors and then the equivalent resistance of the two motors in parallel.

$$V = I * R \rightarrow R = \frac{V}{I} = \frac{12V}{1.39A} = 8.63\Omega$$

$$R_{eq} = \left(\frac{1}{R_1} + \frac{1}{R_2}\right)^{-1} = \left(\frac{1}{8.63\Omega} + \frac{1}{8.63\Omega}\right)^{-1} = 4.315\Omega$$

Here we can see that the equivalent resistance of the two motors in parallel is 4.315Ω. From this equivalent resistance the current draw by the parallel motors can be calculated

$$I = \frac{V}{R} = \frac{12V}{4.315\Omega} = 2.78A$$

Here the combined current draw of the motors can be seen to be 2.78A. From the equivalent resistance and the total current draw that the controller needs to handle could be calculated as such.

$$P = I^2R = 2.78^2 * 4.315 = 33.34W$$

So, whatever controller is chosen would need to be sized to handle up to 34W and a current as high as 3A but should also have a considerable margin of safety. These calculations also prove the parallel arrangement of the motors is amenable. It will allow the power supply and the motors to be made completely separate from the vehicle's electrical systems which improves safety, maintenance, and portability. It also allows for the use of more purchase parts thus simplifying production.

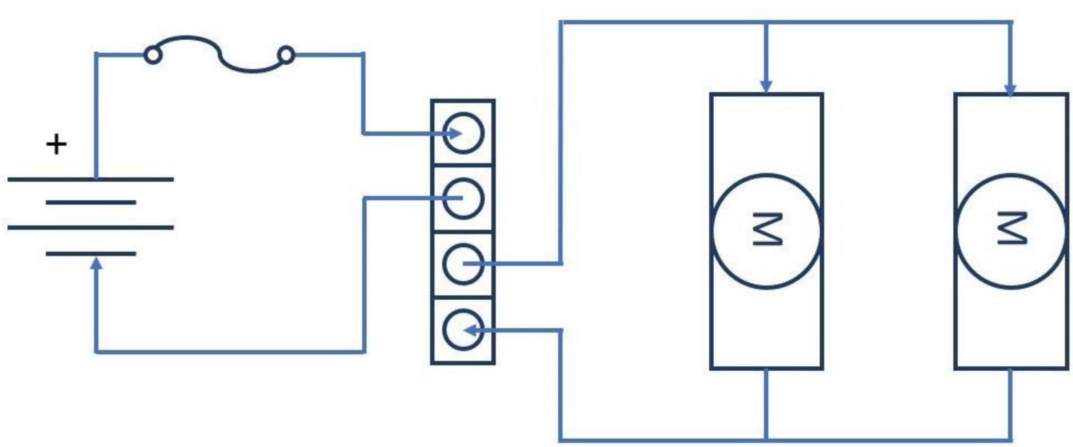


Figure - Electrical System Wiring Diagram

Component Selection

The power system will consist of a battery, two motors, and a controller capable of reversing the motor direction and controlling the motor speed. This controller is sized such that it can handle between 9V and 50V and up to 2000W. These ranges are well above the requirements of the system and will ensure users safety and system reliability. The battery will be connected to the controller by a proprietary connector that came with the battery. This feature will allow the battery to be uncoupled from the larger system and connected to a purchased wall outlet charger. This system does not tie the device from the vehicle electrically and allows the system to use a voltage and amperage that best suits it rather than being limited by the vehicle's auxiliary power outlet output.

The bearings selected have a dynamic load capacity of 710lb. This is well above any weight that will be applied. The specific bearings were chosen for price as well as their low profile, two bolt flange configuration. This mounting configuration makes mounting the bearing simple and saves on space.

The rope chosen is capable of handling up to 550lb, well above the system requirements. This rope was chosen for cost as well as it's wear resistant properties. The spools and pulleys were sized to work with the 3/16" diameter rope.

The pulleys were chosen based on the load and the angle at which the load is applied. Pulleys without housings were chosen in order to reduce costs, as compared to housed pulleys, and make installation and maintenance easier for the end user. As seen in the following figure, the force exerted on the drum guide pulleys will be applied by an angle somewhere between 150° and 120°. In this case the force will be multiplied by a pulley load factor of 1 to allow for the greatest amount of safety in the design. The second pulley, that will pull the mobility device out of the trunk, will have the rope pulled over them at an angle of approximately 30°, and so will have a pulley load factor of 1.93. The third pulley will have less stringent requirements than the second pulley as it will only require the rope to be pulled over it at an angle of approximately 120° so will only have a pulley load factor of 1. This means that the maximum weight on the individual pulleys can be expected to be half of the maximum weight times 1.93 or 128.64lb. The pulleys chosen have a maximum weight capacity of 525lb and were selected for price and for their compatibility with the rope selected.

To Calculate the Load on a Single Pulley	
Rope Angle	Multiply Load By
0°	2.00
30°	1.93
45°	1.84
60°	1.73
90°	1.41
120°	1.00
150°	0.52
160°	0.35
180°	0.00

Figure - Pulley Load Factors

The structural material, 0.125” ASTM A36 mild carbon steel, was chosen from the materials offered by Weiss Technik North America, Inc - CSZ Products for donation. ASTM A36 was chosen for its weldability, which will be the main construction method of the device. Weiss Tecknik has also offered to cut and bend the material to our specifications which has allowed us to design the frame with integrated mounting points for the bearings, pulleys, and motors.

Hardware, such as fasteners, was chosen based upon the size of the attachment points for each of the individual components. It is assumed that for each application that fasteners of such size to fit properly into the attachment points will be strong enough to withstand the forces the individual components are rated to withstand.

Container and Storage Attachment Mechanism

Concept Drawings

Initially, the best (in terms of safety, stability and usefulness as per the surveys) design was to come up with a grid framework that attached to the lifting mechanism at four points. These points would be welded on campus to save money. The grid framework would need to attach to the trunk somehow in order to maintain stability when the vehicle is in motion and accelerating/braking. As per table (1) in the Lifting Mechanism section, the overall dimensions for the vehicles we are designing for can be seen (2010 Ford Fusion and 2012 Ford Focus). It was decided that we would be looking into midsize sedans as they are most common for elderly consumers with a need for a device lift.

After forming the Bill of Materials, it was found that the concept design that was initially preferred was too expensive (each Screw Jack was ~$250) and an alternative was necessary to staying within the budget. It was determined that some components had to be sacrificed in order to get the job done. Options, such as the following, are being explored: finding another attachment method (ropes to frame), cost savings of initial idea (less Screw Jacks, made in-house), less material, univeratility (more permanent installation), weight capacity, etc.

Finally, in order to meet the demands of the $1000 budget, we decided that we would be building a prototype and not the originally discussed design. The frame and all solid parts with solid sheet metal out of a lighter material, like styrofoam, to ensure the dimensions would fit within the trunk of the vehicle. To account for the weight, we will be using a lighter load scaled downwards, in order to cut the costing of the pulleys and to help meet the budget. With everything being scaled downwards evenly, the original calculations will stand, because they are correct in the design process for the original product. This is due to the fact that my work, Weiss-Technik North America, would be covering the cost and labor of bending/welding the materials together. However, with the Coronavirus outbreak we will not be able to retrieve this sheet metal due to the non-essential plant being shut down. This has been brought to the attention of MKV.

Black Lines attach the grid framework to the trunk. Stabilizing jack screws that extend outwards to fit trunk dimensions.
Red Lines attach the lift to the grid framework. Poles come up from the frame to secure the lifting mechanism.

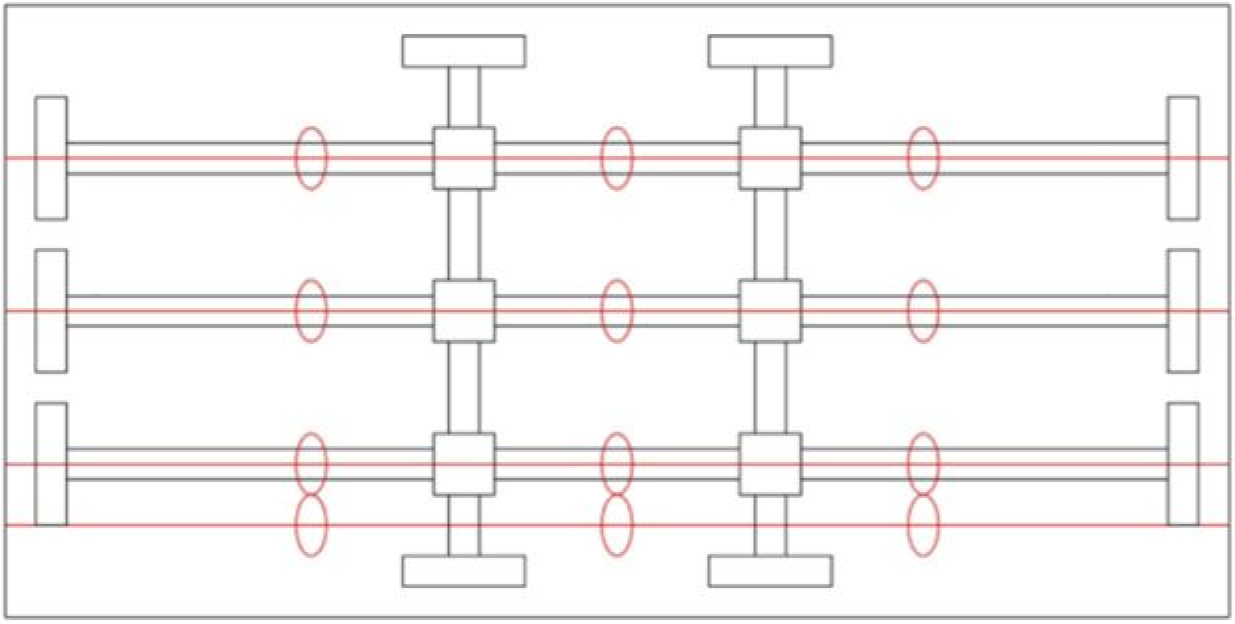


Figure: Initial concept drawing of Screw Jacks (10)

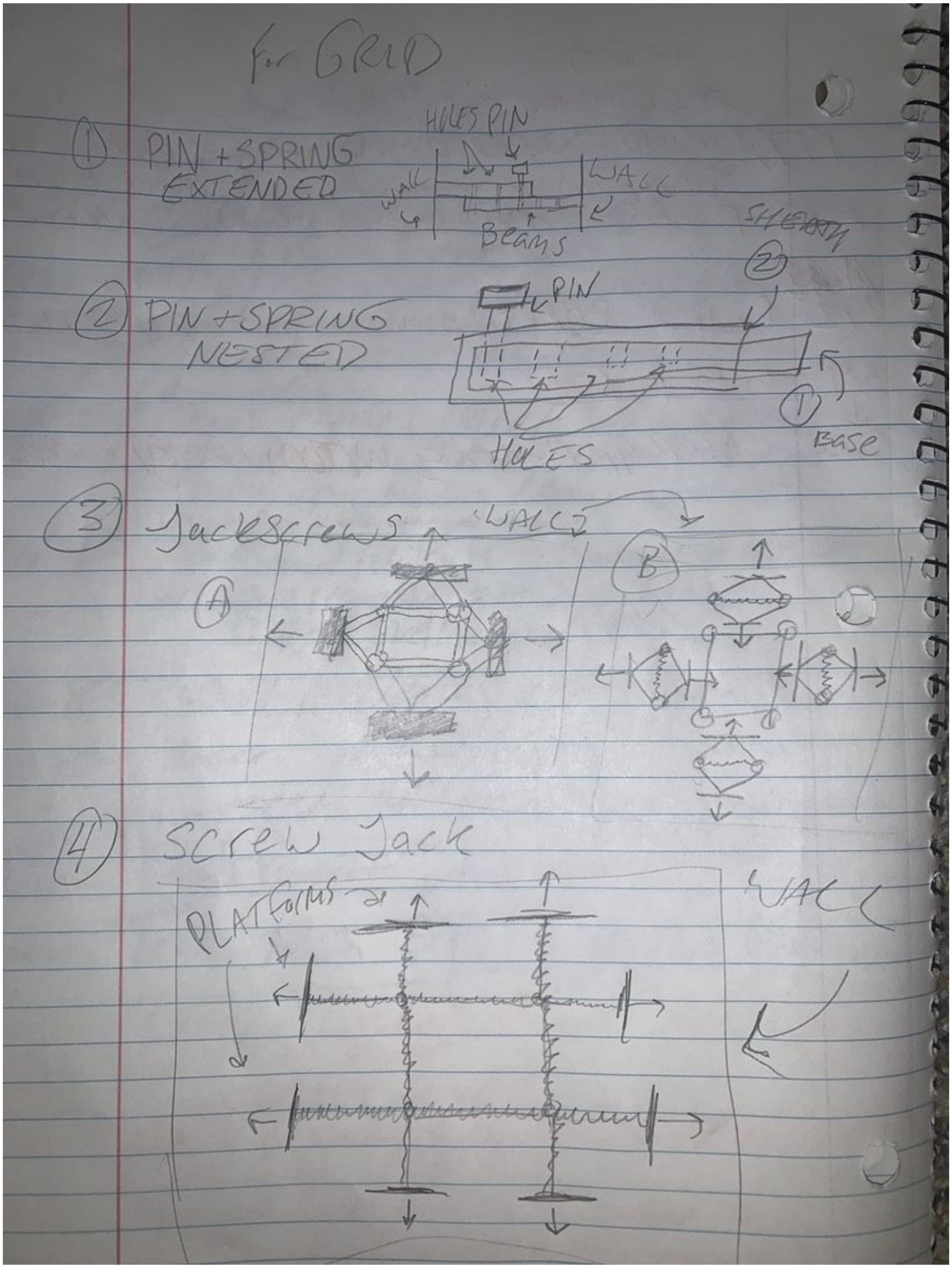


Figure: Preliminary concept drawings of storage attachment to trunk (11)

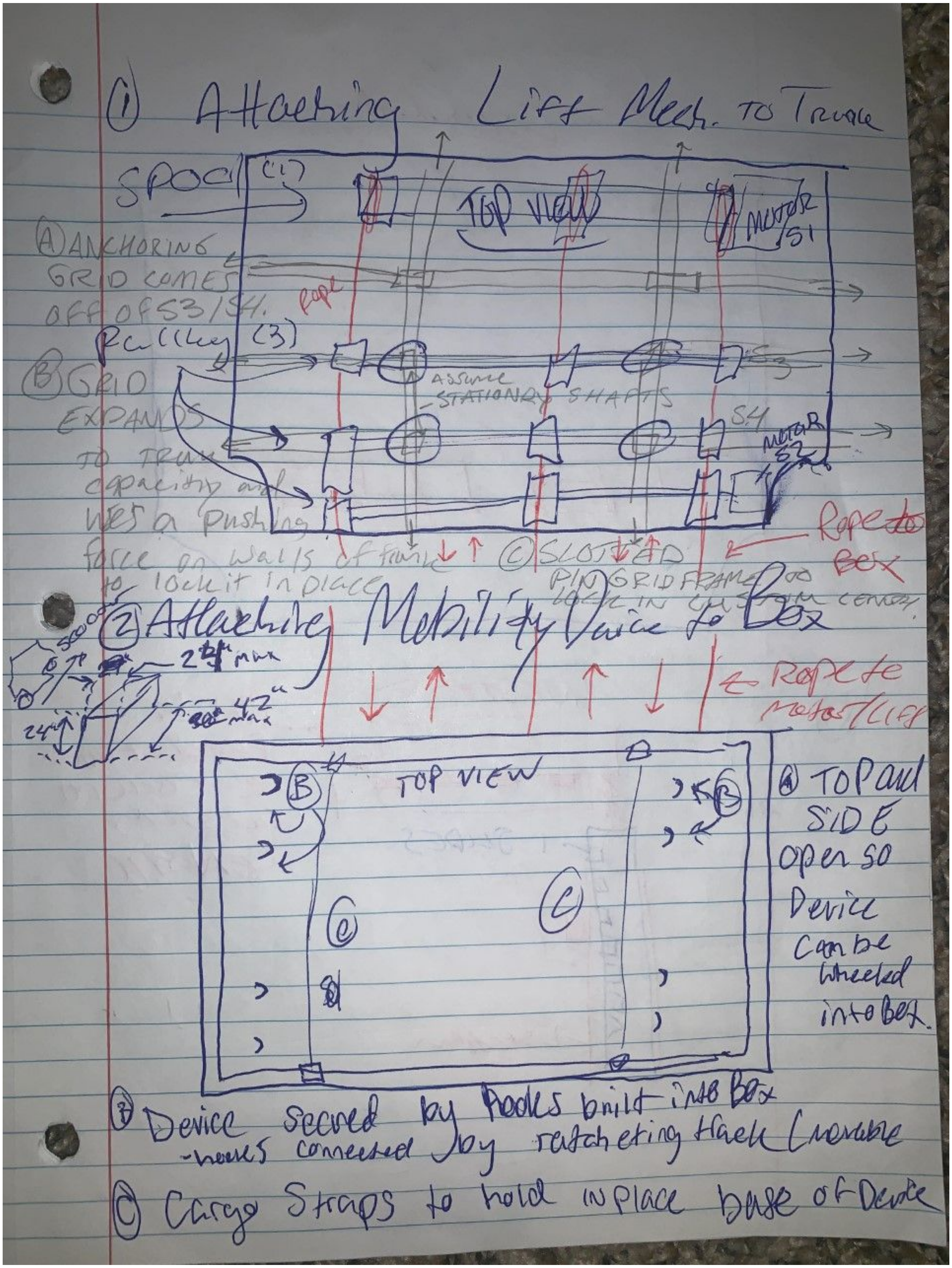


Figure: Preliminary concept attachment ideas of attachment to mobility device (12)

Loading Conditions

The attachment system will be based around two principals; (1) lifting mechanism to the mobility device [known as "attachment"] and (2) lifting mechanism to the vehicle [known as "storage"].

The attachment must be able to hold the weight of the mobility device (41lb) and the weight of the attachment itself (25lbs). It must also account for the forces created when lifting this device upwards vertically, diagonally, and horizontally into the trunk's storage. After a factor of two (2) is added into the mixture, we have a maximum weight capacity to be lifted (133.3lbs) that will need to be lifted by the lifting mechanism.

The storage unit must be able to safely withstand the weight of the mobility device (41lbs), the attachment (25lbs), the total system of the lifting mechanism (estimated 50lbs) [motor, shaft, rope, lines, electrical wiring, etc.]. It must also be able to take this total weight and remain sturdy when taking into account the acceleration and deceleration of the vehicle while in transit. It should able be taken into account that if the driver were to get into an accident, if our senior project would be able to keep its contents safe (given that the damage was not to the trunk area, but more in terms of the forces due to collision).

Design Analysis

Storage Attachment to Trunk

The storage component that is supposed to safely keep/maintain the contents to be transported (including the mobility device and all other components of the senior design project lifting system) must be able to prevent this combined weight from moving when stationary, in operation and while in transit. This means that the stationary forces, static frictional forces to move the system during acceleration and forces due to normal operation must be accounted for. Contrary to the initial design of 8 Screw Jacks (initial 3D designs and preliminary sketches), these design analysis calculations are to be based off of minimal contact areas in an attempt to save as much costs as possible and to stay within the budget limits. Static friction is not negligible for this section. The carpet material of a typical sedan's trunk is usually polyester, with a static friction coefficient of steel on polyester being 0.20. Average acceleration for sedans is about 9.83 ft/s^2.

Fnet = sum forces (taking friction into account) = F1 + F2 + F3 + F4 + F5 + F6
Fnet = Fcontainer + Fdevice + Fpulleys + Fframework + Ftransit + Ffriction
Wmax = 650lbs (without a safety factor)
Fcontainter = 85lbs (estimated)
Fdevice = 215lbs (heavy duty motorized wheelchair)
Fpulleys = 50lbs (estimated)
Fframework = 300lbs (estimated)
Ftransit = (650lbs/32.2ft/2^2) = (20.19slugs*9.83ft/s^2) = 198.42lbs
Ffriction = mew*weight = 0.20*20.18slugs = 130lbs
Fpulleys(with acceleration) = 350lbs+[(10.87slugs*9.83ft/s^2)-(350lbs*0.20)] = 386.85lbs

Fnet = 650lbs+198.42lbs-130lbs = <u>978.42lbs</u>

The system must be able to split just under 1000 pounds of force to ensure no movement occurs when maximum acceleration of the vehicle during transit. Forces caused by an accident or a collision are not accounted for to allow leeway in the budget. The total weight of the combined system without a safety factor is 650lbs. The maximum forces generated by acceleration are just under 200lbs, less 130lbs due to static frictional forces. If there are four (4) Jack screws, each must be able to hold a minimum of 250lbs, which is half of the original estimate of 500lbs. The four beams that connect the storage framework to the pulley system must be able to hold 96.7lbs of force each, for a total of 386.85lbs of force without a safety factor of two (2) (double the pounds*force if aforementioned safety factor is to be taken into consideration).

Attachment to Mobility Device

The attachment component that is supposed to safely carry and hold the mobility device must be able to lift the weight of the container plus the weight of the mobility device plus the forces due to the pulleys in the upward direction. Static friction is negligible for this section.

Fnet = sum forces = F1 + F2
F = m*a = Fa - f = mew*mass*gravity; upward acceleration of 2ft/sec^2 plus gravity
Wmax = m*g; Wmax = (Wdevice)+(Wcontainer) = (215lbs)+(85lbs) = 300lbs
F1 = Fnormal = 300lbs
F2 = (300lbs/32.2ft/s^2)*2ft/s^2 = 18.64lbs
Fnet = ~<u>318.64lbs</u> * safety factor of 2 = <u>637.27lbs</u>

The container must be able to hold a maximum (including a safety factor of 2) of 637.27 pounds of force during operation, assuming the upward acceleration to be 2ft/s^2. If the safety factor is to be excluded, then it can be assumed that the Fnet necessary to be held by the attachment device is ~318.64lbs of force. There are a total of two (2) straps, so each must be able to hold 160lbs.

Component Selection

The attachment system will consist of aluminum sheet metal in order to contain the mobility device. This aluminum sheet metal will be thick enough to avoid damage in normal operation conditions and will prevent the device from being shaken around during transit. Slides drafted in the lifting mechanism's report are used to prevent damage occurring to the vehicle from this sheet metal. The edges and corners will be sanded down to prevent harm to the user or the vehicle. Aluminum was chosen because it is the cheapest sheet metal offered on McMaster-Carr while maintaining required sturdiness.

The storage system had several different methods to solving the problem at hand. It was decided that screw jacks were the best way to go as they can maintain our required degree of safety without damaging the trunk. Screw Jacks are also very universal in the sense that they can be extended or retracted to fit any dimensions within reason. Their weight capacity was found to be so incredibly high that even in the case of if the driver where to get into an accident, the storage unit would be okay afterwards. As seen in the preliminary concept drawing figure (10), forces are only exerted in four (4) perpendicular outward directions, each of 90 degrees of one another.

Bill of Materials

Lifting Mechanism

From the analysis and selection of materials and components shown above the bill of materials for the lifting mechanism itself is as follows. This bill of materials costs well in excess of the proposed budget that is discussed in the Budget section below. This will need to be discussed with Maple Knoll Village and reassessed to find a compromise of possible budget increases, scope changes, and redesign that will satisfy their requirements and remain a cost effective solution. These details were discussed and the budget was confirmed at $1000, which resulted in a change in the Bill of Materials to match this amount. At the end of March, it was discussed via email, in regards to the Coronavirus that we were unable to complete the prototype. MKV will be receiving all of the purchased parts that they paid for and steps for next year's group will be left to take over the project.

Container and Storage Attachment Mechanism

The cheapest possibility found to be around $765, with this to be evaluated again over break or in January. The total after tax looked to be estimated just under $820, which is almost double the original budget of $500. The bulk of the cost estimation was focused around the Screw Jacks. It needs to be looked into if there might be a more cost effective route or not, or perhaps if these expensive parts can be created on campus to save money. In conclusion, the original estimations of forces due to weight were over double the actual, probably due to the safety factor being so high. This means that the budget can (and will) be looked into and reduced from the amounts listed on this report.

Planned Budget							
Source & Date		Part Number	Description	Supplier	Quantity	Unit Cost	Total Cost
V		3434T116	Pulley for lifting - 3/16" rope - 1 1/2" OD	McMaster-Carr	6	$3.95	$23.70
V		5913K71	Low-Profile Mounted Sealed Steel Ball Bearing	McMaster-Carr	2	$11.33	$22.66
V		3790T11	H.T. W.R. Rope - ForLifting	McMaster-Carr	25	$0.66	$16.50
E		WARN 69635	Aluminum Winch Drum	Grainger	2	$39.77	$79.54
A		MTGP-P06-1J008	IronHorse parallel shaft DC gearmotor - 50 lb-in	Automation Direct	2	$171.00	$342.00
O		Lejin-02	ZippBattery 12V 12Ah w/ Harness	Amazon - UPS Battery C	1	$59.99	$59.99
O		Lejin-02	12V 40A Reversible Controller	Amazon - Lejin	1	$14.99	$14.99
O		UNKN	12V Charger w/ Clip	Amazon - SafeAMP	1	$13.98	$13.98
H		803331	#10-32 x 3/4 in. Combo Round Head Zinc Plated	Home Depot	1	$1.18	$1.18
H		92620A587	Zinc Yellow-Chromate Plated Hex Head Screw Gr	McMaster-Carr	1	$5.44	$5.44
H		801746	5/16 in.-18 Zinc Plated Hex Nut	Home Depot	12	$0.13	$1.56
V		7767T42	Low-Carbon Steel Round Tube 0.12" Wall Thickn	McMaster-Carr	1	$11.62	$11.62
H		98023A030	Zinc Yellow-Chromate Plated Grade 8 Steel Was	McMaster-Carr	1	$5.43	$5.43
V		89495K21	304/304L Stainless Steel Tube, 0.083" Thick, 1/2"	McMaster-Carr	1	$26.88	$26.88
V		3014T46	Steel Eyebolt with Shoulder - for Lifting 5/16"-18	McMaster-Carr	2	$3.45	$6.90
V		8672K41	Food-Grade UHMW Plastic Trim 1/8" Wide x 1/4	McMaster-Carr	3	$6.10	$18.30
V		8510K16	SBR Rubber Trim 1/8" Inside Width, 1/4" Inside	McMaster-Carr	25	$0.48	$12.00
V		7165T33	Slippery Trim with Adhesive Back UHMW Plastic,	McMaster-Carr	1	$44.17	$44.17
-							$0.00
V		9657K395	Compression Spring - 2" Long		1	$8.72	$8.72
V		8842T89	Strap and Steel Buckle - 10' long		1	$14.13	$14.13
V		3013T45	Steel Eye Bolt		2	$3.21	$6.42
-					Est. Tax	7.00%	$51.53
-							$0.00
				Total Anticipated Material Cost:			$736.11
				Total Anticipated Cost (w/ tax):			$787.64

Figure - Bill of Materials and Perspective Expenses

Project Management

Budget, Proposed

We planned on using the same $1,000 budget proposed by Clark, Minkoff, and Zito for their design. This was split into two, $500 portions as a framework for the budget for each division of the project: lifting mechanism and frame, and attachment devices.

Budget, Finalized

The budget is something that our group struggled with throughout the design process. Our initial design needed to be changed several times due to it not being within the proposed $1,000 budget. Thankfully, we were able negotiate project objectives with our advisor and Maple Knoll Village to bring our operational targets within range of the budget. In the end we brought our expected expenditures down to $787.64, leaving about $212 as a cushion to cover any additional costs from unexpected acquisition expenses or parts breakage during testing. After ordering and receiving all our parts the final bill came to $824.52, $175.48 under budget. The additional expense came from shipping and handling charges from online retailers. Fasteners and associated hardware were sourced from Home Depot in order to avoid shipping and handling costs.

Actual Expendatures									
Source & Date	Shipped	Part Number	Description	Quantity	Unit Cost	Total Cost	S&H	Tax	Total Recipt
Ebay - 3/8	S&R	WARN 69635	Aluminum Winch Drum	2	$39.77	$79.54	$0.00	$5.57	$85.11
Auto.Di - 3/8	S&R	MTGP-P06-1J008	IronHorse parallel shaft DC gearmotor - 50 lb-in	2	$171.00	$342.00	$0.00	$23.94	$365.94
Home Depot - 3/4	Y	8.8748E+11	MACH SCR RND HD CMB SS #10-32X1"	3	$1.18	$3.54			
	Y	AKD	HEX BOLT 5/16X2	6	$0.27	$1.62			
	-	AHD	1/4-28"X1-1/2"HEX BOLT GR 5 ZP (AHD)	4	$0.32	$1.28			
	-	AAB	HEX NUTS-USS 1/4	20	$0.08	$1.60			
	Y	ABC	HEX NUTS-USS 5/16	10	$0.13	$1.30	$0.00	$0.65	
	-	-	PART RETURN	1	-$3.08	-$3.08	$0.00	-$0.20	$6.71
	Y	ABB	CUT WASHERS 5/16	20	$0.15	$3.00			
	Y	AHB	HEX BOLTS 5/16X1-1/2	4	$0.25	$1.00	$0.00	$0.14	
	-	-	CUSTOMER SATISFACTION DISCOUNT	1	-$2.00	-$2.00	$0.00	$0.00	$2.14
Amazon - 3/7	Y	Lejin-02	ZippBattery 12V 12Ah w/ Harness	1	$59.99	$59.99			
	Y	Lejin-02	12V 40A Reversible Controller	1	$14.99	$14.99			
	Y	UNKN	12V Charger w/ Clip	2	$13.98	$27.96			$102.94
McMaster-Carr - 3/4	Y	3434T116	Pulley for lifting - 3/16" rope - 1 1/2" OD	6	$3.95	$23.70			
	Y	5913K71	Low-Profile Mounted Sealed Steel Ball Bearing	2	$11.33	$22.66			
	Y	3790T11	H.T. W.R. Rope - ForLifting	1	$17.00	$17.00			
	Y	89495K21	304/304L Stainless Steel Tube, 0.083" Thick, 1/2"	1	$26.88	$26.88			
	Y	3014T46	Steel Eyebolt with Shoulder - for Lifting 5/16"-18	2	$3.45	$6.90			
	Y	8672K41	Food-Grade UHMW Plastic Trim 1/8" Wide x 1/4	3	$6.10	$18.30			
	Y	8510K16	SBR Rubber Trim 1/8" Inside Width, 1/4" Inside I	1	$12.00	$12.00			
	Y	7165T33	Slippery Trim with Adhesive Back UHMW Plastic,	1	$44.17	$44.17			
	Y	9657K395	Compression Spring - 2" Long	1	$8.72	$8.72			
	Y	8842T89	Strap and Steel Buckle - 10' long	1	$14.13	$14.13			
	Y	3013T45	Steel Eye Bolt	2	$3.05	$6.10	$35.53	$17.12	$253.21
McMaster-Carr - 3/13	Y	7767T42	Low-Carbon Steel Round Tube 0.12" Wall Thickn	1	$11.62	$11.62	$7.11	$1.36	$20.09
				Category Cost:		$733.30	$42.64	$48.58	
				Total Cost:				$824.52	

Figure - Final Bill of Materials and Expenditures

Schedule, Proposed

The following list addresses the key milestones we planned for Senior Design III. The dates listed are a mix of start dates for individual tasks, such as ordering parts on January 13th, and deadlines, like Tech Expo on April 9th. This was planned on being revised during the recap meeting on January 13th.

- January 13th
  - Recap from break
  - Order parts
- January 20th
  - Begin Tech Expo presentation draft
- January 27th
  - Finalize Tech Expo presentation
- February 3rd
  - Receive ordered materials
  - Begin build
  - Begin writing build instructions
- February 10th
  - Finalize build and check against Bill of Materials
- February 17th
  - If all works, add simulations and BoM to Tech Expo presentation
- February 24th
  - Complete build
  - Test build
  - Complete Tech Expo Presentation
- March 2nd
  - Complete BoM
  - Complete build instructions
- March 9th – March 30th
  - Flex month.
  - Time reserved to absorb overages in scheduled tasks
- March 30th
  - Finalize completed project and polish deliverables
  - Review presentation with advisor
- ~~April 9th~~
  - Tech Expo presentation - Canceled due to COVID-19 Pandemic
- April 18th
  - Finalize completed project and polish deliverables
  - Voiceover recording of presentation submitted to supervisor, Dr. Dong
  - Submit final presentation and final report

Schedule, Finalized

Most of our schedule went according to plan but was moved back by about a month after we determined we would need to revise our design from a light-duty variation to a proof of concept due to budget limitations after our Senior Design II review presentation. We were able to give our Senior Design II presentation and submit our Senior Design II report as planned. After our rework for budget, our budget presentation was successfully made and all of our purchase parts were ordered and received as planned. However, the last two months of our schedule were disrupted quite completely by the outbreak of COVID-19. Due to the various social distancing measures and the stay of all nonessential work, the supplier of the frame material and part fabrication, Weiss Technik North America, Inc - CSZ Products, was forced to halt operations until May 2nd, 2020 (as of the writing of this report). Additionally all UC facilities were closed well though the end of the spring semester and into summer. These two obstacles made it impossible to gather the parts and use the machines necessary to complete the build phase of the project.

Course Syllabus

Spring Semester outline -

Design Finalize: Jan 17

Design presentation due: Jan 23

Design Presentations: Jan 27 - Jan 31

Build and Test Complete: April 2, for reference

Tech Expo: April 9th, canceled

Final Presentation and video due: April 16, new due date April 18

Final Presentations: April 20 - April 24, canceled

Final Report due: April 25, new due date April 18

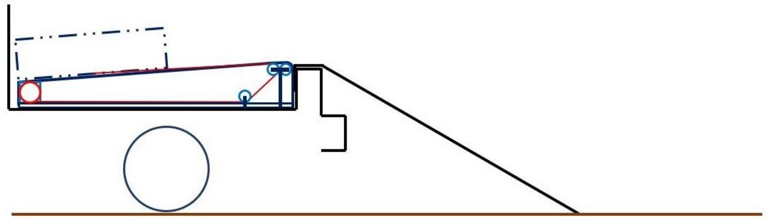
Course Summary:

Figure - Updated Final Due Dates of the Project

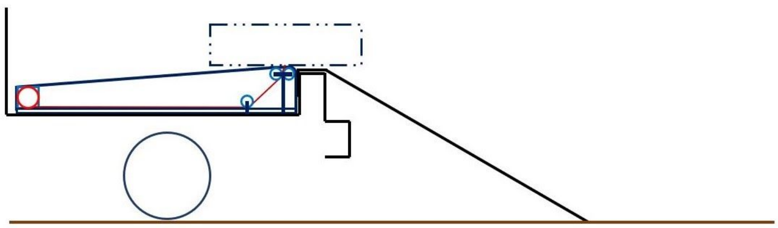
Proof of Design

Operation Description

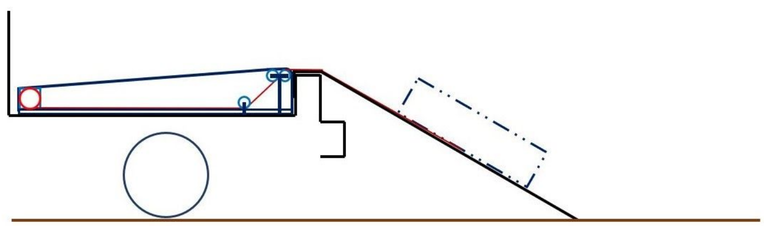
While we were unable to build the mobility device lift a detailed description of the operation if the device is included below. This description is broken down into four major steps characterized by the position of the device attachment. For the purpose of this explanation it will be assumed that the mobility device is attached to the mobility device attachment and is stored in the trunk of the subject sedan.



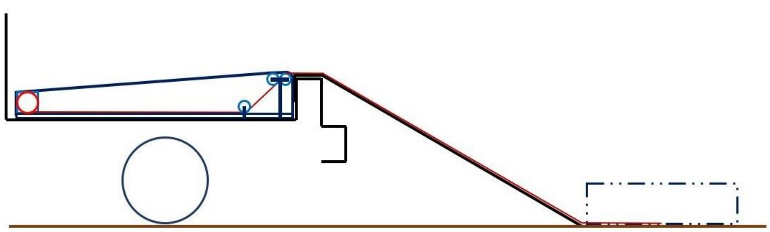
1. Fully Loaded Position - In this position the device and attachment are in the storage position in the trunk, furthest to the front of the sedan. From this position the motors can be energized to spool the lifting ropes in and raise the device to the second position.



2. Inflection Position - Once the device has reached this position the motors are stopped. The device can rest in this position without moving into or out of the trunk due to the resistive breaking force of the motors.



3. On-Ramp Position - From the inflection position the motors can be reversed so that they begin to unspool. This will allow the device attachment to begin to lower out of the vehicle and down a ramp set up behind the vehicle.



4. Fully Unloaded Position - Once the device is fully lowered to the ground behind the vehicle the mobility device can be removed from the attachment and reassembled/brought to usable configuration.

This process would be reversed for storing the device attachment back into the vehicle and for loading a mobility device into the vehicle.

Testing

While the mechanical components could not be assembled due to the lack of the frame, the electrical components could be tentatively assembled and tested for proper function and expected operation. The motors were placed in the orientation they would have taken in the final construction and the battery, controller, and motors were connected together.

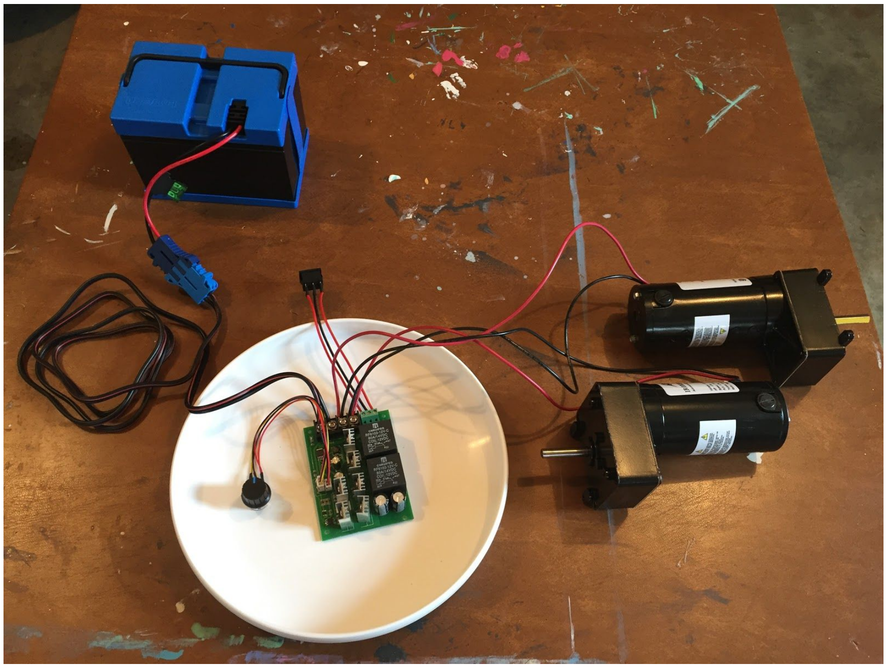


Figure - Electrical System Fully Assembled for Testing

The electrical system was assembled for work bench testing in the configuration seen above. The battery was connected to the controller via cable and connector repurposed from a wall outlet charging adapter. The two proprietary blue connectors are designed to only allow a single orientation when connected ensuring proper DC circuit establishment. The controller consists of a three position rocker switch which controls the motor direction and acts as a secondary on/off switch and a potentiometer which acts as the main on/off switch and speed adjuster. The motors were connected to the circuit in opposition to each other i.e. the positive and negative leads of one of the motors was wired to the other terminal positive to negative and vice versa. This ensured the shafts spun in the same direction while the motors were mounted in opposite directions. The test went smoothly and it was successfully demonstrated that all of the components are properly sized for the system, the system can operate the motors in both directions, the speed of the motors can be controlled, and that the motors can be changed from one direction to the other while at speed (though this is discouraged).

Future Planning

Fabrication
All of the sheet metal is to be cut out and bent to shape at Weiss-Technik, as they have the machinery to complete this in one process and is the company sponsoring this portion of the project. If or when these parts are produced they will be delivered to Dr. Dong.

Assembly
The sheet metal will need to be brought to the Victory Parkway campus to have any minor changes such as sanding, trimming, welding, and drilling completed. When the frame and container have been completed, they will then have the pulley systems installed manually; the instructions will need to be written as the initial prototype is created in the lab. A final check will need to be made before moving onto the testing phase to ensure stability prior to the load being added.

Testing
After installing the pulley system into the framework, the framework will need to be installed into a compact sedan for testing. This may be accomplished with a personal vehicle such as the 2018 Mazda 3 or 2012 Ford Focus. Testing may consist of the several processes. The compression springs may be manually tested by pushing and pulling on the frame in various directions. Once stability is certain, the ramp can be added to the trunk and the container can be attached to the pulley system via eye bolts and rope. Plastic trim will be placed on the ramp, vehicle, and container to ensure no damage will result. Once secured, the operator can utilize the remote to bring the container up the ramp into the trunk, and then reverse to bring the container back down the ramp. The load can then be added into the container and secured via heavy duty straps and the process repeated again to confirm the prototype is able to lift the expected load.

Suggested Future Work
Before testing may commence, several steps must be taken. First the frame must be manufactured and assembled. Manufacturing of the frame may take place over the summer if/when Weiss Technik reopens. If this business does not reopen over the summer another source for frame material will need to be found. The frame must then be assembled by welding. Again, this process was halted by the COVID-19 outbreak. Once UC facilities reopen this can be completed at Victory Parkway North Labs. All further assembly can be accomplished with commonly available hand tools. A proper housing for the controller will also have to be made. Finally, a ramp will need to be designed and built. It was planned that a demonstration ramp would be built from wood and the design of a proper ramp would be reserved for another project. After these steps and if the proof of concept works as intended, the next step will be to provide Maple Knoll Village with a demonstration of the prototype. Following this demonstration, the project should shift to design and construction of the full scale device capable of lifting the mobility devices used by the residents. A much larger budget will need to be acquired in order to afford the materials necessary to build the full scale device.

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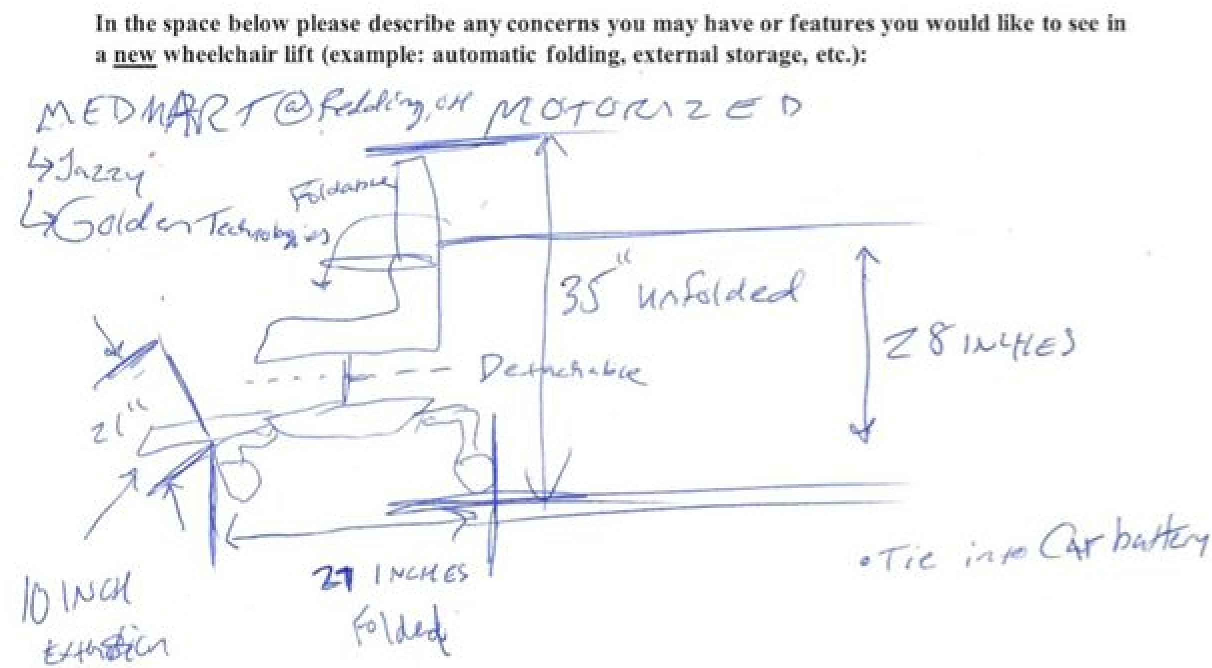
Appendix

Survey Open Responses

- Would prefer something not attached to the car. Would want automatic folding. Simple to use. Easily moved to other cars. Perhaps something that would fold up into the trunk with/on top of the wheelchair.
- 1) Easily cleaned material 2) Light weight
- MEDMART @ Reading, OH Motorized Jazzy, Golden Technologies, Quick dimensional sketch of above mobility scooter by Zachary Waas



Lift should be able to move from car to car, Nothing should hang off car, Shouldn't take up too much trunk space

Customer Survey

Wheelchair Lift Customer Survey

This survey will be used to prioritize various features to maximize customer satisfaction. The system in question will address issues associated with loading and unloading a wheelchair from a personal vehicle.

What mobility device do you currently use? Please circle your response.

Manual wheelchair   Power wheelchair   Scooter   Walker   Other

If other, please specify:

What is the estimated weight of your mobility device? Please circle your response.

0-15 lbs   15-30 lbs   30-60 lbs   60-125 lbs   125-250 lbs   >250 lbs

If other, please specify:

What style of vehicle do you use? Please circle your response.

Sedan   Hatchback   Van   Truck   Other

If other, please specify:

How important is each feature to you in a wheelchair lift? Please circle your response.

1 = Least Importance   5 = Greatest Importance

Initial Investment Cost	1	2	3	4	5	N/A
Weightlifting Capability	1	2	3	4	5	N/A
Overall Weight of Lift	1	2	3	4	5	N/A
Overall Size of Lift	1	2	3	4	5	N/A
Ease of Set-Up	1	2	3	4	5	N/A
Ease of Use	1	2	3	4	5	N/A
Quietness of Use	1	2	3	4	5	N/A
Time to Load/Unload	1	2	3	4	5	N/A
Trunk Space Used	1	2	3	4	5	N/A

Please continue on the back of this page.

Wheelchair Lift Customer Survey

How satisfied are you with your current wheelchair lift? Please circle your response.

1 = Not Satisfied 5 = Very Satisfied

Please circle "N/A" if you do not currently have a wheelchair lift.

Initial Investment Cost	1	2	3	4	5	N/A
Weightlifting Capability	1	2	3	4	5	N/A
Overall Weight of Lift	1	2	3	4	5	N/A
Overall Size of Lift	1	2	3	4	5	N/A
Ease of Set-Up	1	2	3	4	5	N/A
Ease of Use	1	2	3	4	5	N/A
Quietness of Use	1	2	3	4	5	N/A
Time to Load/Unload	1	2	3	4	5	N/A
Trunk Space Used	1	2	3	4	5	N/A

In the space below please describe any concerns you may have or features you would like to see in a new wheelchair lift (example: automatic folding, external storage, etc.):