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Bicycle Snow Removal Device
Design Report 5
Team 28

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Executive Summary

This project was motivated by Professor Martin Strauss, a University of Michigan Math and Computer Science professor. Professor Strauss desired an environmental and residential friendly snow removal device that can be easily attached to his bicycle and clear snow as he rides. The project addresses the challenge of reducing carbon emissions and noise produced by large scale commercial snow blowers. While the concept of a human powered snow removal device is not new, there are no devices available on the market that achieve this goal. Through research, the team found several models of human powered snow removal devices but none of these designs have been patented or commercialized.

The main design drivers of the project were to remove snow from the sidewalk and driveway, disengage, adjust the trajectory angle of snow, easy to attach and cost. To satisfy these criteria, Pugh charts were constructed to analytically assess each component and concept generated (Appendix B). A list of criteria was then generated and weighted according to the importance and each component and concept was subsequently rated based on the ability to fulfill the criterion. The highest scoring components were then combined to create system level concepts. These system level concepts were then evaluated in a similar manner, looking at a combination of engineering and customer requirements, allowing for a final design to be chosen.

Our final design features a disengagement linkage, an indexer to control snow trajectory, a motor and sprocket to spin the bristles, a battery assembly to power the motor and two support wheels to ensure stability of the device and bicycle while disengaged. The first feature is the ability to disengage the bristle by pushing a lever. The angle of the bristles can be adjusted by aligning the bristles with preset holes on the indexer. The user slides a quick release pin through the hole to lock the bristle in place. The transmission system that drives the bristles consist of a sprocket fastened to the bristle axle via an adaptor and a set screw. The rotation and torque of the motor is transmitted via a chain with a 1:5 gear ratio. The motor is powered by two 12V lead acid batteries connected in series. The speed of the bristles are controlled by a throttle controller that is mounted to the handlebar of the bicycle. Lastly, two support wheels are added to the device to support the moment produced when the device is disengaged.

For validation testing, we mounted the device onto Professor Strauss' bicycle and observed the stability with the device on and off. The device was able to stay in-line with the bicycle when he was cycling and was able to be disengaged when not in use. We were able to validate that the device has enough force to clear soil from a straight path. However, further testing will be required for to ensure that the device is efficient in removing snow.

For future work, we propose that a ball joint be used at the bicycle attachment because it will allow the bicycle to roll and the user to ride in a more natural manner. Next, a closed loop control system can also be implemented to allow for automatic bristle speed regulation depending on snow density. Lastly, actuators can be installed in place of the indexer and disengage mechanism to enable these task to be done while the user is riding.

BACKGROUND

Our sponsor has presented us with the challenge of creating a bicycle snow removal device as a greener and more residential friendly alternative for removing snow. We realize the need for such a device because of the heavy snowfall in the Midwest during the winter months. The average annual snowfall in Ann Arbor is 42.5" [1], which leads to hours upon hours spent shoveling or operating a snow blower every year. As weather patterns differ in temperature so does the density of snow, varying from 0.6 to 37 [lbs/ft^3] [2].These dynamically changing and unpredictable snowfall patterns result in wasteful emissions from snow blowers when removing light, low density snow. Similarly, shoveling dense snow is very taxing on the human body and can lead to back pain.

The current market for residential snow removal is dominated by snow blowers and shovels. A snow blower is a gasoline powered rotating blade system that grabs snow, pulls it into the blower body and shoots it in the user specified direction. These machines are costly, loud and harmful to the environment. Shovels, on the other hand, are a more cost effective solution, but the tradeoff is the intensive labor along with relying heavily on the user's ability to penetrate the layers of snow and ice. To elaborate on the existing technology, patents that exist define specific design characteristics of removal mechanisms and material claims, such as a composite blade [3]. Existing patents for bicycle snow models focus on traction and snow mobility as opposed to removing snow [4, 5]. Based on our research, the bicycle snow removal device is not a new idea because bicycles have been jury rigged to remove snow via a front or a rear towed plow. Before the start of this project, however, there does not seem to be any system or component level patents for the general bicycle snow plow concept. The design of the existing solutions is primarily focused on a rigid blade(s) digging into the snow as the bicycle moves, while depositing the snow to the right, left, or both sides of the bicycle's path. These benchmark devices do not have a mechanism that allows for user adjustability and disengagement. Another popular method of removing snow by machine is a rotating bristle design, however we have found no evidence of any prototype that has been developed to apply this idea to a bicycle platform.

While current methods of snow removal are effective, there are numerous negative side effects. The first being that gasoline powered snow blowers release large quantities of carbon monoxide (CO) while running. The average snow blower releases 1 lb/hr of carbon monoxide [6]. For comparison, according to the EPA [7], an average light-duty passenger car in 2008 emitted 0.15 lbs/hr. Thus, a typical snow blower emits roughly seven times more CO than the average automobile in 2008. High concentrations of carbon monoxide damage the environment and can lead to CO poisoning and with the right conditions can lead to a fatality. Similarly in regards to urban friendliness, an average snow blower emits noise at a level of 106 dB [8]. For context, a typical siren has a noise level of 120 dB and the threshold for potential hearing damage is 85 dB [8]. This shows that prolonged use of snow blowers can lead to hearing damage. While shovels are safe for the environment and have low noise impact, they do have some tradeoffs. The primary downfalls are the effectiveness compared to a snow blower and the labor intensity. These two tradeoffs lead to longer time spent removing snow and substantial stress on the body. It is our task to create a more ergonomic device that matches the effectiveness of a snow blower for most conditions, while emitting no greenhouse gases and maintaining noise levels equivalent to a manual shovel.

USER REQUIREMENTS AND ENGINEERING SPECIFICATIONS

The user requirements and engineering specifications were set by meeting with the sponsor of our project, Professor Martin Strauss, and the Snow Buddies organization. In our initial meeting we discussed the overall goals of the project and asked probing questions to understand the background. From this meeting, we determined that the bicycle snow removal device will be used to clear driveways and sidewalks of snow accumulations up to 6 inches. Table 1 below shows the 4 primary categories and the user requirements derived from those upper level categories.

Table 1: User Requirements and Specifications

Category	User Requirement	Specification	Numeric Spec	Weight	Source
Functions	Plow Driveway	Displace Snow from path of device	Move up to 1 foot	10	Team
		Adjust Angle	<= 30 Degrees	7	Sponsor
	Plow Sidewalk	Max. Width of Average Sidewalk	< 3 Feet Wide	9	Sponsor
	Disengage	Raises from Ground	> 5 Inches	7	450 Team
Attachment	Compatibility	Attaches to Multiple Styles of Bicycles	N/A	8	Sponsor
	Mounting Points	Clamps/Slots/Bolt Holes on Attachment	N/A	5	Sponsor
	Easy to Attach	Attaches to Bicycle Quickly	< 5 Minutes	7	Sponsor

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Category	User Requirement	Specification	Numeric Spec	Weight	Source
User	No Riding Interference	Does Not Interfere with Steering	> 1 Inch from Bicycle Parts	9	Sponsor
		Minimum Clearance from Frame	> 0.5 inches	6	Sponsor
	Maintenance	Easily Repaired	< 10 Minutes	5	450 Team
	Storage/Transportation	Lightweight and Folds Up/Disassembles	10 CU. Ft.	5	Sponsor
	Easy to Use	Quickly Adjustable	< 30 Sec.	8	Sponsor
	Lighting/Indicators	Indication of Path	Class 1 Regs.	6	Sponsor
	Safety	Shock Absorption to Absorb Impact with Cracks	< 1 Inch Cracks	7	Sponsor
		Attachment Does Not Impact Stability of Bicycle	Dependent on Design	7	Sponsor
	Length of Use	Battery Life (Electric powered only)	> 30 minutes	8	Team
Cost	Affordable Prototype	ME450 Budget	< $400	6	Sponsor

Functionality is the first user requirement as seen above. This category defines the functions and characteristics that the device must have to fulfill the user requirements. The three user sub-requirements contained within functionality are: the ability to plow a driveway and/or a sidewalk and it must have the ability to disengage/engage as the user demands. The rationale for the user requirements are presented below:

- Snow must be displaced off of the desired path
- Adjustability of the blade/brush angle allowing for different snow deflection directions

- Width must be a maximum of 5 feet based on the width of average residential sidewalks
- A minimum of 5 inches of disengagement height above the ground is required to allow the user to ride without interference when not removing snow

A second requirement is attachment. This category defines characteristics the device should have to be easily attached to any bicycle. There are three sub-requirements set forth: compatibility, mounting points and ease of attachment. The rationale for the user requirements corresponding to Table 1 are as follows:

- The device should be universal in its attachment method allowing for the largest number of bicycles to be utilized and thus increasing its marketability
- Allow room for customization and the addition of accessories (warning lights, lane width indicators, lamps, storage device, etc.)
- Minimize the required set-up time to make it as user friendly and marketable as possible

The user represents the third portion of our requirements. This category defines characteristics that benefit or protect the user of the device. The six user requirements set forth are: no riding interference, ease of maintenance, small footprint for storage/ transportation, easy to adjust, lighting/ path indicators, and safety. The rationales corresponding to these user requirements are:

- Attachment should not interfere with the rear wheel, braking mechanism, or gearing
- Parts can be easily replaced with a minimal amount of tools and effort
- The device can be stored in the garage or fit into the trunk of an average sedan for transportation
- Users will be able to adjust direction snow is being deposited
- Users are able to view a projected path and avoid obstacles
- Device can pass over obstructions typically found on sidewalks
- Batteries last long enough to finish plowing all snow on sidewalk and driveway.

Cost represents the final category of our requirements. This defines how much will be spent on the project this semester. The prototyping budget will be the established ME450 budget of $400 with the sponsor offering to pitch in a small amount more if necessary. Seeing as this is a consumer product we have also set a retail target price of $200. This is based on speaking with a few local bicycle shops and benchmarking other bicycle attachment prices (i.e. kid trailers, wagons, single wheel attachable training bicycles).

KEY DESIGN DRIVERS AND CHALLENGES

After identifying customer requirements and engineering specifications, we isolated the key design drivers to guide our concept generation. We identified what the design drivers were, why they were important and a plan for analysis and validation of each. This is summarized in Table 2.

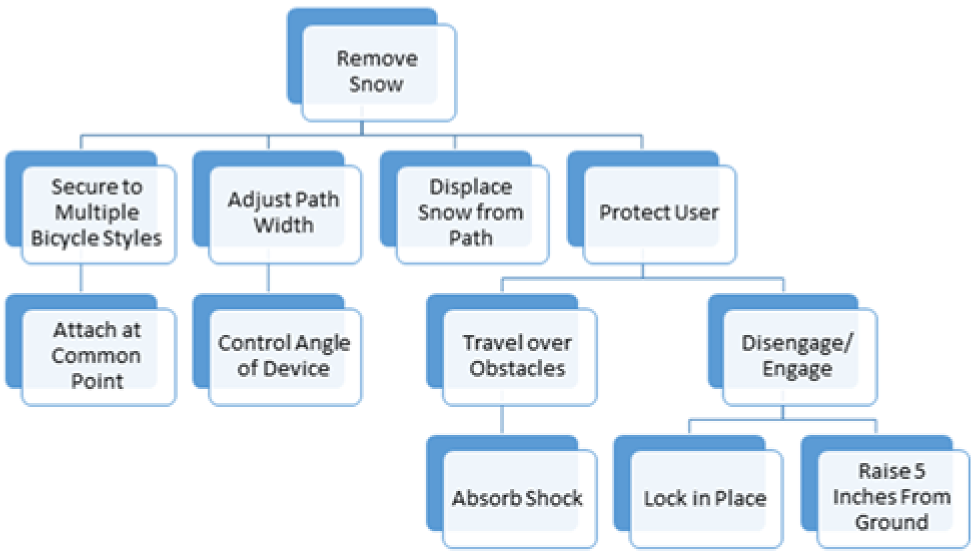
Table 2: Design Drivers Chart

Design Driver ID	Description	Importance	Design Driver Analysis	Validation
Remove snow from sidewalk and driveway	Must effectively remove snow of different densities	If this function does not work then the entire device is useless and the concept fails verification and validation	Analytical model to determine torque/RPM (if necessary). Test proof of concept without attachment	Test prototype in different snow densities
Disengage	Need to determine mechanical method to store device >5” off the ground	Allows user to ride without interference after snow is removed and reduce device wear	Analytical model linkage system to develop system with small user input force	Conduct test with multiple users to gather feedback on input force
Adjust Angle	Need to ensure the device can rotate in either direction to a max of 45°	Allows user to change the direction that snow is deposited in	Perform sensitivity test on adjustment design prototype	Conduct user test on driveway to gauge effectiveness
Easy to Attach	Need device to attach to bicycle in <5 minutes	Increased incentive for user to use this product over the existing market	Optimize the attachment for speed and strength	Focused group of users to measure average speed of attachment
Cost	Need to design prototype for <$400 and consumer product for <$200	Within our allowable budget and increased incentive for consumer to purchase product	BOM cost analysis on a component level. Proper sourcing for the materials used	Final cost comparison to pricing targets

CONCEPT GENERATION

The strategy we chose for concept generation was to generate component level concepts for each function that was identified by the stakeholders. To begin this concept generation we constructed a functional decomposition tree to identify the critical sub functions that should be accounted for and which align with our design drivers.

Figure 1: Functional Decomposition Tree



The primary function of our device is to remove snow. This breaks down into four sub-level functions: secure to multiple styles of bicycles, adjust path width, displace snow from path and protect the user. In order to appeal to the most customers, the device must secure to multiple styles of bicycles. This can be achieved through the use of a common attachment point for a majority of bicycles.

The second sub-function is that the width of the path of snow cleared must be adjustable. This is important because the width of the path will vary depending on the width of the driveway or sidewalk. To account for this the angle of the device must be adjustable. This will also allow for control of how much snow it displaces, as well as the direction that the snow is displaced.

The third sub-function is to displace the snow from the path of the device. This is important so that snow does not accumulate on the front of the device, which would inhibit its primary function of removing snow.

The final sub-function is user protection and safety. To ensure the safety of the user, the device needs to have the ability to pass over obstructions in the path without causing the user to stop or crash. To achieve this the device needs to have shock absorbing features so that when it hits an obstruction it absorbs the energy, rather than interfering with the rider's stability. When the device is engaged the frame should lock into place so it does not sway from side to side behind the bicycle and affect the stability of the user while it is being towed. Last, the device must be able to disengage once snow has been cleared to allow the bicycle to be ridden without additional resistance. These relationships can be seen in Fig.1 above.

Using a functional decomposition we discovered our critical sub-functions. These sub functions were the main topic of thought when brainstorming potential concepts. Instead of producing a full solution first, 20 concepts for solutions for the sub-functions were generated to achieve the most diverse solution pool. Using this concept pool we compiled and compared the unique individual concepts to create a super pool of concepts.

The main sub-functions for concept generation were: methods to displace snow, method of attachment to the bicycle, methods of adjusting the device angle, and engagement / disengagement of the device. During our concept generation the primary focus was on the component that would be interacting with the snow. The two main ideas for this category were to use a standard plow type design or a rotating bristle device. An idea generated for a standard plow is shown in Fig 2, with an inverted plow shown in Fig 3. The other concept to collect the snow was the rotating device with stiff bristles, as shown in Fig. 4. The rest of the component concepts can be seen in Appendix A.

To power the rotation of the bristles several ideas were generated, including: using an electric motor, using a cam system with the pedals and a pulley system with a coupler on the back tire, which is shown in Fig. 4.

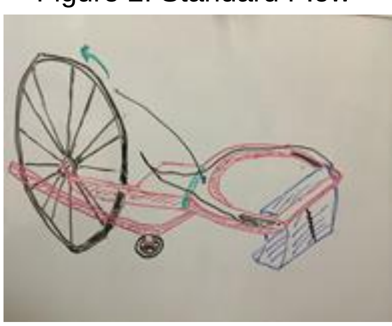


Figure 2: Standard Plow


Figure 3: Inverted Plow

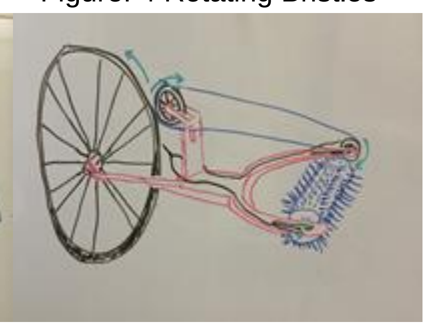


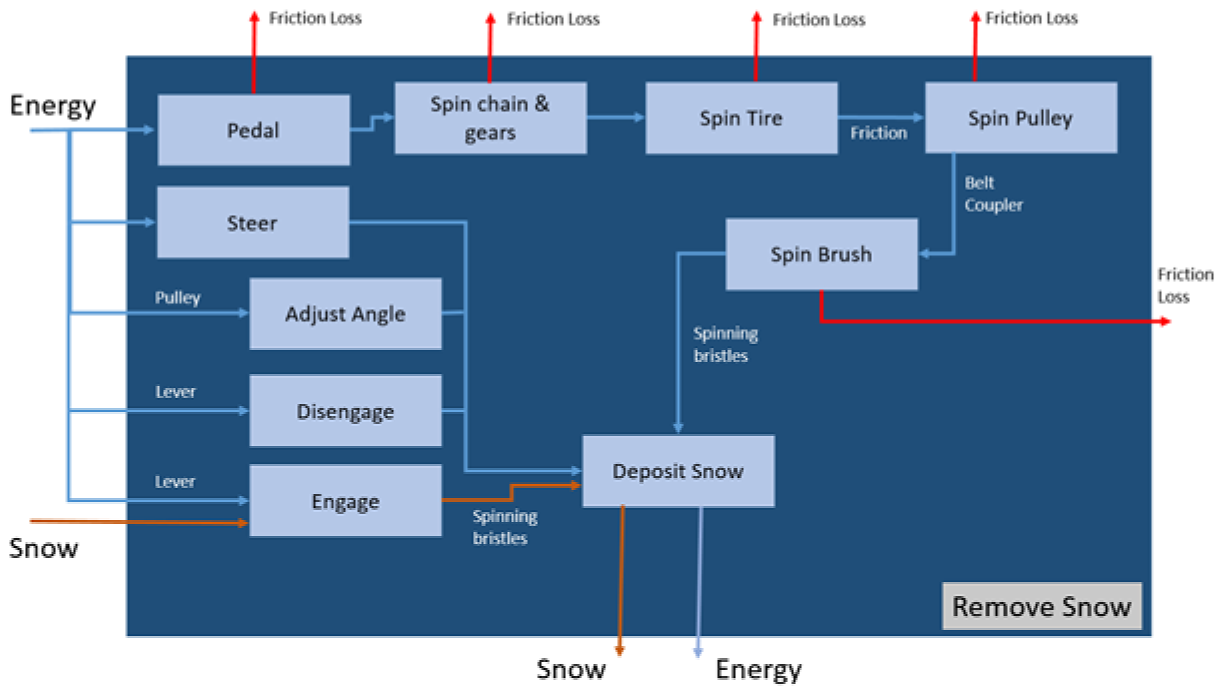
Figure: 4 Rotating Bristles

CONCEPT SELECTION

Concept selection began at the component level, similar to concept generation. After generating a pool of concepts for solutions to the individual sub-functions, we used Pugh charts for each sub-function to empirically determine the best concept. The details of the scoring and Pugh chart sub-function can be seen in Appendix B.

From the sub-function Pugh charts we were able to pick concepts that scored high the best and then combined those sub-functions to create a full system solution. While combining sub-functions, we were aware that some solutions are incompatible. To better understand how the components worked together we generated a functional structure diagram, shown in Fig. 5. The diagram shows how energy is transformed from the human input of pedaling to displacing the snow. Finally, it demonstrates how snow will travel after the device has been engaged by the user. The final energy block is the spinning bristles engaging with the snow and displacing it from the path. Figure 5 below is an example of a specific functional block diagram created for a brush system solutions.

Figure 5. Functional Structure Diagram



We generated nine full system solutions utilizing a Pugh chart to evaluate each (Appendix B). After using this system to combine high ranked sub-components we chose a final concept. This concept entails a spinning bristle powered by a motor or by the user. The bristle will be fixed on one side for power transmission through a chain and sprockets. The bristle will have the ability to adjust the angle of engagement through the use of an indexer to choose between 5 pre-set angles, 2 of which for storage. In our final Pugh chart we took both user and engineering drivers into account, see Table 2.

Consumer Criteria

We believe the primary drivers for the consumer will be cost (40%) and effectiveness (a result of many other drivers). After meeting with Mike Soloman, from Sic Transit Cycles, we came to the conclusion that a snow removal device under $300 is a reasonable retail price point and would have the best chance at selling. We hope to build the prototype for less than $400 and ultimately drive the consumer cost for production down to $200. This price is based on average costs of blades and cylindrical bristles, material prices for the fixture hardware, and other components such as bearings and bolts.

The second critical consumer driver is ease of use (20%). In order to compete against other methods of snow removal, the ease of use of our device would have to rival simpler alternatives, such as shovels, for it to appeal to the customer. We believe that having a towed, pull pin adjustable bristle will be easy for the user to understand and use. Alongside of ease of use comes set up time and storage footprint (15% each). The time required to set the device should be short. The targeted time for the device to be connected/disconnected from the bicycle is under 5 minutes. Consumers who are considering a purchase would also be weighing the size footprint of the device against the function it provides. Thus, we need to make this device foldable to minimize the size footprint of the device to allow for easy storage. However, one downfall of selecting a bristle over a plow is the bristle inherently takes up a larger amount of space. We plan to mitigate this by minimizing the frame size and adding the ability to fold it into a small footprint.

Engineering Criteria

The primary criterion for engineering aspects of the design is focused around feasibility which we split into two categories, complexity (30%) and manufacturing time (30%). This metric concentrates on our likelihood to successfully design and build each system within the limited time period. The shovel designs, inverted and regular, scored higher in complexity because of their simplistic design and high usage in the current market. The shovels are self-functional and only require bicycle acceleration to remove snow. The bristle design scored lower due to the need for a drivetrain system to power the device. This system, rather than being self-functional, requires the transmission of rotational power from the bicycle or a motor and therefore is more complex. Manufacturing time was reversed between the two designs in that the bristle scored higher because we plan to purchase it already assembled. The regular and inverted shovels scored lower because additional effort will be required to bend sheet metal and adjust the contour to develop a blade for the device.

The second critical engineering criteria is shock absorption (20%). For this, the blades scored lower than the bristle because it requires springs, dampers or another method to absorb shock that is generated by the blade encountering obstacles in the bicycle’s path. The bristles, however, are flexible and will bend over any obstacles, yielding shape to allow the bicycle to ride without obstruction.

The final two engineering criteria are: component cost (10%) and depth of snow that can be moved effectively (10%). The regular and inverted shovels both scored the same in the cost category, scoring higher than the bristle. The reason being the material and components required are identical for both the regular and inverted shovel. They only vary in orientation and contour. The bristle design scored lower in this category as a result of research we conducted on the price of implementable bristles. For depth of snow, the shovels scored higher than the bristle. This is due to the uncertainty that surrounds the bristle. While this category is very subjective and requires verification, it is our engineering judgment that the shovels can be manufactured to have a height exceeding required specifications; the bristle is being purchased at a fixed height and can only effectively remove snow up to a height equal to the center of rotation.

Table 2: Final Selection Pugh Chart

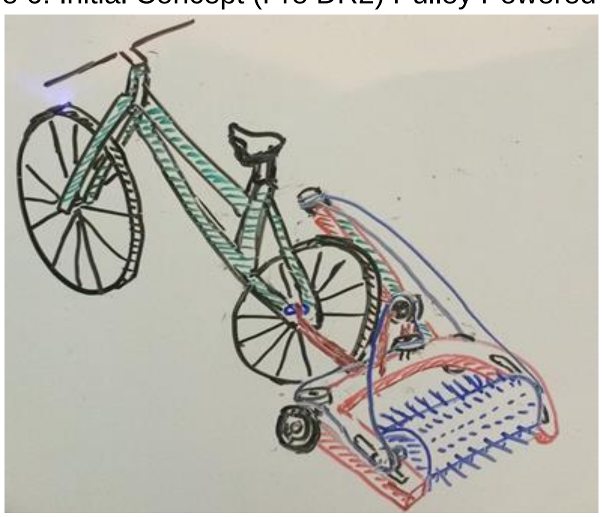
		Concept 1	Concept 2	Concept 3
CONSUMER	Weight	Inverted Plow one side axle	Spinning Bristles one side axle	Regular Plow one side axle
Consumer Cost	0.4	3	2	3
Ease of use	0.2	3	4	3
Setup Time	0.15	3	2	3
Depth of snow	0.1	3	2	3
Storage	0.15	4	3	4
Sums	1	3.15	2.55	3.15
ENGINEERING		Inverted Plow one side axle	Spinning Bristles one side axle	Regular Plow one side axle
Cost of components	0.1	3	2	3
Shock Absorption	0.2	3	4	2
Complexity	0.3	3	2	3
Manufacturing Time	0.3	2	3	2
Depth of snow	0.1	3	2	3
	1			
Sums	1	2.7	2.7	2.5
FINAL SELECTION		Inverted Plow one side axle	Spinning Bristles one side axle	Regular Plow one side axle
Consumer	0.6	3.15	2.55	3.15
Engineer	0.4	2.7	2.7	2.5
Sums		2.97	2.61	2.89

Although the bristle scored lower than both the regular shovel and inverted shovel in the final selection Pugh chart, Table 2, we chose to pursue this design. This system can be seen below in Fig. 6. The primary reason we chose this design is displacement of snow. As a result of the rotation, snow will be flung and deposited at a greater distance than what is capable of a shovel design. A second reason is multi-functionality. In addition to removing snow, the bristle can serve as a device for sweeping dirt from a sidewalk, removing leaves, and more. Additionally, one of the important criteria for our stakeholders is to have a quiet device. While the shovels would not be loud for heavy snowfall, it is a concern that during a light dusting the shovels would drag on the ground, generating lots of noise and creating wear to the device. The bristles will be nearly silent and more sustainable in light snow, which, as stated in the background, is more prevalent here in Ann Arbor with an average individual snowfall of four inches.

The main disadvantage to this design is the complex transmission necessary to power rotating bristles. As conceived below in Fig. 6, it is a series of four pulleys with the drive pulley being driven with friction against the rear wheel of the bicycle. The second and third pulleys are in place to change the direction of the belt so that it aligns with the driven pulley that is attached to the axle of the brush. There is potential for high cost depending on the bristle material chosen, the size of the bristles and the rotating drum itself. The final concern is cost of replacement parts; based on research for rotating bristle devices we found the cheapest retail can vary tremendously, reaching expenses close to our target price.

The concept in Fig. 6 was chosen prior to Design Review 2. After performing torque and RPM calculations, the pulley system to spin bristle was replaced with an electric motor due to user power input constraints and system complexity. This system will now rely on a chain and sprocket transmission mounted near the bristle and powered by batteries. By changing to this design we increase device effectiveness, reduce the overall size, and lower the system complexity. The finalized system will be discussed in detail below in the description of final design section.

Figure 6: Initial Concept (Pre DR2) Pulley Powered Bristle



DESCRIPTION OF FINAL DESIGN

This section will describe the final design. The key features of this design include: a lever and four bar linkage to disengage, an indexer to control the direction of snow displacement, a motor and sprocket to spin the bristles and a battery to power the motor. All these features can be seen highlighted below in Fig. 7.

Figure 7: Isometric View of Snow Removal Device

The first feature of this design is the ability to disengage the bristle by the use of a lever and linkage system. The rider pulls the lever while the bike is stopped, causing the links to lift the bristles off of the ground (Fig. 8). As the lever is pulled up, the pin slides along the disengagement mechanism into the slot. When the lever is released, the weight of the bristle pulls it back into the slot and hold it in position. This allows for the bristle to be towed easily because the back wheel supports the load while it is disengaged.

Figure 8: Snow Removal Device when Disengaged

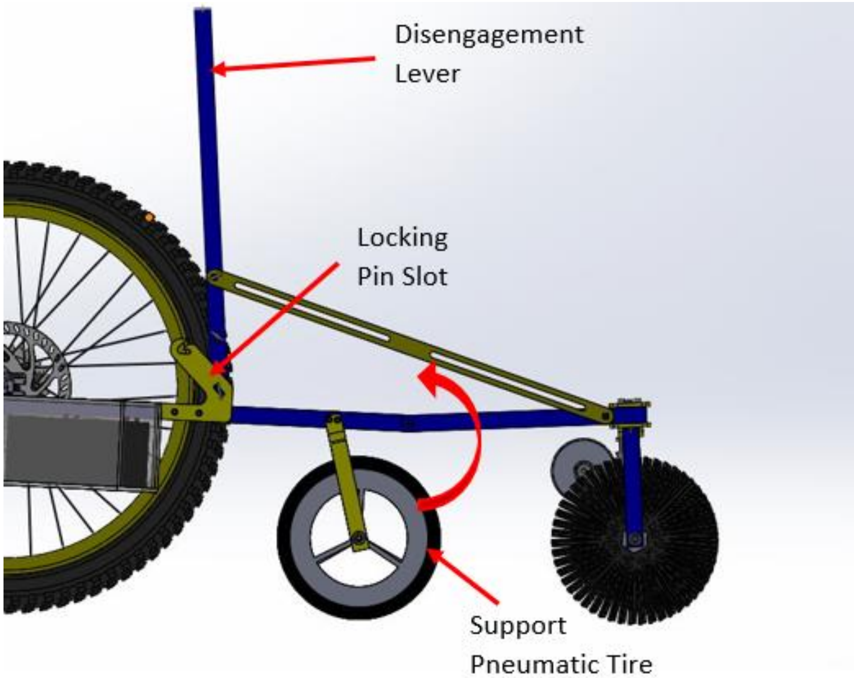
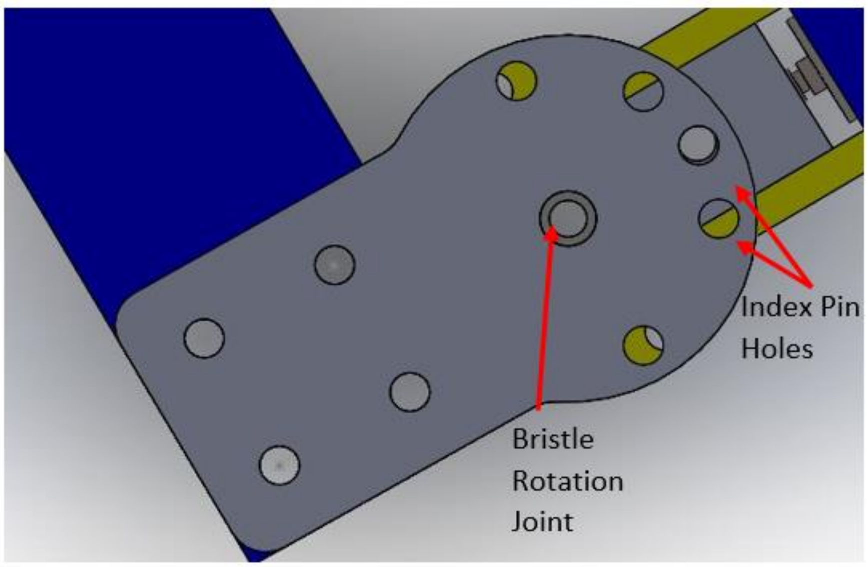


Figure 9: Indexer Adjustment Features



For the angle adjustment feature, we have designed a pin and indexer mechanism. This feature allows for adjustment of the angle up to 30 degrees from parallel to the bicycle's back tire axle, in the clockwise direction as the pull pin holding the angle engages with the indexer and cross bar. The pin has two notches at its end which are spring loaded to lock the bristle in place. This ensures that the pin does not does not come out while riding and angle of the bristle is maintained. The angle can be changed by pulling the pin up through the indexer, adjusting the top cross bar to the desired angle and reinserting the pin.

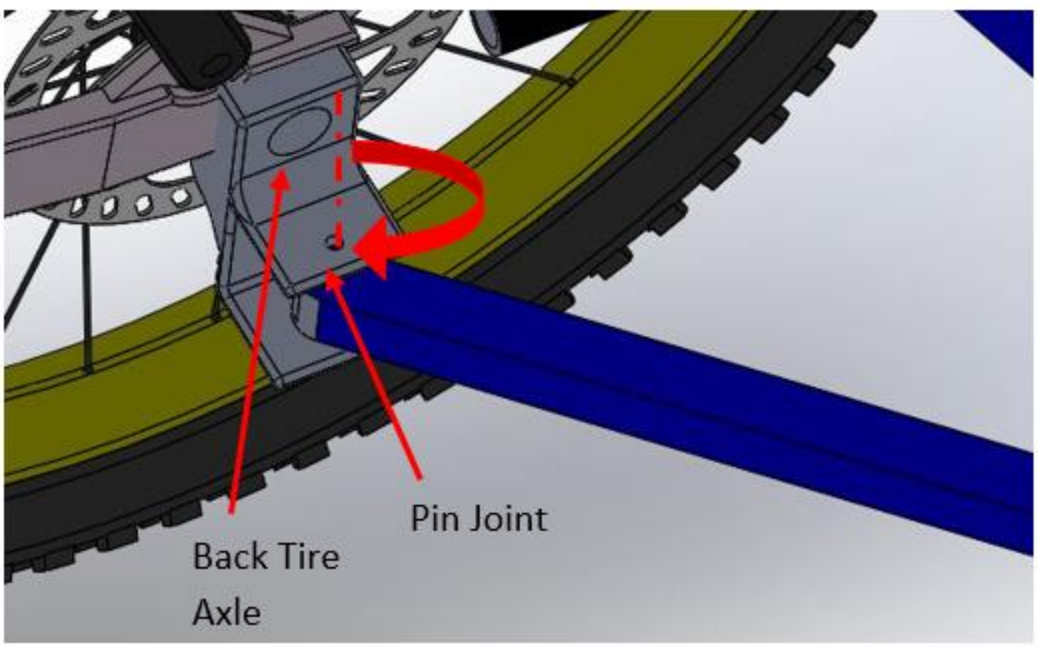
Figure 10: Bristles in 30° Indexed Position

The rotation of the bristles is driven by a motor. The motor is mounted on the frame that holds the bristle. A sprocket is attached to the bristle axle in order to transmit the rotational motion and increase/decrease the torque/RPM respectively by a factor of 5. The motor is connected to the sprocket through the use of a #25 chain. The axle is supported by two bearings on each side located in the frame around the bristle. The shaft diameter is 0.5” through the bristles and sprocket, but 0.25” in the bearings due to size limitations. This is done to match the size of the sprocket bore we needed for our 1:5 transmission while keeping the device structure small. A axle diameter larger than 0.25” requires bearings that can only fit in a larger frame. These features can be seen in fig. 11 and fig. 14.

Figure 11: Motor, Sprocket, Bearing and Locations

The joint at the bicycle attachment point allows for quick attachment and detachment while also enabling rotation to allow for tight turns to be made by the bicycle. The quick attachment and detachment are achieved through the use of a pin joint. This pin joint allows for lateral rotation perpendicular to the tire axle as the bike turns. To prevent excessive lateral forces, a pneumatic tire is used to keep the device on a forward path, but allow for rotation perpendicular to the back-tire axis.

Figure 12: Attachment Point to Bicycle

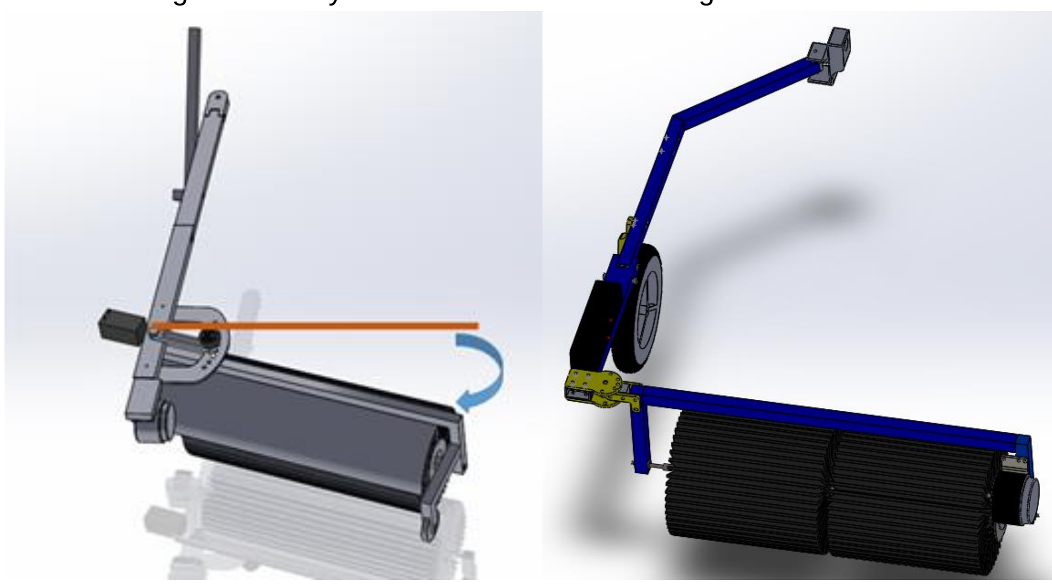


Design Updates

Bicycle Attachment Bar

In the initial CAD model for the link connecting to the bicycle was a straight bar. The bristle was then offset fully from the side of this bar, as shown in fig. 13. This has since been changed to rearrange the bristle to be centered behind the back tire. To do so, we split the straight bar into two pieces that first connect to the bicycle at an angle, giving separation from the left side of the bristle to the back tire, and then connecting at a 45° angle to become straight again. This not only centers the bristle assembly behind the back tire, it also gives the bicycle attachment joint more freedom to rotate during turns. The new attachment bar can be seen in fig. 13.

Figure 13: Bicycle Attachment Part Redesign



Motor Placement

In the early stages of our design we mounted the motor near the yaw axis of rotation. This design required the use of a coupler to transmit the axle rotation as the bristle yaws. After doing research on couplers, we found that all couplers within our budget, in the range of $50, do not meet the specifications set forth for our design (30° angular rotation at a max of 3.7 ft-lbs of torque). As a solution we, redesigned our transmission to mount on the side of the bristle opposite of the axis of rotation. By doing so, we eliminated the need for the coupler, making our device more effective and cost efficient.

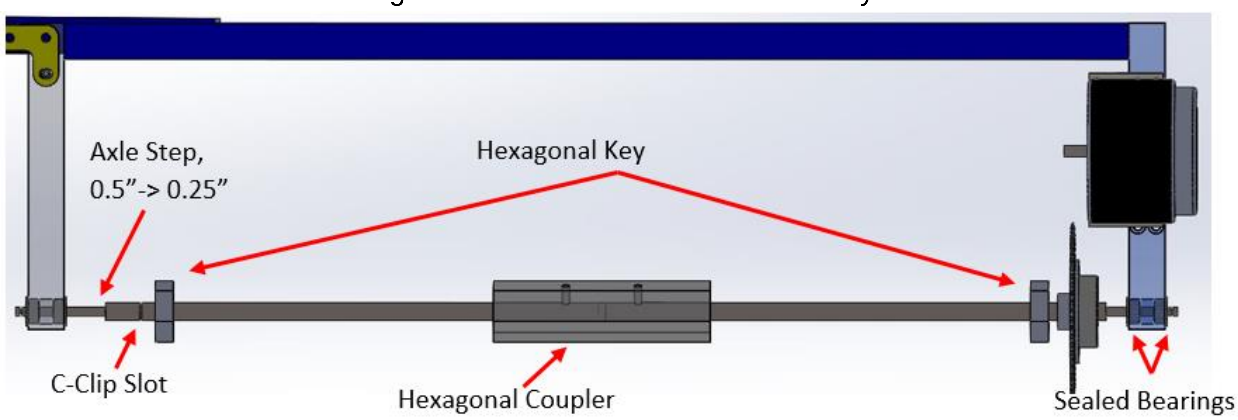
Bristle Roll Joint

While designing the height and compatibility of our device, we realized that if the bristle is set to an angle of -30° and needs to pitch downward to contact the ground, it is constrained by the indexer. Therefore, the transmission side of the bristle be suspended above the ground. To resolve this, we added a roll joint near the indexer to give the bristle freedom to adjust height and always fully contact the ground. This involves using a double pin joint on two separate hollow rectangular tubes that are connected by a square aluminum insert.

Bristle Axle Connection

The bristle we are using is a replacement part for the Stihl Yard Boss. This bristle is driven by a 1.5" hexagonal key shaft, which we have adopted and are using to connect to our transmission drive shaft. We are doing this with two 0.5" axle shafts that are turned down on the ends to 0.25", allowing the axles to fit inside bearings mounted on both sides of the bristle. The bristles are modular, split into two 12" lengths. Therefore to connect the pieces with our axle we are using two drive shafts coupled by a hexagonal key. This hexagonal key serves as a multi-purpose component, allowing us to couple the 12" bristle modules and allowing for easy disassembly of the axle and drivetrain assemblies.

Figure 14: Bristle Drive Shaft Assembly



Support Wheels

A 30" bar is used to space two 1.75" wide, 8" diameter wheels. The wheels are held in place by supports that are cut from 1" aluminum plate on the water jet. A 0.5" axle turned down to 0.25" at both ends is used to keep the wheels aligned.

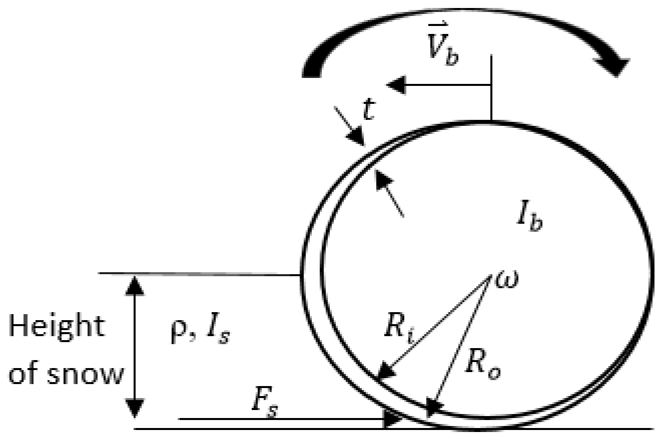
ENGINEERING ANALYSIS

This section will discuss the engineering analysis we performed on critical components of the design. Analysis includes: speed and torque requirements for the bristle, range of angle adjustment, disengagement of the mechanism, ease of attachment, and cost.

Remove Snow from Driveway/Sidewalk

This analysis is to satisfy the requirement for removing snow from the path of the device. The selected mechanism for removing snow is a rotational bristle. This system relies on stiff bristles bending and creating a flinging force to project snow. The purpose of this analysis was performed to determine what torque and RPM is required to remove snow in the max height (7") and max density (37) conditions within the scope of our project. We formulated a model for the bristle and created a free-body diagram of the bristle to look at the forces generated by contact with snow at the maximum operational riding speed (10 mph).

Figure 15: Bristle Free Body Diagram



The first calculation we performed was to set a low-end RPM threshold. The linear momentum from the bicycle is equated with the rotational momentum of the bristle (eq. 1-6). We then calculated the rotational velocity (ω) of the bristle needed to oppose the linear snow velocity () and determined a maximum operating RPM. This maximum was calculated using the worst case conditions of engaged snow height (R), density of snow (), and the speed of the bicycle () as shown in eq. 2 and 6. These extreme conditions are rare, however they provide us with an order of magnitude for reference purposes.

Eq. 1: $I\omega = Rm_s\overrightarrow{V_b}$ Eq. 2: $m_s = \rho_s V_s$ Eq. 3: $I = I_b + I_S$ Eq. 4: $I_b = \frac{1}{2}m_b(a^2 + b^2)$

Eq. 5: $I_s = \frac{1}{8}m_s(c^2 + b^2)$ Eq. 6: $V_s = RLt$

In equation 1: I is the total inertia of the brush system, ω is the rotational velocity of bristle, *R* is the engaged snow height, m_s is the mass of the snow, and V_b is the speed of the bicycle.
In equation 2: m_s is the mass of the snow, ρ_s is the density of snow and V_s is the volume of the snow.
In equation 3: I the total inertia of the brush system, I_b is the inertia of the bristle, and I_s is the inertia of the snow layer on the bristle.
In equation 4: I_b is the inertia of the bristle, m_b is the mass of the bristle, *a* is the inner diameter of the hollow bristle and *b* is the outer diameter of the bristle.
In equation 5: m_s is the mass of the snow, *c* is the radius corresponding to the centroid of the snow engaged in the bristle, *b* is the outer diameter of the bristle.
In equation 6: V_s is the volume of snow, *R* is the engaged snow height, *L* is the length of the bristle, *t* is the thickness of snow engaged with the bristle.

The second set of analysis was performed to determine the torque (τ) required to move snow with a maximum height and worst case density conditions as stated above. We summed moments about the rotational axis of the bristle with the primary force being applied by the snow as a result of the acceleration needed to move the mass of snow 45° (eq. 7,8). This angular value was chosen based off assumptions made from viewing previous bristle devices such as the SnowBuddy.

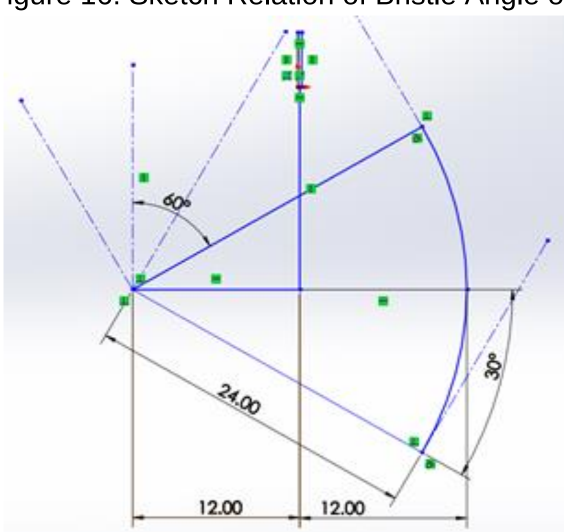
After performing these analyses, we determined a minimum rotational speed of 350 RPM and a maximum torque value of 23 Nm is needed for the most extreme conditions mentioned above. Following these conclusions we set expected nominal conditions of 5 mph, 5” of snow at 9 lb/ft^3 density. With these nominal conditions we determined that a speed between 200 - 350 RPM and a torque of 2 - 4 *lb-ft* is required for typical operation.

A free-body diagram analysis was chosen because it is simple and quick compared to creating a prototype. This type of model is appropriate because with appropriate assumptions it provides an order of magnitude for the upper and lower bounds. Knowing these values allows us to design with a safety factor along with ensuring proper components are selected. However, consequences exist in this model in regards to the bristle dimensions. The bristle component has not yet been finalized and changing the diameter will vary both our RPM and torque requirements.

Angle Adjustment

This analysis is to satisfy the requirement of adjusting the angle of device and no interfering with the user. A sketch relation model was necessary to determine the arc angle and position needed for our adjustment indexer. To do so, we assumed a 24” bristle length and adjusted the angles while assessing snow projection perpendicular to the surface of the bristle. This process can be seen in the figure below.

Figure 16: Sketch Relation of Bristle Angle of Rotation



After drawing the sketch relation, we determined that a rotational angle of 30° is the maximum allowable angle fore and aft of perpendicular to the bike. This ensures that the snow is projected off the path and not at the rider or bicycle.

This sketch was created assuming 1 foot of snow displacement (perpendicular to brush). The distance was chosen to ensure snow that engages on the brush will shoot clear of the path while the bicycle is moving forward. Using this logic reduces the effort and energy wasted by shooting snow forward onto the path and then re-engaging it. However, after further analysis of the speeds and torque required to do this, we performed our later calculations using a snow displacement of 3-6 inches in front of the bristle.

Disengagement

We performed theoretical analysis and modeling to determine the mechanical advantage of the disengagement mechanism along with reducing the amount of input force required to disengage the device.

We performed output over input transfer function calculations to determine a rough estimate of the mechanical advantage in our lever design. In doing so we took the results and performed many reiterations of the system attachment points to determine the best combination of lever arm placement for user interaction, and the mechanical advantage. This can be seen in figure 15.

The transfer function is given by equation 7 below:

Eq. 7: Mechanical advantage of the hand-bar disengagement linkage assembly.

$$MA = \frac{X}{Y} * \frac{Perp.Hand\ Radius}{Perp.Weight\ Radius}$$

Where X is the variable distance on the indexer bar and Y is the variable distance on the lever, as shown in fig 17. The perpendicular hand radius is the distance from the ground on the lever to the end of the lever, as shown by the line in green. The perpendicular weight radius is the distance from the ground on the lever to the end of the indexer bar, as shown by the line in green. In our analysis, the perpendicular hand radius was constant at 24" and the perpendicular weight radius was constant at 14".

The analysis performed was done by varying the values of X and Y and determining the mechanical advantage of each configuration (Figure 17). From the analysis, we found that the hole on the lever was already in the optimal position and that the hole location on the indexer was too close to the ground on the indexer link. Analysis showed that for the highest mechanical advantage, smallest user input, the hole location on the indexer link should be as far from the ground on that link as possible.

This analysis was performed after validation testing on the disengagement linkage as part of an engineering change notice. Figure 18 shows the mechanical advantage relationship with hole location on the lever and the indexer link.

Figure 17. Sketch Relation on Disengagement Linkage

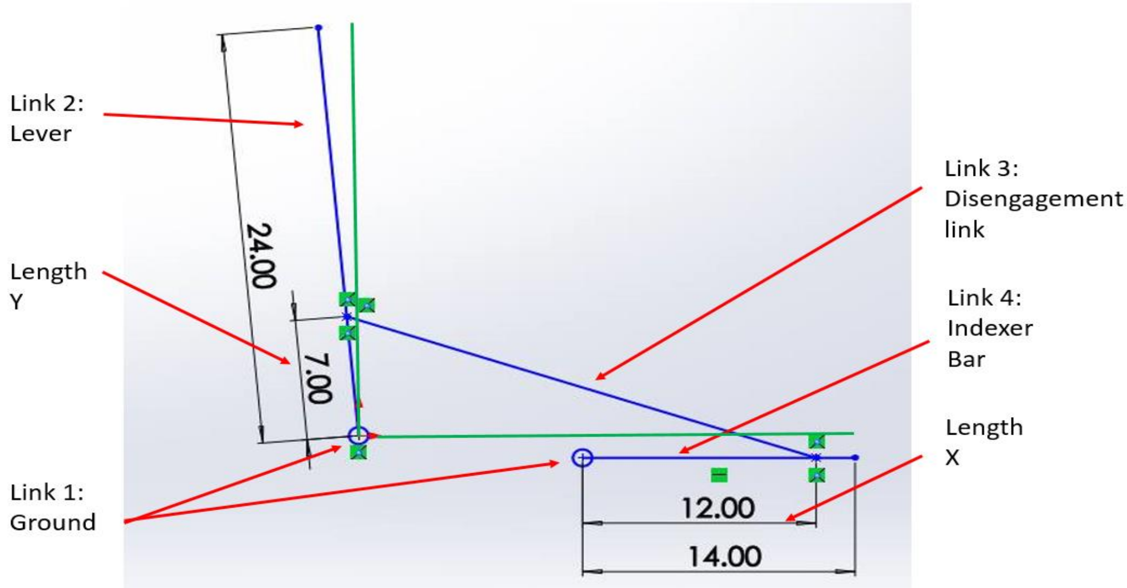
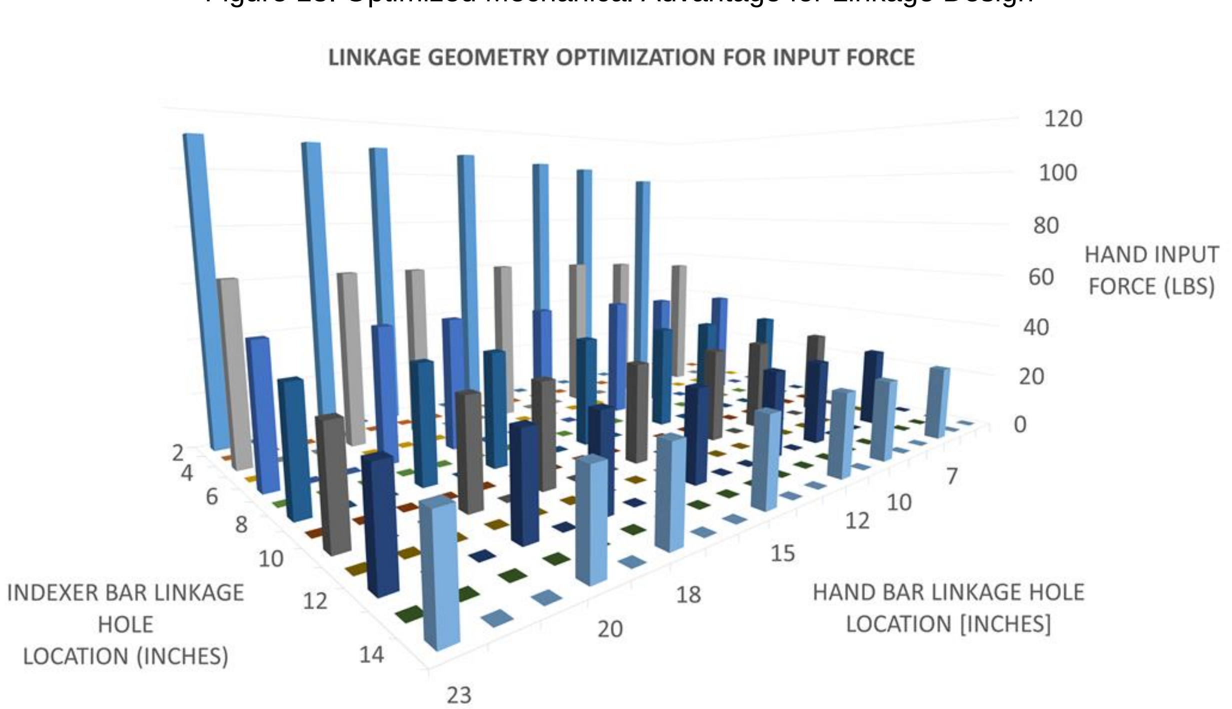


Figure 18. Optimized Mechanical Advantage for Linkage Design



Easy to Attach

This design driver focuses around the simplicity of the attachment method rather than force, torque or speed requirements. Therefore, our analysis plan for this design driver is to perform validation testing with our first prototype and onward. This will allow us to gather feedback from our stakeholders on the time needed to attach the device to a bicycle and use this feedback to redesign and minimize the time.

Cost

For cost a theoretical/empirical model is not applicable, rather, we will perform trade studies to reduce material and component cost. These trade studies will be performed to optimize the components in our system (i.e., different motors, batteries, motor controllers and transmission parts). Furthermore, we have performed and will be continuing to perform trade studies comparing materials for the links and brackets.

System Level Testing

Once the component level validation is complete we will move forward with validating the performance on a system level. This will be done via empirical and qualitative testing with multiple users (including our sponsor). Currently our plan is to test the device within MCity and on local sidewalks in Ann Arbor to test multiple environments of use for the device.

RISK ANALYSIS

This section will discuss the risk analysis and failure mode effects analysis (FMEA) we performed. The table on the following pages contains all of the functions.

Table 3. Risk and Failure Modes Effects Analysis

Function	Potential Failure Mode	Potential Effects of Failure	Severity	Potential Causes of Failure	Occurence	Current Design Controls	Detection	RPN	Actions Taken
One Side Axle Attachment									
Attaches device to bicycle	Attachment point breaks	Device will no longer function	9	High stress due to loading, bending and/or oxidation	1	Pivot joint, test and validate	6	54	Joint with greater than 1 DOF, stress analysis and design changes
	Attachment point loosens	Device will be ineffective or no longer function	8	Poorly assembled, vibrations	3	Choose strong and robust connection method, test and validate	4	66	Robust joint with resistance to vibration impacts
	Mobility is too high	Device swings out of control and causes user to lose balance or becomes trapped in snow	4	No restriction on free rotation of the trailer	2	Choose joint that has indexed restrictions	3	24	Sufficient weight to limit motion and robust joint to limit degrees of freedom
	Mobility is too low	Device causes user to tail end and crash into an obstacle	4	Too much restriction set on free rotation of the trailer/somethin g becomes jammed or stuck in the joint	2	Choose joint with appropriate rotation, test and validate	3	24	Joint to ensure enough degrees of freedom
Angle Adjustment Pin									
Enables user to change the angle of orientation of the device	Spring pin fails	The pin no longer has potential energy that enables it to lock the bristle at different angles, this leads to free rotation of the bristle	6	Internal spring loosens or breaks	2	Choose appropriate springs, with high enough stiffness and appropriate load bearing characteristics	6	72	Increase the diameter of the spring pin, reducing stress
	Vibrations	Vibrations during use cause the pin to jump out of the hole leading to free rotation of the bristles	6	Low depth in the groove	3	Choose a pin with a large length	2	36	Increase the depth of the slot that the indexer pin rests in
Indexer									
Allows user to set angle of the device	Debris in the holes	User has difficulty or is no longer able to adjust the angle of the device	3	Snow, salt or ice buildup in the hole	3	Shield to protect holes from snow, ice and debris	3	27	Housing to protect the slot
Disengagement Lever/Pulley									
Enables user to disengage/enga ge the device	Bristle weight is too high	User cannot disengage device	5	Mechanical advantage of linkage system is too low	2	Mechanical advantage calculations, free-body analysis, material selection	3	30	Selecting lightweight material and redesigning placement of lever to reduce moment

Function	Potential Failure Mode	Potential Effects of Failure	Severity	Potential Causes of Failure	Occurence	Current Design Controls	Detection	RPN	Actions Taken
Disengagement Locking Method									
Enables user to lock the device in a disengaged position	locking mechanism fails	The disengaged device falls down and re-engages the ground	4	Stress from lever, freezing, spring breaks	1	Test and validate	7	28	Add mechanism to lock it in place
	Lever wont dettach	Disengaged device is difficult or cannto be re-engaged to remove snow	7	Too much weight on the locking teeth, rust/debris stuck in the teeth, teeth frozen	2	Peform debris testing in extreme conditions and validate	2	28	Reduce weight of device by modifying bristle fixture
Bristle									
Rotates and contacts snow to remove it from the path	Bearing breaks	Axial shaft loses freedom to rotate, leading to wear on the axle, heat generation and overall system performance issues or failure	8	Radial forces cause the bearing to crack	1	Perform FEA for stress contour information	10	80	Redesigns performed to reduce high stress concentrations
	Bristles break and/or fall off	Reduction of device performance and possible failure	3	Torque loading from higher density snow and contact with the road	6	Test and validate	2	36	High packing density of bristles
	Coupler Fails	Bristle loses ability to rotate and have variability in the angle	7	Friction from oxidation/debris	2	Test and validate	3	42	Corrosion resistant material selected
	Not enough torque to overcome volume of snow	Bristle is unable to rotate and the bicycle and device become stuck	9	High volume of high density snow or ice	2	Free body analysis using maximum operating volume and snow density values	2	36	Safety factor for transmission system
Motor									
Transmits rotational power to the bristle	Overheats	Loss of rotation and ultimate device failure	8	Torque demand on bristle is too high	1	Free body analysis using maximum operating volume and snow density values	2	16	Shutoff controls and allowed slippage of the belt

Function	Potential Failure Mode	Potential Effects of Failure	Severity	Potential Causes of Failure	Occurence	Current Design Controls	Detection	RPN	Actions Taken
Belt and Sprockets									
Transmit rotational power while varying torque/speed ratio	Belt too loose	Bristles slip constantly resulting in low effectiveness	6	Belt length is difficult to calculate and thermal expansions	2	Perform CAD measurements and choose low thermal expansion materials	2	24	High tolerances on belt length and considering including tensioners
	Belt slips on sprockets	Bristles slip constantly resulting in low effectiveness	5	Snow/water buildup on the sprocket(s) surface(s)	5	Material selection. test and validate	3	75	High tolerances on belt length and considering including tensioners and/or housing for sprockets
Power Source (Battery)									
Provides electrical power to the motor	Shorts	Loss of power to the motor leading to loss of rotation and primary functino of the device	8	Electrical wiring is poorly insulated	1	Insulation material selection and wiring plans	5	40	Adding excess insulation with little to no contact with the aluminum surface of the device
	Low capacity	Device is operable for a short period of time and dies during use	4	Poor charging capability and poorly selected power source	2	Motor and power source selection	4	32	Carefully selecting a motor and power source to have necessary capacitance
Hinge									
Allows for bristles to rotate upward/downward into a disengaged/engaged position	Pin connection breaks	The bristle portion of the device breaks off and loses all function while being potentially damaged	10	High stress concentrations on the pin joint	1	FEA analysis of initial CAD design	9	90	Performing iterative design to reduce/remove stress concentrations

As shown in Table 3 above, the component with the highest risk is the hinge joints. If these joints fail the device will fall off the bike, rendering it useless and possibly injuring the user and others in the process. This, however, would be a rare occurrence because the hinge direction of rotation allows for the bristle to support itself. To further characterize this failure mode, we will perform final design FEA, after characterizing the size and weights of our components, such as the motor and power source. We are also implementing design changes to reduce the risk of the hinge by supporting the bristle with at least one caster wheel while engaged and while disengaged. This can be seen in Fig. 7 and 8.

PROTOTYPE

This section will discuss the progress on the prototype. This includes the type of prototype that will be built, material choice, outsourced components and machining processes involved in manufacturing the prototype

We produced a full-scaled, high-fidelity prototype as per request of our sponsor. The bristle is able to disengage via a lever and have angle adjustability of the bristle with a locking pin and preset indexer holes. The prototype was tested for functionality upon assembly and has been presented to our sponsor. Primarily the prototype will be fully functional to clear snow from both sidewalks and driveways.

The material choice for the frame around the bristles is multipurpose 6061 Aluminum. This was chosen because it is lightweight and corrosion resistant. These criteria were set because the device will be lifted, towed and stored frequently while also exposed to water, snow and salt. Where possible, hollow aluminum tubing is used to further reduce weight, such as in the bars attaching the bike to the bristle frame and in the cross bar. The axle is to be made out of stainless steel, which was chosen for its high strength, resistance to wear, and resistance to corrosion, all necessary because this part will be constantly in contact with snow and salt.

Outsourced components used in the prototype include the bristle, motor, batteries, throttle controller, sprocket, steel ball bearings and the bushings. The bristle was purchased from a Stihl supplier store, while the motor, throttle, and controller were ordered from eBay. The bearings, bushings and thrust bearings were purchased online from McMaster-Carr.

Parts with complex geometries, such as the disengage lock, indexer and disengage links have been made with the waterjet. Most of the main structure was manufactured from square or rectangular aluminum stock via a mill. The bristle axle was faced and turned to size on the lathe. Bushing and bearing holes were reamed to ensure the tolerances are met.

Our manufacturing plan was to manufacture parts specific to certain systems. By doing so, we were able to complete the subassembly of different modular systems such as our disengagement assembly and indexer. This allowed us to focus on assembly and manufacturing in parallel and speed up the assembly required for the full prototype, allowing us to begin wiring and validation testing sooner.

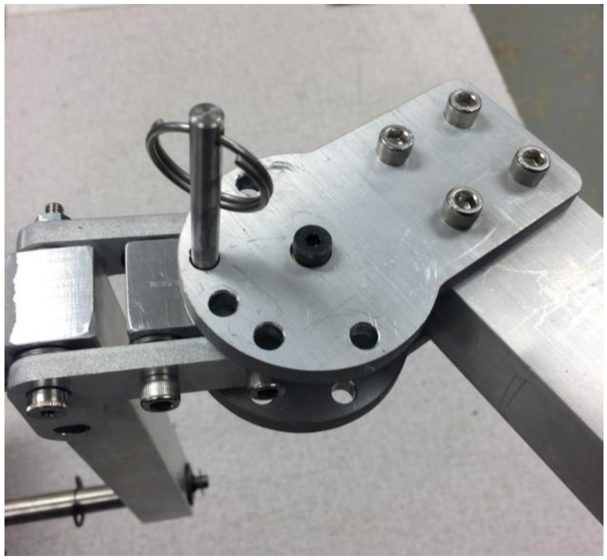
Electrical components such as the motor, controller and batteries were installed once the main structure of the device had been assembled. We then installed the full system on a bicycle and ran validation tests for maximum operation time, bristle functionality and disengage functionality.

ASSEMBLY

This section discusses the assembly process, along with issues that were not foreseen during the design phase.

The first issue that we encountered was alignment of the indexer system, making it more difficult to insert the locking pin. To lock the brush arm to the rest of the assembly, the spring pin is inserted into the top indexer, through the center block that is linked to the brush assembly and through the bottom indexer piece as seen below in figure 19. During the design phase we knew that the holes needed tight tolerances because any excess clearance would be amplified by the moment arm of the brush assembly (approx. 30”) and create slack. With this reasoning we made all 3 holes in the alignment ¼” diameter “close fits”. This proved to be too tight of a tolerance because each piece was manufactured (and mounted) independent of the other pieces in the alignment. This problem was mitigated by slightly increasing the middle bristle-linked bushing diameter from ¼” to 0.2520”. This change allowed us to insert the pin much easier than before, however, there is still difficulty in inserting the pin when the bristle is not resting on the ground.

Figure 19. Indexer Assembly



Another issue that arose was the force required on the lever to disengage the device. When the device was assembled, we realized there was not enough mechanical advantage to easily disengage the bristles. There were two causes of this issue, the first being that the links connecting the lever to the indexer bar attach too closely to the pivot joint, limiting the mechanical advantage. The second issue is the weight distribution of the bristle sub-assembly, mainly due to the motor being mounted on the side opposite of the pivot joint. To correct these issues we remanufactured longer disengagement links that attach towards the end of the indexer bar (i.e. closer to the indexer) and higher on the lever. This can be seen in figure 20 and 21.

Next, we realized that mounting the motor on the unsupported side of the bristles produces a significantly large offset moment. This made it difficult for the bristles to be disengaged because the moment causes the bicycle to tilt to the right. To fix the issue, two wheels, 30” apart from each other were added to support the moment created by the motor. This bar was made compatible with the wheel axle supports and was implemented in that location.

Figure 20. Disengagement Assembly Prior to Design Changes

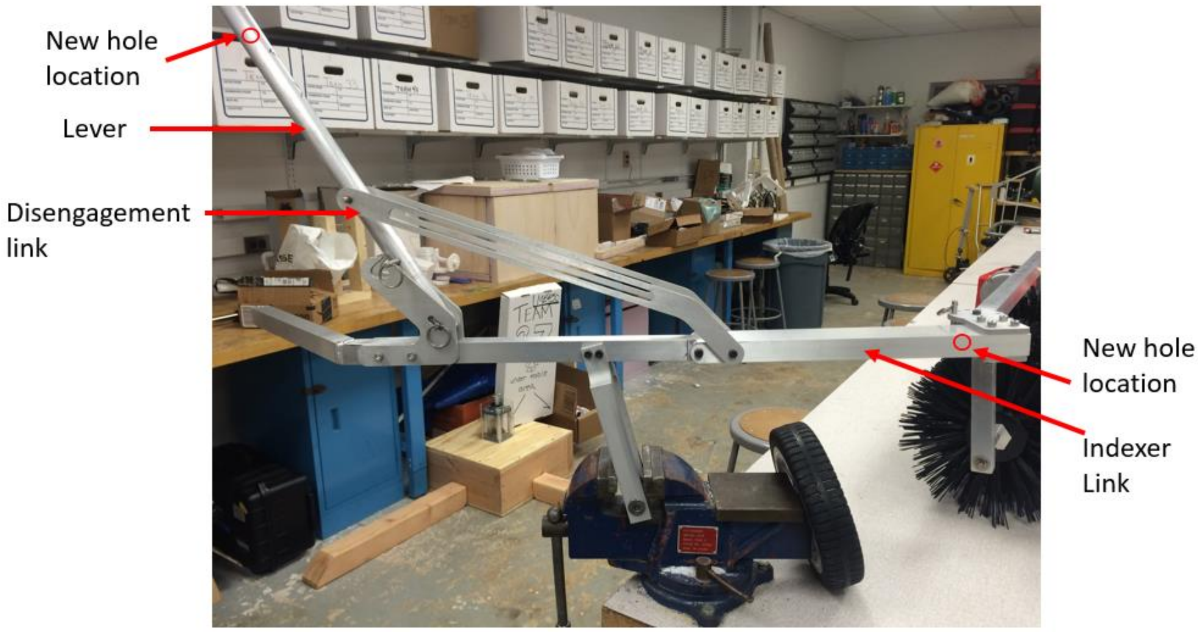


Figure 21: Disengagement Assembly with Design Changes

ENGINEERING CHANGE NOTICES

Several design changes have occurred since DR4, a few very minimal for assembly purposes and a few more severe due to functionality impedances. The smaller changes focused around reducing the length of the bristle axles to allow for easier assembly and disassembly of the bristle transmission. The more severe changes focused around significantly increasing the disengagement systems mechanical advantage. This issue has been discussed above in the Assembly section. All ECN's performed can be seen in Appendix F.

An ECN was issued for the indexer bar where the disengagement links attach. During validation of the disengagement linkage, we found that it was too difficult to move the lever and disengage the bristles. From this, we performed analysis to determine where the hole locations should be for optimal mechanical advantage, as discussed in the Engineering Analysis section. Based on this, the holes on the indexer bar were moved and the holes on the lever remained in the same location.

The lever had an ECN issued after validation testing of the locking mechanism. We found that the pin that goes into the locking slot was too low on the lever and inhibited disengagement. From this, we changed the hole to a slot and implemented a spring system to lift the pin in the slot. Further validation testing verified that the slot allowed for proper disengagement.

The disengagement links had an ECN issued once the holes on the indexer had been moved. This change was made so that the links were long enough to reach from the holes on the lever to the new indexer holes, see Appendix F, Figure F.9.

The sprocket had an ECN issued during assembly of the transmission because there was no way to accurately drill a set screw into the sprocket and rigidly fix it to the axle. To resolve this issue, we designed a sprocket adapter to attach to the front of the sprocket and have a set screw thread through the adapter to attach to the axle, see figures F.5 and F.6.

During validation testing with the device attached to the bike we found that the device had a tendency to swing out from behind the bike and there was not enough support for disengaging the bristles. To correct this issue, an ECN was made to add a cross bar and additional wheel, so that the second wheel would help support the weight and prevent the device from swinging out. This bar was attached to the fame and is made out of one inch, square aluminum stock. As a result an engineering change notice was made to extend the wheel shaft so that the wheels could be placed on either end of the wheel cross bar.

During the final assembly, we found that attaching the battery cage to the top of the bent bar would be too difficult. To change this, we created brackets so that it could be hung on the bar or in a desired location, and easily detachable rather than mounted on top.

VALIDATION PROTOCOL

First we performed validation testing of our smaller systems, the indexer and disengagement that can be tested without the device attached to a bicycle. This proved immediately useful and led to some critical design changes to improve functionality. After completing the changes which included modifying the disengagement system to improve the mechanical advantage, we were able to validate that these systems met the design specifications. Validation of the indexer was performed by removing the pull pin and testing the ease and time required to change the position of the bristles relative to the bicycle. The disengagement system was validated by confirming the system locked in the upwards position, was easy to lift, and did not impact the stability of the bicycle and rider. Ease of lifting and stability were determined by user feedback.

We performed multiple iterations of validation testing with the device attached to our sponsor's bicycle, each time performing the tests with him as the rider and recording what we see and his feedback. Immediately we noticed that with the bristles rotating, the reaction force was much greater than we originally anticipated, causing the device to swing out until perpendicular with the bike. Additionally this reactional force along with the frictional force generated by the bristles caused the necessary user input power to be higher. Speaking with our sponsor we determined this input was not excessive and is an allowable amount. We also noticed that while disengaging the system, the weight was unsupported and the moment of the device caused the bicycle to sit off balance. These results led to changes discussed in the Engineering Change Notices section, such as adding a cross bar and expanding the wheel axle to add an additional wheel to support the disengaged weight. To fix the reactional sway of the device, we added a steel cable attachment between the bicycle adapter and the device frame, see figure 22.

Figure 22: Steel Cable to Eliminate Excessive Device Rotation

As a result of weather conditions we were unable to properly validate the device's snow removal capabilities and the operating time at max conditions. However we were able to perform simulation tests on leaves, gravel and soil where the device performed as expected, removing all from its path. We ran the battery for a series of hours at a low load application to get a general idea of the battery life, outside of actual operational load cases. Future testing will need to be performed in a variety of snowy conditions to evaluate the effectiveness of the device and whether or not the specifications are met. Details of all validation protocols and procedures can be seen in Appendix G

FUTURE WORK

This section will discuss our recommendations for the project moving forward along with comments on moving from a prototype to mass production.

Summary of Recommendations:

1. Move motor closer to the pivot location for easier disengagement and device performance and explore alternative materials to reduce the overall weight.
2. Rather than use an attachment that only has a lateral degree of freedom use a ball joint.
3. To increase the mechanical advantage, redesign the disengagement links along with the bars they are attached to.
4. Implement actuators and controls to allow for full control of the bristle assembly while riding the bike.

Our first recommendation is to both, redistribute and reduce, the weight of the device. We believe the largest improvement can be achieved by moving the motor closer to the rotating side of the frame. This would eliminate an unnecessary moment on the device when disengaging the bristles. We also recommend reducing the overall weight, which would reduce the effort to tow and disengage the device. This may be achieved by exploring the use of alternative materials such as plastics, fiberglass, carbon fiber, etc.

Our second recommendation is to replace the trailer hitch with a ball joint. Currently, the trailer hitch constrains the bike from being able to tip from side to side. A ball joint would allow for this extra degree of freedom, although it would increase overall cost and require additional validation testing. This will not only improve functionality, but will also significantly improve the rider’s safety while turning or mounting their bike.

Another recommendation is to redesign the disengagement linkage for better mechanical advantage. Currently, the linkage offers a mechanical advantage slightly greater than 1. While we did perform an optimization for the attachment locations of the linkages, we did not consider changing the attached bar lengths into this optimization due to time constraints. For further optimization of mechanical advantage, we believe introducing this variable may result in a much lower input force to disengage the device.

Finally, we believe the use of electrically driven actuators and controls to control both the angle of the bristles and rotational speed of the bristles is beneficial to the user. Adding the actuator to the indexer would allow for adjustment without getting off of the bicycle. A closed loop control on the bristle speed would allow for optimum speed to be used for snow removal, without the user having to constantly adjust the speed. This would allow for the battery life to be optimized, and in fact this closed loop control system is already available with some electric snow blowers currently on the market.

Transition to Mass Production

In order to move our device into production a few things must happen: the device needs to be optimized for material, manufacturing, and component costs, the cost of the sourced components needs to be negotiated for both cost and functionality, a marketing plan developed alongside consumer packaging design, and finally for all of this to happen funding is needed to cover initial inventory along with putting deposits down on manufacturing contracts.

A predicted cost of materials and components when mass produced in small batches (<500) has been provided in Appendix C - Bill of Materials. The final cost of materials and components for the prototype device was $596 while the predicted mass production cost is around $185. Our target market price at the beginning of the project was around $200, so our predicted cost of production requires that either the material prices be negotiated down further or a higher consumer selling price is targeted. If the device is to be primarily marketed to household consumers, moving farther away from $200 may result in smaller sales. However if the device is to be marketed as an industrial, business oriented product, the selling price may be raised closer to $500 with the promise of reduced maintenance costs, an environmentally friendly solution that can be utilized for marketing, and an in-house snow removal method that does not require outside resources or contracts.

Appendix

APPENDIX A: CONCEPTS GENERATED

A1: Snow Removal Devices

Figure A1.1: Regular shovel design with pin connection to allow for horizontal rotation.

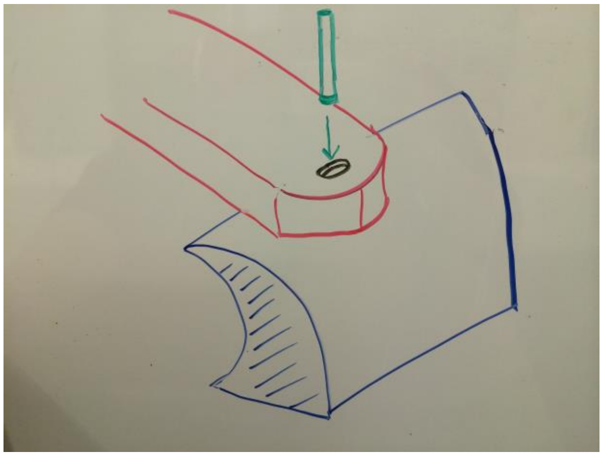


Figure A1.2: Inverted shovel design with pin connection to allow for horizontal rotation.

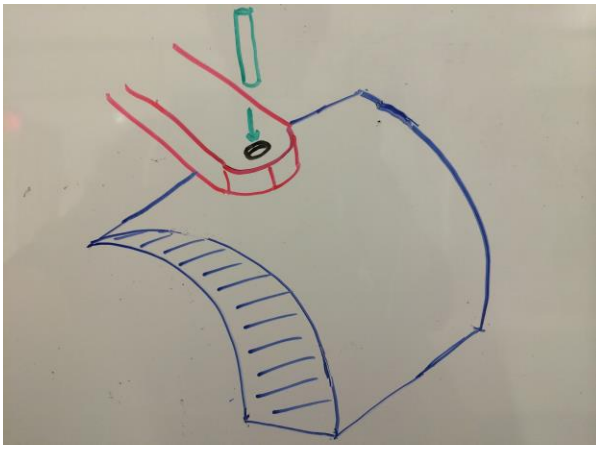


Figure A1.3: Rotational bristle device to fling snow, similar to what is used on tractor machinery on campus.

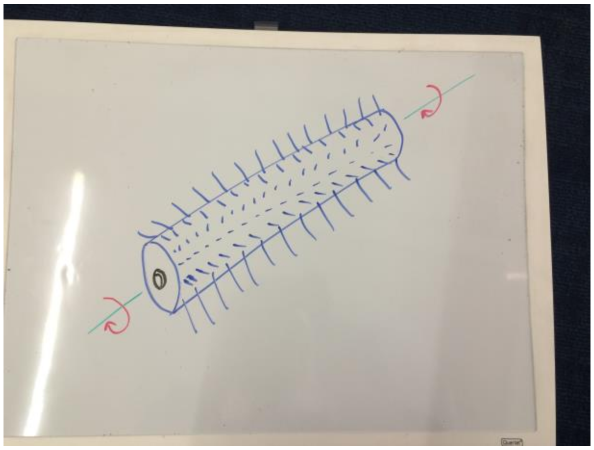
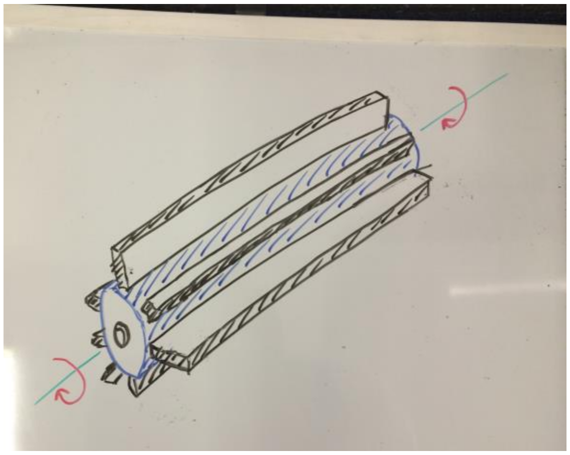


Figure A1.4: Rotational flap device made of rubber or plastic.



A2: Attachment Methods

Figure A2.1: One-sided axle hook attachment on the back tire.

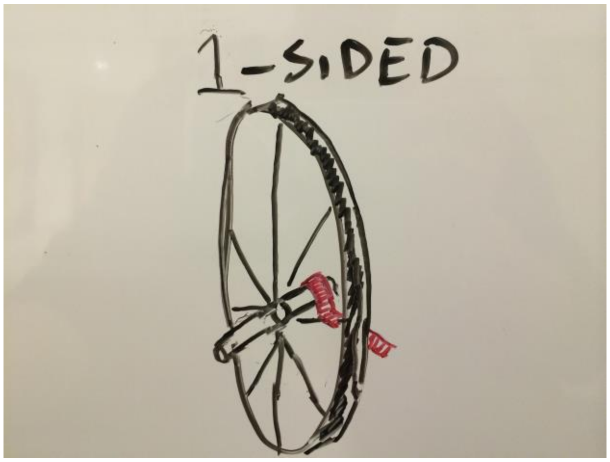


Figure A2.2: Under the seat post clamp attachment.

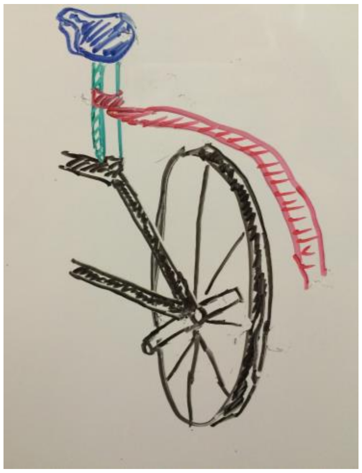
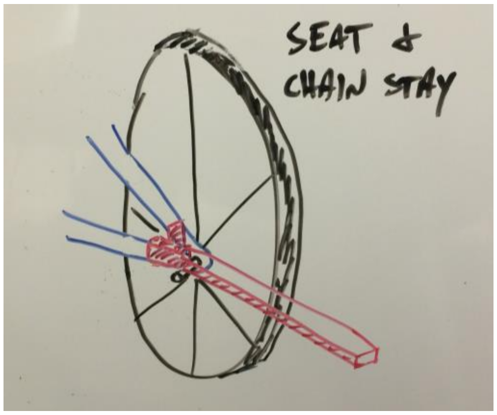


Figure A2.3: Seat stay and chain stay attachment with support arm on one side.



<u>A3: Shock Absorption Method</u>

Figure A3.1: Spring for shovel shock absorption when contacting obstacle.

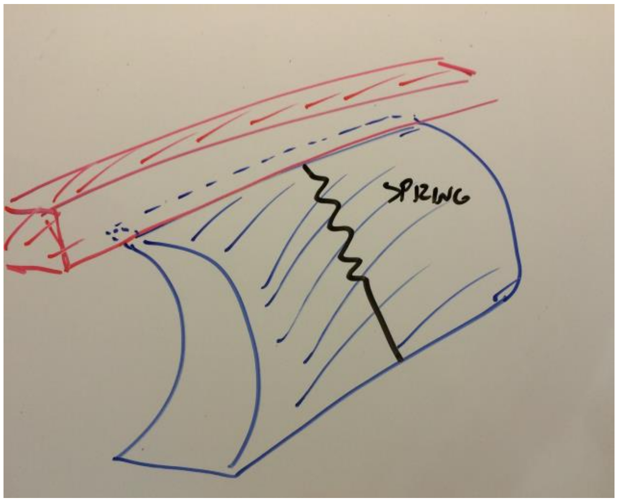


Figure A3.2: Damper for shovel shock absorption when contacting obstacle.

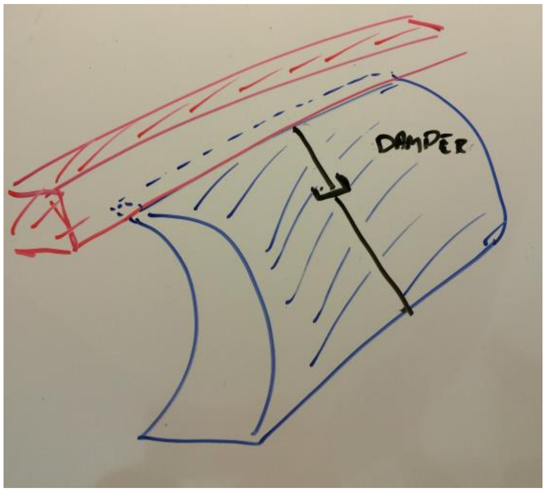
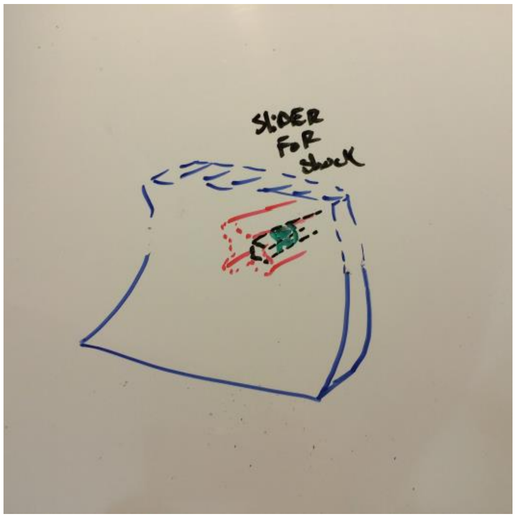


Figure A3.3: Sliding, linear bearing attachment to shovel for shock absorption. Slides up an angled slot when contacting obstacle then gravity pulls shovel back down to engaged state.



A4: Angle Adjustment Methods

Figure A4.1: Lever arm with side slots and vertical slot for angle adjustment and disengaging.

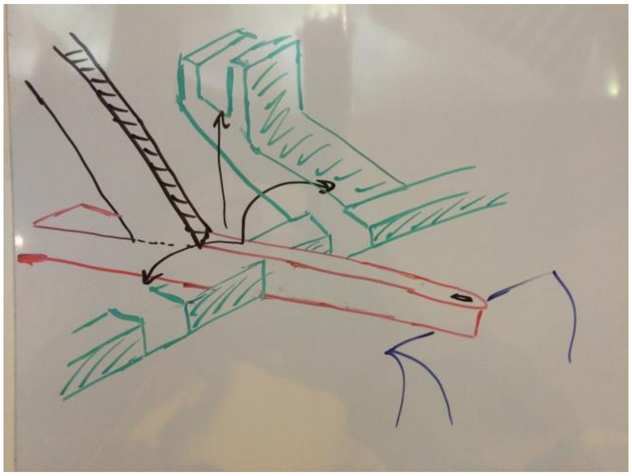


Figure A4.2: Crank wheel and pulley system for adjusting the angle of the device. User rotates wheel clockwise or counterclockwise to change angle of device.

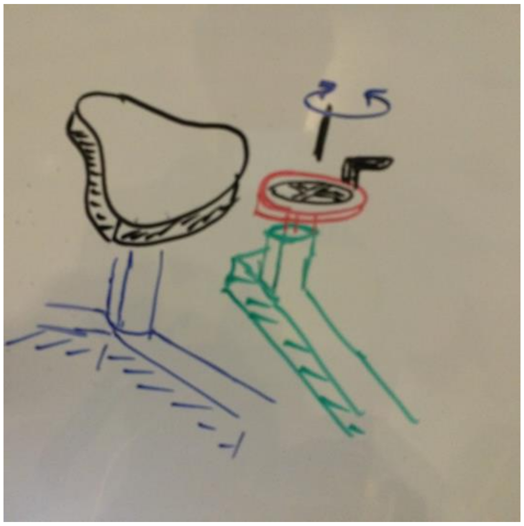


Figure A4.3: Cable and levers mounted to handlebar for adjusting the angle of the device. User pushes on lever, similar to brakes on bicycle. Left lever angles device to the right, right lever angles device to the left.

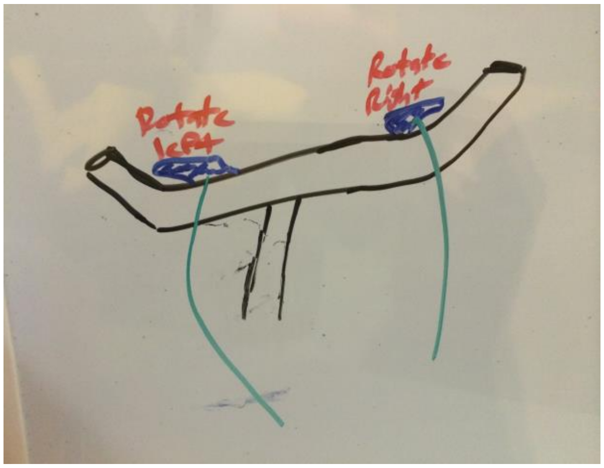
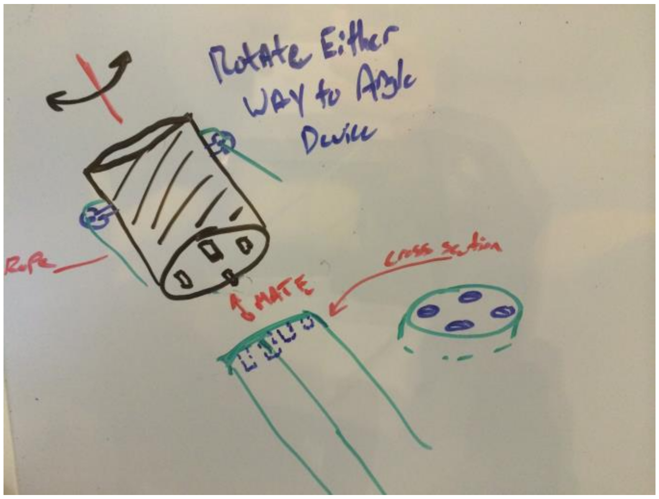


Figure A4.4: Rotational pin indexer with cables mounted on either side for adjusting the angle of the device. When user wants to change angle, pull up on the handle to unlock the pins and rotate in either direction, depending on direction of angle desired until the pins lock. Can add additional sensitivity for more angle adjustment control.



A5: Disengagement Methods

Figure A5.1: Angular track, similar to snowboard boots that allow for a locked disengagement and height adjustment. When user wishes to disengage the device, they push or pull on a lever or pulley and this locks downwards on the angled contact points. When the user wishes to re-engage the device, pull outward on a lever to remove contact with the angled edges and release the device.

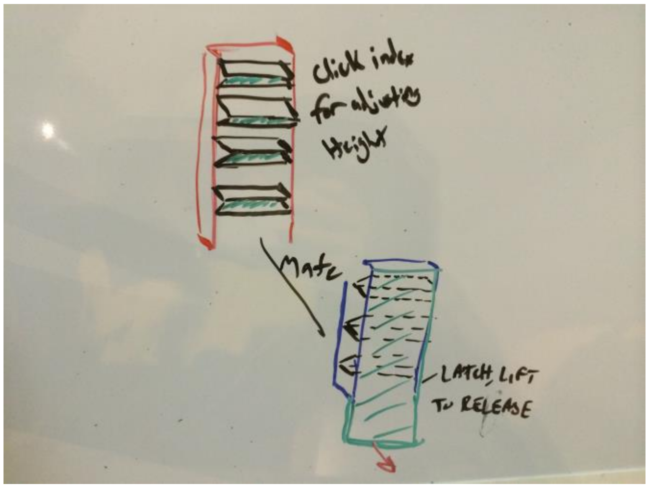


Figure A5.2: Hinged cable attachment for vertical and angle adjustment. Cables are used to rotate shovel by locking tension and also to provide an upward force to disengage the device.

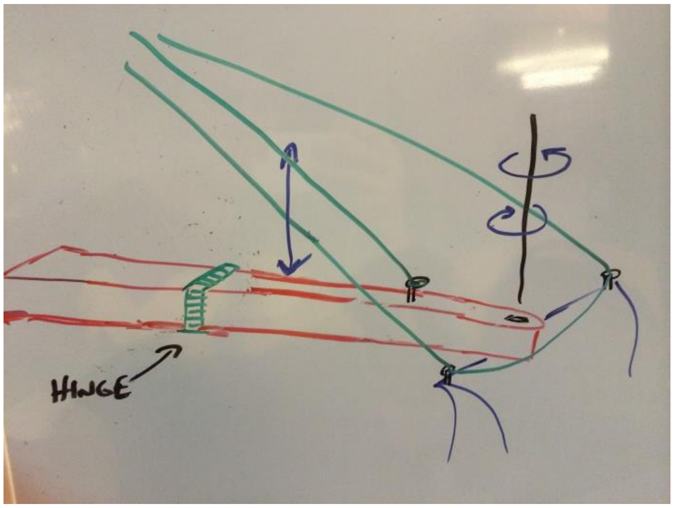
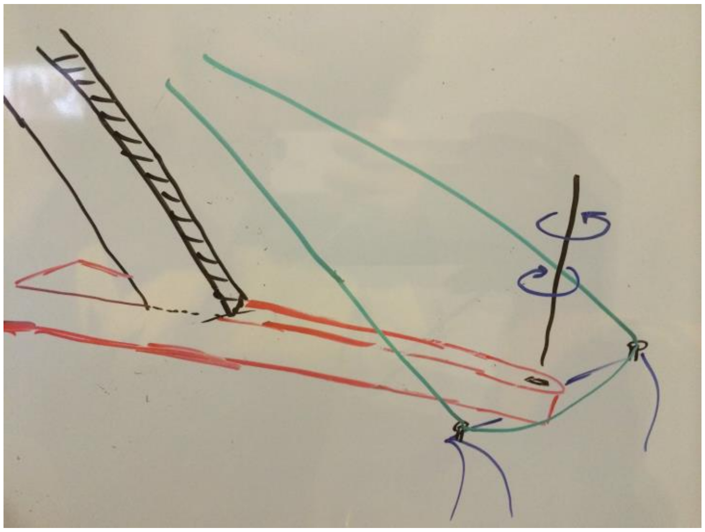


Figure A5.3: Lever arm for disengagement with cables for angle adjustment. This can be pushed down by the user to lift up the device when it is no longer needed. Cables are used to rotate the shovel in either direction.



APPENDIX B: PUGH CHARTS FOR GENERATED CONCEPTS

Table B1: Attachment to Bicycle Pugh Chart

Attachment to Bicycle							
	Weight	1 Hook	2 Hooks	Clamp to Chain Stay	Clamp to Seat Stay	Clamp Under Seat	Clamp to Both
Compatibility (95%)	5	4	2	4	4	4	3
Ease of Attachment (5 Minutes)	3	2	2	4	4	4	3
Stability	2	2	3	2	2	1	3
	Total	30	22	36	36	34	30

Table B2: Device Disengagement/Engagement Method Pugh Chart

Disengage/Engage Method							
	Weight	Lever and Cable on Handlebar	Pneumatics	Linkage System	Wheel and Rope	Set Positions	Crank on Handle Bar
Ability to do While Riding	4	4	4	3	4	0	2
Feasibility	2	2	1	3	2	4	2
Ease of Use	3	4	2	3	2	3	4
Rider Interference	1	3	4	2	3	4	3
	Total	35	28	29	29	21	27

Table B3: Shock Absorption Pugh Chart

Shock Absorption						
	Weight	**Spring Behind Blade**	**Spring on Connecting Rod**	**Slider in Slot on Connecting Rod**	**Damper**	**Bristles**
Feasibility	**2**	**3**	**3**	**2**	**3**	**4**
Durability	**4**	**3**	**3**	**1**	**3**	**2**
Cost	**1**	**3**	**4**	**3**	**2**	**2**
Effectiveness	**3**	**3**	**2**	**2**	**3**	**2**
	Total	**30**	**28**	**17**	**29**	**24**

Table B4: Adjustment of Angle Pugh Chart

Adjustment of angle								
	Weight	**Indexer with Pin**	**Indexer with Lever**	**Pulley System**	**Motor - Rack and Pinion**	**Motor-Belt**	**Crank on Handle Bar**	**Lever with Cables**
Adjustability While on Bicycle	**4**	**0**	**3**	**3**	**4**	**4**	**3**	**3**
Durability	**2**	**3**	**3**	**3**	**1**	**1**	**3**	**3**
Feasibility	**3**	**3**	**3**	**4**	**2**	**2**	**4**	**3**
Precision	**1**	**2**	**2**	**3**	**4**	**4**	**3**	**2**
	Total	**17**	**29**	**33**	**28**	**28**	**33**	**29**

Table B5: Final Full System Pugh Chart

		Concept 4	Concept 5	Concept 6	Concept 7	Concept 8	Concept 9
CONSUMER	Weight	Inverted Plow Under the Seat	Spinning Bristles Under the Seat	Regular Plow Under the Seat	Inverted Plow Two Side Axle	Spinning Bristles Two Side Axle	Regular Plow Two Side Axle
Consumer Cost	0.4	2	1	2	3	2	3
Ease of use	0.2	3	4	3	3	4	2
Setup Time	0.15	4	3	4	3	1	3
Depth of snow	0.1	3	2	3	3	2	3
Storage	0.15	3	2	3	4	3	4
Sums	1	2.75	2.15	2.75	3.15	2.4	2.95
ENGINEERING		Inverted Plow Under the Seat	Spinning Bristles Under the Seat	Regular Plow Under the Seat	Inverted Plow Two Side Axle	Spinning Bristles Two Side Axle	Regular Plow Two Side Axle
Cost of components	0.1	2	1	2	3	2	3
Shock Absorption	0.2	3	4	2	3	4	2
Complexity	0.3	3	2	3	3	2	3
Manufacturing Time	0.3	2	3	2	2	3	2
Depth of snow	0.1	3	2	3	3	2	3
Sums	1	2.6	2.6	2.4	2.7	2.7	2.5
FINAL SELECTION		Inverted Plow Under the Seat	Spinning Bristles Under the Seat	Regular Plow Under the Seat	Inverted Plow Two Side Axle	Spinning Bristles Two Side Axle	Regular Plow Two Side Axle
Consumer	0.6	2.75	2.15	2.75	3.15	2.4	2.95
Engineer	0.4	2.6	2.6	2.4	2.7	2.7	2.5
Sums		2.69	2.33	2.61	2.97	2.52	2.77

Appendix C : Bill of Materials

Table C1: Bill of Materials for Bicycle Snow Brush

Part Name	Material	Proto. Price per Unit	Proto. Total Cost	Predicted "MP" Price per unit	Predicted MP Cost	Change
Bristle	12" Diameter, 10" Length	$55.50	$111.00	$10.00	$20.00	-81.98%
Motor	24V, 250W, 2750 Rated RPM, 11 tooth	$39.57	$39.57	$25.00	$25.00	-36.82%
Controller	24V, 250W controller	$19.50	$19.50	$8.00	$8.00	-58.97%
Throttle	24V thumb throttle w/ led	$7.55	$7.55	$2.00	$2.00	-73.51%
Battery	12 V 7Ah	$33.49	$66.98	$13.00	$26.00	-61.18%
Battery Charger	24 V	$10.00	$10.00	$5.00	$5.00	-50.00%
Hex Axle	1.5" OD, 1' Length	$19.51	$19.51	$10.00	$10.00	-48.74%
Axle Attachment	Burley Trailer Attachment	$21.99	$21.99	$4.00	$4.00	-81.81%
Shaft	Stainless Steel Drive Shaft; 1/4"Dia, 36	$11.65	$11.65	$3.00	$3.00	-74.25%
Removable Locking Pin	Stainless Steel, 1/4:Dia, 1-1/2" Effective	$1.95	$3.90	$1.25	$2.50	-35.90%
Removable Locking Pin	Stainless Steel, 1/4:Dia, 2-1/2" Effective	$2.19	$4.38	$1.30	$2.60	-40.64%
Oversized Dowel Pin	Stainless Steel Dowel Pin, 0.2501" Dia	$3.03	$3.03	$1.00	$1.00	-67.00%
Dowel Pin	Stainless Steel Dowel Pin 1/4" Dia. 1-1/	$1.38	$6.89	$0.90	$1.80	-73.88%
Flange Double Sealed Steel Ball Bearings	Shaft Dia 1/4, OD 11/16	$6.79	$40.74	$0.00	$0.00	-100.00%
Bushing (Corrosion Resistant)	Shaft Dia 1/4, OD 3/8 sleeve, 1/4" Leng	$0.78	$10.92	$0.47	$6.58	-39.74%
Bushing (Corrision Resistant)	Shaft Dia 1/4", OD 3/8" Sleeve, 1" L	$0.82	$2.46	$0.46	$1.38	-43.90%
Thrust Bearing	Stainless Steel Washers, for 1/4" Sh	$3.11	$12.44	$1.25	$5.00	-59.81%
60 Tooth 1/4" Pitch Gear	Steel 1/2" I.D.	$38.90	$38.90	$14.00	$14.00	-64.01%
Chain 3'	6261K171, Roller Chain, ANSI Number	$15.42	$15.42	$3.00	$3.00	-80.54%
Rubber Wheel	10" Semi Pneumatic Wheel	$10.59	$21.18	$3.00	$6.00	-71.67%
1.5" Shoulder Bolt	1/4" Diameter, 1.5" Shoulder Length	1.31	$2.62	$1.00	$2.00	-23.66%
1/4 - 20 Bolt	1.75" Length, Dia 0.25"	0.557	$5.57	$0.40	$4.00	-28.19%
2" Shoulder Bolt	1/4" Diameter, 2" Shoulder Length	$1.65	$1.65	$0.80	$0.80	-51.52%
2.5" Shoulder Bolt	1/4" Diameter, 2.5" Shoulder Length	$1.96	$1.96	$1.20	$1.20	-38.78%
M6 Screws	1" Length	$0.18	$8.79	$0.12	$0.60	-93.17%
Set Screws	1/4" Set Screws 1/4-20 Thread 3/8" Le	$0.19	$4.85	$0.12	$0.48	-90.10%
C-Clips	1/2" I.D., 0.06 Max Width	$0.10	$0.40	$0.08	$0.32	-20.00%
C-Clips	1/4" I.D., 0.06 Max Width	$0.10	$0.60	$0.08	$0.48	-20.00%
Aluminum Axle	3 ft, 0.5"	$7.00	$7.00	$3.00	$3.00	-57.14%
Link Plate	5 lbs (0.25" Plate)	$14.95	$14.95	$4.00	$4.00	-73.24%
Grommet for Battery Case	3/4" OD	$2.64	$2.64	$0.50	$0.50	-81.06%
Tubing Heatshrink	1"	$3.17	$3.17	$0.00	$0.00	-100.00%
Wire Rope Clip	1/8" Galvanized	$1.37	$1.37	$0.25	$0.50	-63.43%
Weatherstrip (Battery Case)	EPDM 17'	$9.00	$9.00	$3.00	$3.00	-66.66%
Motor Wire	7'	$0.63	$4.38	$0.30	$2.10	-52.03%
Raw Materials	1"x1" Solid 6061 AL (3ft), 1"x1" Hollow	$60.00	$60.00	$15.00	$15.00	-75.00%
Final Cost		Prototype $596.95		Mass Production $184.84		-69.04%

Appendix D : Manufacturing Plans

Part Number: Team 28 ME450-01				Revision Date: 11/10/2015	
Part Name: Bent Bar Attachment - Angled					
Raw Material Stock: 6061-T6 Rectangular Aluminum Bar, 1"x 1",⅛" thick					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (rpm)**
1	Cut tube to 13.25"	Bandsaw	Vise	bandsaw	300 ft/min
2	Mill off rough edges for datum locations	Mill	Vise	1/4" end mill, collet	1200
3	Define Datum Points on Mill	Mill	Vise	edge finder,collet, chuck	1200
4	Mill part to 13" by taking 0.1 passes	Mill	Vise	1/4" endmill, collet	1200
5	Center drill hole	Mill	Vise	center drill, chuck	800
6	Mark radius of rounded edge	N/A	N/A	protractor	N/A
7	Drill 0.375" hole according to dimension for reamer	Mill	Vise	U drill bit, chuck	800
8	Ream 0.375" hole for bushings	Mill	Vise	.3745" reamer, chuck	100
9	Debur all edges	Mill	Vise	deburring tool	N/A
10	Mark 22.5° angle	N/A	N/A	compass	N/A
11	Grind radial edge and angular edge to size	Grinder	Vise	grinder	5000 sfpm
12	File edges	N/A	N/A	file	N/A

Part Number: Team 28 ME450-02				Revision Date: 11/10/2015	
Part Name: Cross Bar					
Raw Material Stock: 6061-T6 Rectangular Aluminum Tubing, 1”x 1”,⅛” thick					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (rpm)**
1	Cut aluminum tube to 29.75"	Bandsaw	Vise	Bandsaw	300 ft/min
2	Mill off rough side of parts at both ends	Mill	N/A	1/4" endmill, collet	1200
3	Mark part at 29.5" and edge find X and Y datums on Mill	Mill	Vise	edge finder,collet	100
4	Mill part to size by taking 0.1" passes	Mill	Vise	1/4" endmill, collet	1200

Part Number: Team 28 ME450-03				Revision Date: 11/10/2015	
Part Name: Disengage Lock		Quantity: 2			
Raw Material Stock: Raw Material Stock: 6061-T6 Aluminum plate,0.25" thick					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (rpm)**
1	Load part geometry into waterjet computer	waterjet	N/A	waterjet, computer	1200
2	Cut geometry with water jet	waterjet	N/A	waterjet	1200
3	Drill 1/4-20 clearance holes with drill press	Drill Press	Vise	F Drill, drill chuck	800
4	Debur holes	Debur	Vise	chamfer	N/A

Part Number: Team 28 ME450-04				Revision Date: 11/10/2015	
Part Name: Disengage Link		Quantity: 2			
Raw Material Stock: Raw Material Stock: 6061-T6 Aluminum plate,0.25" thick					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (rpm)**
1	Load part geometry into waterjet computer	waterjet	N/A	waterjet, computer	N/A
2	Cut geometry with water jet	waterjet	N/A	waterjet	N/A
3	Mount part relative to datum	Mill	Vise	N/A	N/A
4	Edge find X and Y datum	Mill	Vise	edge finder,chuck	100
5	Center drill all holes	Mill	Vise	Center drill, chuck	800
6	Drill inner diameter of 3/8" bushing holes	Mill	Vise	U drill bit, chuck	800
7	Ream inner diameter of 3/8" bushing hole	Mill	Vise	0.3745" reamer, chuck	100
8	Press bushing into hole	Arbor Press	Vise	N/A	N/A
9	Debur holes	Debur	Vise	chamfer	N/A

Part Number: Team 28 ME450-05				Revision Date: 10/22/2015	
Part Name: Disengage Lever					
Raw Material Stock: Raw Material Stock: 6061-T6 Aluminum cylindrical tube, 1"					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (rpm)**
1	Cute tube to size	Bandsaw	Vise	bandsaw	300 ft/min
2	Mill off rough edges for datum locations	Mill	Vise	1/4" end mill, collet	1200
3	Define Datum Points on Mill	Mill	Vise	edge finder,collet, chuck	1200
4	Mill part to size by taking 0.1 passes	Mill	Vise	collet, 1/4" endmill	1200
5	Center drill all holes	Mill	Vise	Center drill, chuck	800
6	Drill 0.25" thru hole	Mill	Vise	F Drill Bit, chuck	800
7	Drill pre-ream bushing holes	Mill	Vise	C Drill Bit, chuck	800
8	Ream 0.2495" holes	Mill	Vise	0.2495" Reamers, chuck	100
9	Debur holes	chamfer	N/A	chamfer	N/A

Part Number: Team 28 ME450-06				Revision Date: 11/5/2015	
Part Name: Bent Bar Attachment - Vertical					
Raw Material Stock: 6061-T6 Rectangular Aluminum Bar, 1”x 1”,⅛” thick					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (rpm)**
1	Cut tube to 17.25"	Bandsaw	Vise	bandsaw	300 ft/min
2	Mill off rough edges for datum locations	Mill	Vise	1/4" end mill, collet	1200
3	Define Datum Points on Mill	Mill	Vise	edge finder,collet, chuck	100
4	Mill part to 17" by taking 0.1 passes	Mill	Vise	collet, 1/4" endmill	1200
5	Define Z datum	Mill	Vise	collet, 1/4" endmill	N/A
6	Center drill holes	Mill	Vise	center drill, chuck	800
7	Remove face of one end, reducing it by 0.02" according to dimension	Mill	Vise	collet, 1/4" endmill	1200
8	Rotate part 180°, redefine datums	Mill	Vise	edge finder,collet, chuck, 1/4" endmill	100
9	Remove face of other end, reducing it by 0.02" according to dimension	Mill	Vise	collet, 1/4" endmill	1200
10	Center drill holes	Mill	Vise	center drill, chuck	800
11	Drill 0.25" hole according to dimension for reamer	Mill	Vise	C drill bit, chuck	800
12	Ream 0.2495" hole for bushings	Mill	Vise	.2495" reamer, chuck	100
13	Drill 1/4-20 thru holes according to dimensions	Mill	Vise	F drill bit, chuck	800
14	Debur all edges	Mill	Vise	deburring tool	N/A
15	Mark 22.5° angle from left edge	N/A	N/A	compass	N/A
16	Grind radial edge and angular edge to size	Grinder	Vise	grinder	5000 sfpm
17	File edges	N/A	N/A	file	N/A

Part Number: Team 28 ME450-07				Revision Date: 11/10/2015	
Part Name: Indexer					
Raw Material Stock: Raw Material Stock: 6061-T6 Aluminum plate,0.25" thick					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (rpm)**
1	Load part geometry into waterjet computer	waterjet	N/A	waterjet, computer	N/A
2	Cut geometry and pilot holes with water jet	waterjet	N/A	waterjet	N/A
3	Mill X and Y datum surfaces	Mill	Vise	1/4" end mill, collet	1200
4	Mount part relative to datum	Mill	Vise	N/A	N/A
5	Edge find X and Y datum	Mill	Vise	edge finder,chuck	100
6	Center drill holes	Mill	Vise	center drill, chuck	800
7	Drill inner diameter of 3/8" thru hole	Mill	Vise	U Drill Bit, Chuck	800
8	Ream inner diameter of 3/8" thru hole	Mill	Vise	0.3745" reamer, chuck	100
9	Define Z datum	Mill	Vise	0.5" face mill, collet	1200
10	Plunge outer diameter 1/16" deep	Mill	Vise	0.5" face mill, collet	1200
11	Clearance ream for 0.5" plunged hole	Mill	Vise	0.5005" reamer, chuck	100
12	Zero X and Y datum at center of bushing hole	Mill	Vise	N/A	N/A
13	Drill 3 pilot holes for 0.25" indexer pin holes	Mill	Vise	E drill bit, chuck	800
14	Ream the 3 pilot holes for 0.25" indexer pin holes	Mill	Vise	0.2505" reamer, chuck	100
15	Drill 4 1/4-20 mounting holes	Mill	Vise	F drill, chuck	800
16	Debur holes	Debur	Vise	deburring tool	N/A

Part Number: Team 28 ME450-08				Revision Date: 11/10/2015	
Part Name: Motor Side Axle Support					
Raw Material Stock: 6061-T6 Aluminum Bar, 1”x 1”					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (rpm)**
1	Cut tube to 8.75"	Bandsaw	Vise	bandsaw	300 ft/min
2	Mill off rough edges for datum locations	Mill	Vise	1/4" end mill, collet	1200
3	Define Datum Points on Mill	Mill	Vise	edge finder, chuck	100
4	Mill part to 8.5" by taking 0.1 passes	Mill	Vise	1/4" endmill, collet	1200
5	Zero the Z-axis	Mill	Vise	1/4" endmill, collet	N/A
6	Endmill slots with 0.1" depth passes	Mill	Vise	1/4" endmill, collet	1200
7	Center drill holes	Mill	Vise	center drill, chuck	800
8	Drill 1/4-20 thru holes according to dimensions	Mill	Vise	F drill bit, chuck	800
9	Rotate part in vise 90°	Mill	Vise	N/A	N/A
10	Define Datum Points on Mill	Mill	Vise	edge finder,collet, chuck	1200
11	Center drill holes	Mill	Vise	center drill, chuck	800
12	Drill 0.6875" holes according to dimension for bore	Mill	Vise	17mm drill bit, chuck	800
13	Bore 0.6875" hole for bushings	Mill	Vise	Bore, micrometer	100
14	Debur all edges	Mill	Vise	deburring tool	N/A

Part Number: Team 28 ME450-09				Revision Date: 11/10/2015	
Part Name: Left Side Axle Support					
Raw Material Stock: 6061-T6 Aluminum Bar, 1”x 1”					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (rpm)**
1	Cut tube to 8.75"	Bandsaw	Vise	bandsaw	300 ft/min
2	Mill off rough edges for datum locations	Mill	Vise	1/4" end mill, collet	1200
3	Define Datum Points on Mill	Mill	Vise	edge finder,collet, chuck	1200
4	Mill part to 8.5" by taking 0.1 passes	Mill	Vise	1/4" endmill, collet	1200
5	Center drill holes	Mill	Vise	center drill, chuck	800
7	Drill 0.6875" holes according to dimension for bore	Mill	Vise	17mm drill bit, chuck	800
8	Bore 0.6875" hole for bushings	Mill	Vise	Bore, micrometer	100
9	Rotate part in vise 90°	Mill	Vise	N/A	N/A
10	Define Datum Points on Mill	Mill	Vise	edge finder,collet, chuck	1200
11	Center drill holes	Mill	Vise	center drill, chuck	800
12	Drill 1/4-20 thru hole according to dimensions	Mill	Vise	F drill bit, chuck	800
13	Drill pilot hole for 0.25" dowel pin hole	Mill	Vise	E drill bit, chuck	800
14	Ream the pilot hole for 0.25" dowel pin hole	Mill	Vise	0.250" reamer, chuck	100
15	Debur all edges	Mill	Vise	deburring tool	N/A

Part Number: Team 28 ME450-10				Revision Date: 11/10/2015	
Part Name: Indexer Link					
Raw Material Stock: Raw Material Stock: 6061-T6 Rectangular Aluminum Tubing, 2”x 1”,⅛” thick					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (rpm)**
1	Cut aluminum tube to 15.25"	Bandsaw	Vise	Bandsaw	300 ft/min
2	Mill off rough side of parts at both ends	Mill	N/A	1/4" endmill, collet	1200
3	Mark part at 15" and edge find X and Y datums on Mill	Mill	Vise	edge finder,collet	100
4	Mill part to size by taking 0.1" passes	Mill	Vise	1/4" endmill, collet	1200
5	Mill slot according to dimensions, 4 passes of endmill	Mill	Vise	1/4" endmill, collet	1200
6	Center drill holes	Mill	Vise	center drill, chuck	800
7	Drill 0.25" clearance holes thru part according to dimensions	Mill	Vise	F drill bit, drill chuck	800
8	Rotate part in vise 90°, and edge find X and Y datums	Mill	Vise	edge finder,collet	100
9	Center drill holes	Mill	Vise	center drill, chuck	800
10	Drill 0.25" clearance holes thru part according to dimensions	Mill	Vise	F drill bit, drill chuck	800
11	Drill 0.375" hole according to dimension for reamer	Mill	Vise	U drill bit, chuck	800
12	Ream 0.375" hole for bushings	Mill	Vise	.3745" reamer, chuck	100
13	Debur all edges	Mill	Vise	deburring tool	N/A

Part Number: Team 28 ME450-11				Revision Date: 11/10/2015	
Part Name: Wheel Axle Bracket		Quantity: 2			
Raw Material Stock: Raw Material Stock: 6061-T6 Aluminum plate,1" thick					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (rpm)**
1	Load part geometry into waterjet computer	waterjet	N/A	waterjet, computer	1200
2	Cut geometry with water jet	waterjet	N/A	waterjet	1200
3	Define Datum Points on Mill	Mill	Vise	edge finder,collet, chuck	1200
4	Center drill all holes	Mill	Vise	center drill, chuck	800
5	Drill 1/4-20 thru holes according to dimensions	Mill	Vise	F drill bit, chuck	800
6	Drill 0.6875" holes according to dimension for bore	Mill	Vise	17mm drill bit, chuck	800
7	Bore 0.6875" hole for bushings	Mill	Vise	Bore, micrometer	100
8	Debur holes	Debur	Vise	chamfer	N/A

Part Number: Team 28 ME450-12				Revision Date: 11/10/2015	
Part Name: Axle					
Raw Material Stock: Stainless Steel 0.5" Shaft					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (rpm)**
1	Cut shaft to 13.75"	Bandsaw	Vise	Bandsaw	200ft/min
2	Put ½ of rod into chuck and fasten	Lathe	Chuck	N/A	N/A
3	Attach tool post	Lathe	Compound axis	Facing tool	
4	Zero the axis	Lathe	Compound axis	Facing tool	N/A
5	Face material to size according to dimensions, 13.65"	Lathe	Chuck	Facing tool	3100 rpm
6	Turn material to 0.25" diameter according to dimensions	Lathe	Chuck	Facing tool	3100 rpm
7	Turn material to 0.4" diameter along 0.5" section according to dimensions	Lathe	Chuck	Facing tool	3100 rpm
8	Turn material to 0.15" diameter along 0.25" section according to dimensions	Lathe	Chuck	Facing tool	3100 rpm

Part Number: Team 28 ME450-13				Revision Date: 11/10/2015	
Part Name: Indexer - Top Bar Connector					
Raw Material Stock: Raw Material Stock: 6061-T6 Aluminum plate, 1"X1" solid bar					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (rpm)**
1	Cut aluminum bar to 2.5"	Bandsaw	Vise	Bandsaw	300 ft/min
2	Mill X and Y datum surfaces	Mill	Vise	1/4" end mill, collet	1200
3	Mount part relative to datum	Mill	Vise	N/A	N/A
4	Edge find X and Y datum	Mill	Vise	edge finder,chuck	100
5	Define Z datum	Mill	Vise	1/4" end mill, collet	N/A
6	Remove 0.2" from top, by taking 0.1" plunges and taking passes	Mill	Vise	1/4" end mill, collet	1200
7	Center drill holes	Mill	Vise	center drill, chuck	800
8	Drill inner diameter of 3/8" thru hole	Mill	Vise	U Drill Bit, Chuck	800
9	Ream inner diameter of 3/8" thru hole	Mill	Vise	0.3745" reamer, chuck	100
10	Rotate part in vise 90°, and edge find X and Y datums	Mill	Vise	edge finder,collet	100
11	Center drill holes	Mill	Vise	center drill, chuck	800
12	Drill 1/4-20 mounting holes according to dimensions	Mill	Vise	F drill, chuck	800
13	Debur holes	Debur	Vise	deburring tool	N/A
14	File edges down to create filet	N/A	N/A	File	N/A

Part Number: Team 28 ME450-14				Revision Date: 10/22/2015	
Part Name: Hexagonal Coupler					
Raw Material Stock: Raw Material Stock: 6061-T6 Aluminum 1.5" hexagonal stock					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (rpm)**
1	Cute stock to size	Bandsaw	Vise	bandsaw	300 ft/min
2	Mill part to size by taking 0.1 passes	Mill	Vise	collet, 1/4" endmill	1200
3	Center drill set screw holes	Mill	Vise	Center drill, chuck	800
4	Drill 0.25" hole	Drill Press	Vise	#7 Drill, drill chuck	800
5	Tap 1/4-20 hole	Tap	Vise	1/4-20 Tap, Tap Hole	N/A
6	Mount part in lathe	Lathe	Chuck	Tool Post	N/A
7	Center drill thru hole	Lathe	Chuck	Center drill, chuck	800
8	Drill close fit hole thru part (rotate if need be)	Lathe	Chuck	33/64 Drill	800
9	Debur holes	chamfer	N/A	chamfer	N/A
10	Grind stock until it fits in bristle	Grinder	Vise	Grinder	1200

Part Number: Team 28 ME450-15				Revision Date: 11/10/2015	
Part Name: Motor Side Axle					
Raw Material Stock: Stainless Steel 0.5" Shaft					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (rpm)**
1	Cut shaft to 15.75	Bandsaw	Vise	Bandsaw	200ft/min
2	Put ½ of rod into chuck and fasten	Lathe	Chuck	N/A	N/A
3	Attach tool post	Lathe	Compound axis	Facing tool	
4	Zero the axis	Lathe	Compound axis	Facing tool	N/A
5	Face material to size according to dimensions, 15.55"	Lathe	Chuck	Facing tool	3100 rpm
6	Turn material to 0.25” diameter according to dimensions	Lathe	Chuck	Facing tool	3100 rpm
7	Turn material to 0.4" diameter along 0.5" section according to dimensions	Lathe	Chuck	Facing tool	3100 rpm
8	Turn material to 0.15" diameter along 0.25" section according to dimensions	Lathe	Chuck	Facing tool	3100 rpm

Part Number: Team 28 ME450-16				Revision Date: 11/10/2015	
Part Name: Ground Contour Angle Bracket Unthreaded		Quantity: 1			
Raw Material Stock: Raw Material Stock: 6061-T6 Aluminum plate,0.25" thick					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (rpm)**
1	Load part geometry into waterjet computer	waterjet	N/A	waterjet, computer	1200
2	Cut geometry with water jet	waterjet	N/A	waterjet	1200
3	Drill 0.25" holes with drill press	Drill Press	Vise	F Drill Bit, drill chuck	800
4	Drill inner diameter of 3/8" thru hole	Drill Press	Vise	U Drill Bit, Chuck	800
5	Ream inner diameter of 3/8" thru hole	Drill Press	Vise	0.3745" reamer, chuck	100
6	Debur all edges	Debur	N/A	Deburring Tool	N/A

Part Number: Team 28 ME450-17				Revision Date: 11/10/2015	
Part Name: Ground Contour Angle Bracket Threaded		Quantity: 1			
Raw Material Stock: Raw Material Stock: 6061-T6 Aluminum plate,0.25" thick					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (rpm)**
1	Load part geometry into waterjet computer	waterjet	N/A	waterjet, computer	1200
2	Cut geometry with water jet	waterjet	N/A	waterjet	1200
3	Drill 0.25" hole	Drill Press	Vise	#7 Drill, drill chuck	800
4	Tap 1/4-20 hole	Tap	Vise	1/4-20 Tap, Tap Hole	N/A
5	Drill inner diameter of 3/8" thru hole	Drill Press	Vise	U Drill Bit, Chuck	800
6	Ream inner diameter of 3/8" thru hole	Drill Press	Vise	0.3745" reamer, chuck	100
7	Debur all edges	Debur	N/A	Deburring Tool	N/A

Part Number: Team 28 ME450-18				Revision Date: 11/24/2015	
Part Name: Wheel Axle					
Raw Material Stock: Stainless Steel 0.5" Shaft					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (rpm)**
1	Cut shaft to 4"	Bandsaw	Vise	Bandsaw	200ft/min
2	Put ½ of rod into chuck and fasten	Lathe	Chuck	N/A	N/A
3	Attach tool post	Lathe	Compound axis	Facing tool	N/A
4	Zero the axis	Lathe	Compound axis	Facing tool	N/A
5	Face material to size according to dimensions, 3.625"	Lathe	Chuck	Facing tool	3100 rpm
6	Turn material to 0.25" diameter according to dimensions	Lathe	Chuck	Facing tool	3100 rpm
7	Turn material to 0.4" diameter along 0.5" section according to dimensions	Lathe	Chuck	Facing tool	3100 rpm
8	Turn material to 0.15" diameter along 0.25" section according to dimensions	Lathe	Chuck	Facing tool	3100 rpm

Appendix E : Engineering Drawings

Figure E.1 : Bent Bike Attachment Angle Bar, Part # 1

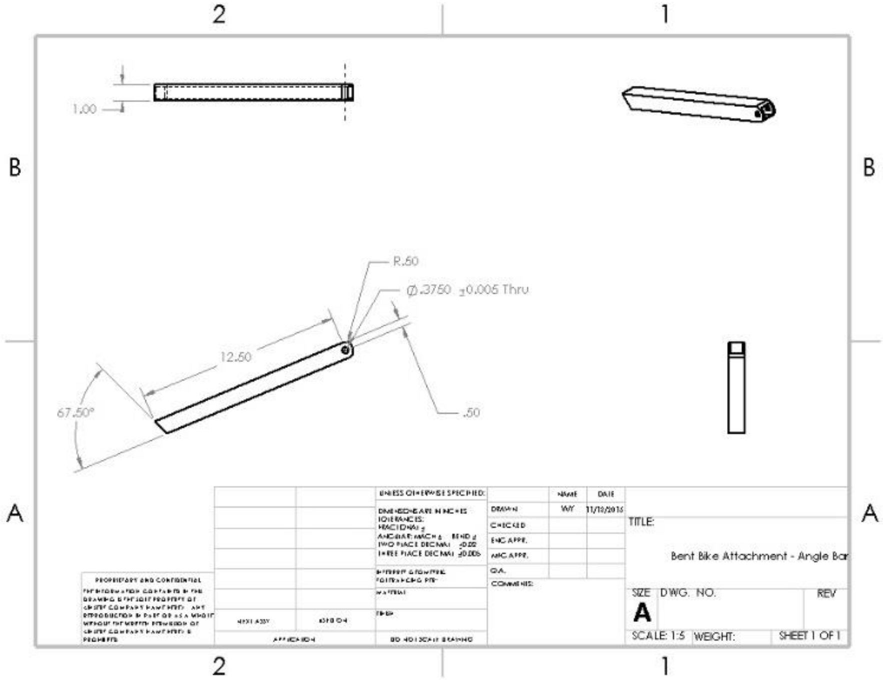


Figure E.2 : Cross Bar, Part # 2

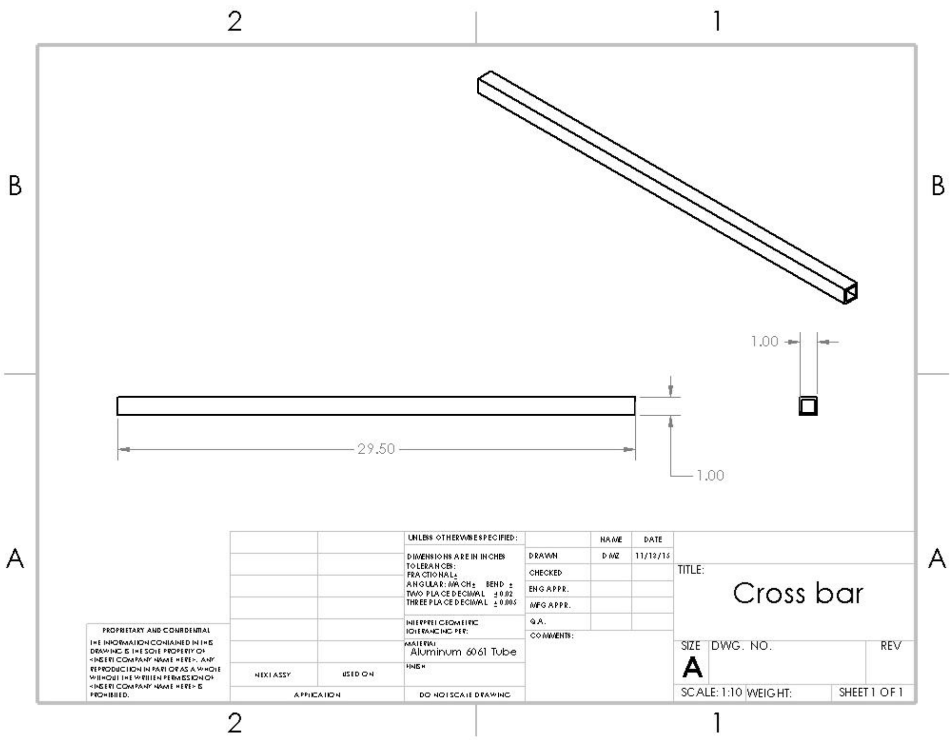


Figure E.3 : Disengage Lock, Part # 3

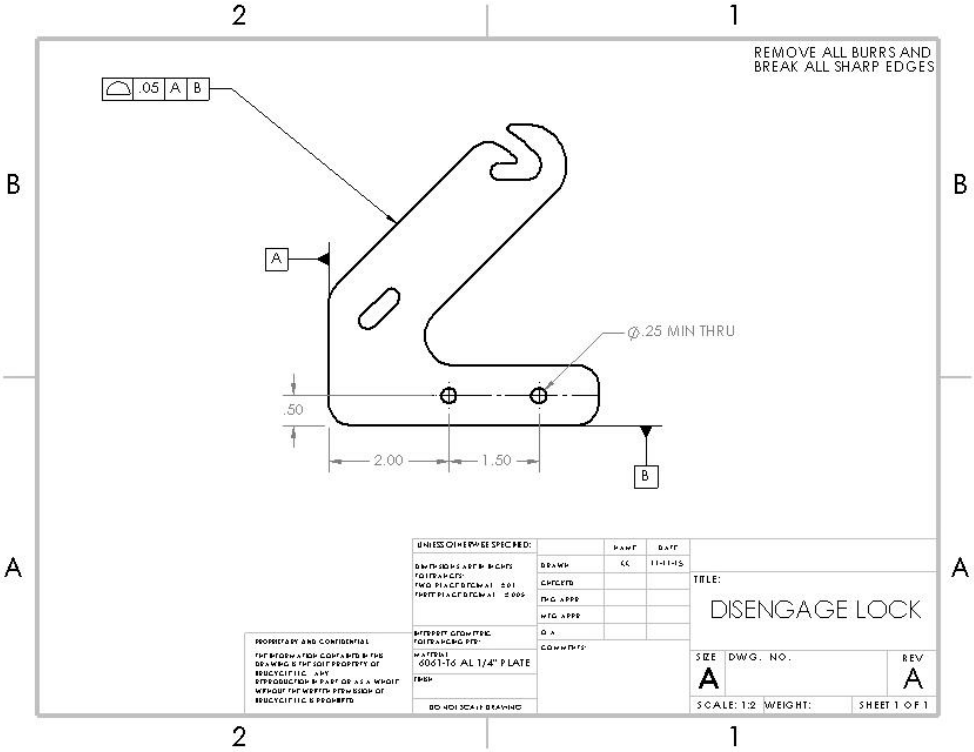


Figure E.4 : Disengage Lock, Part # 4

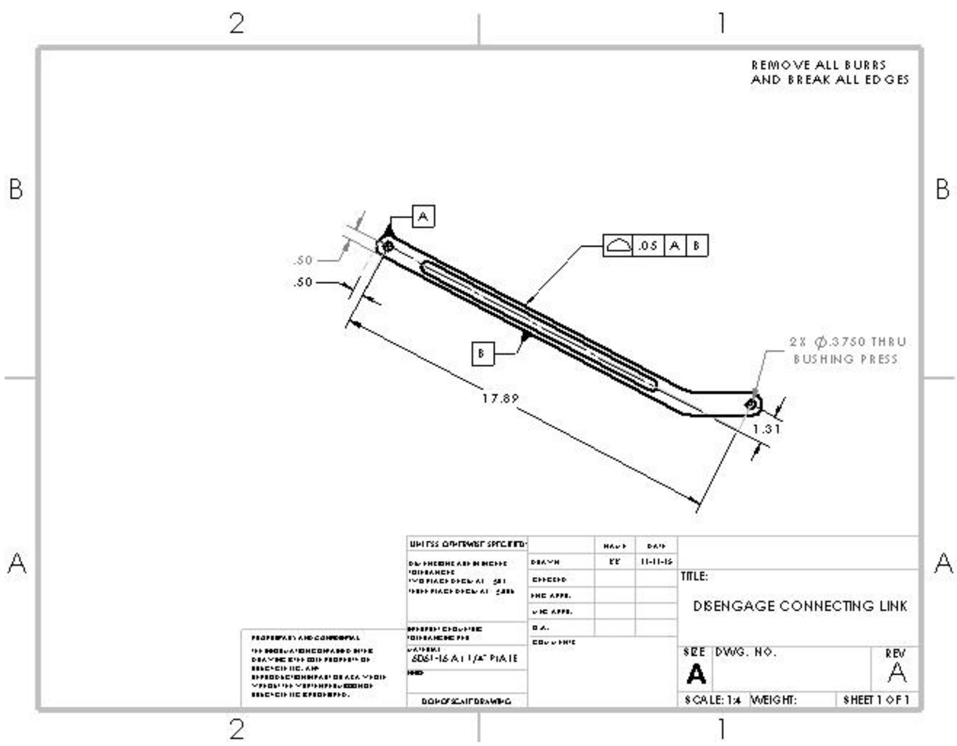


Figure E.5 : Disengage Lever, Part # 5

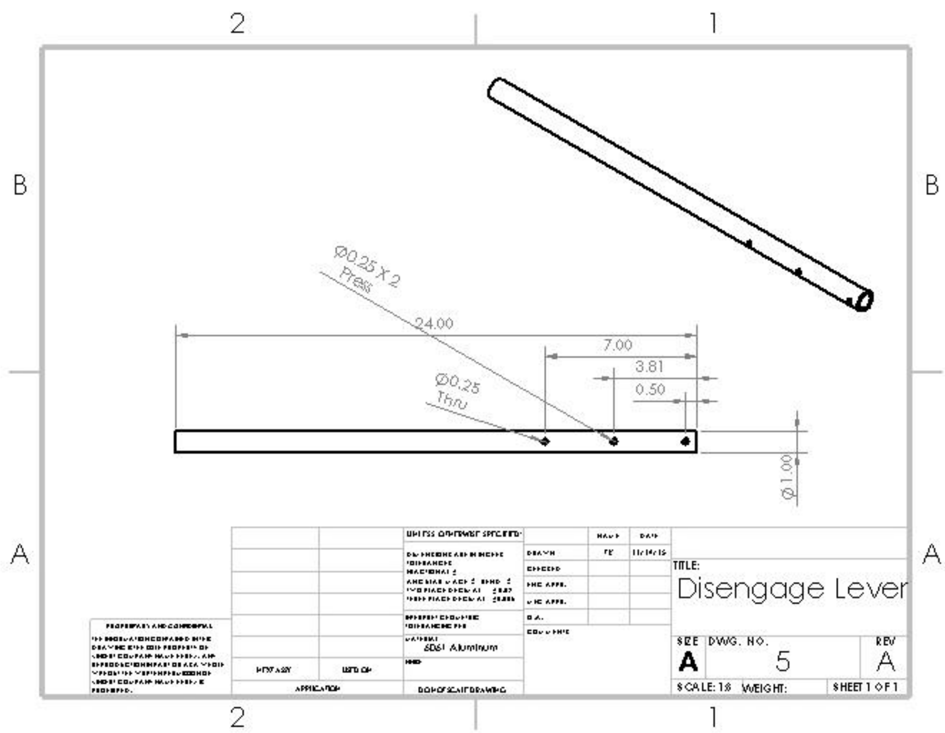


Figure E.6 : Bent Bike Attachment Straight Bar, Part #6

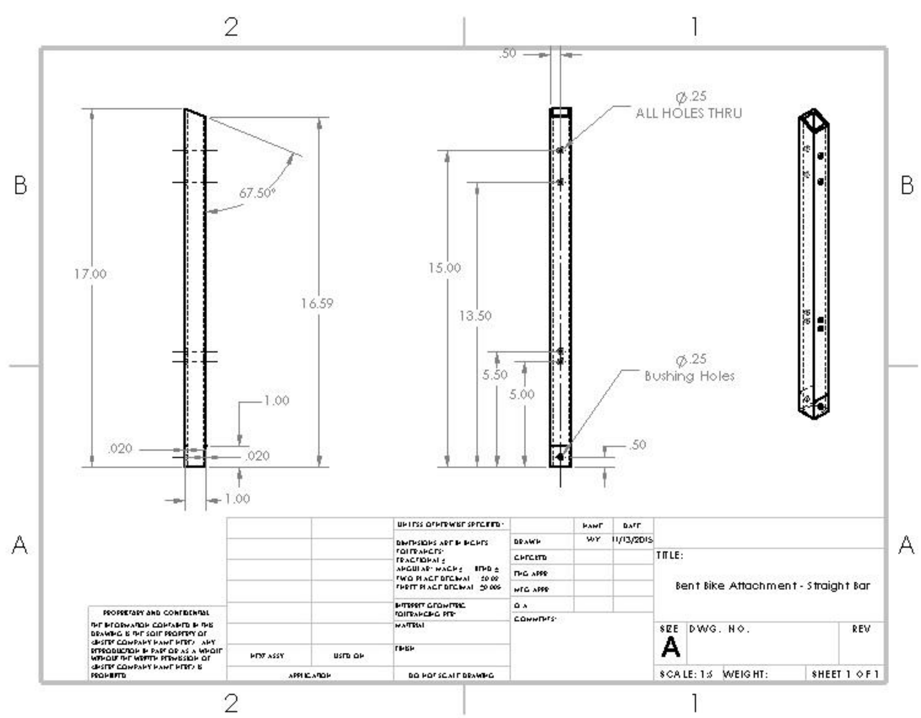


Figure E.7 : Indexer, Part #7

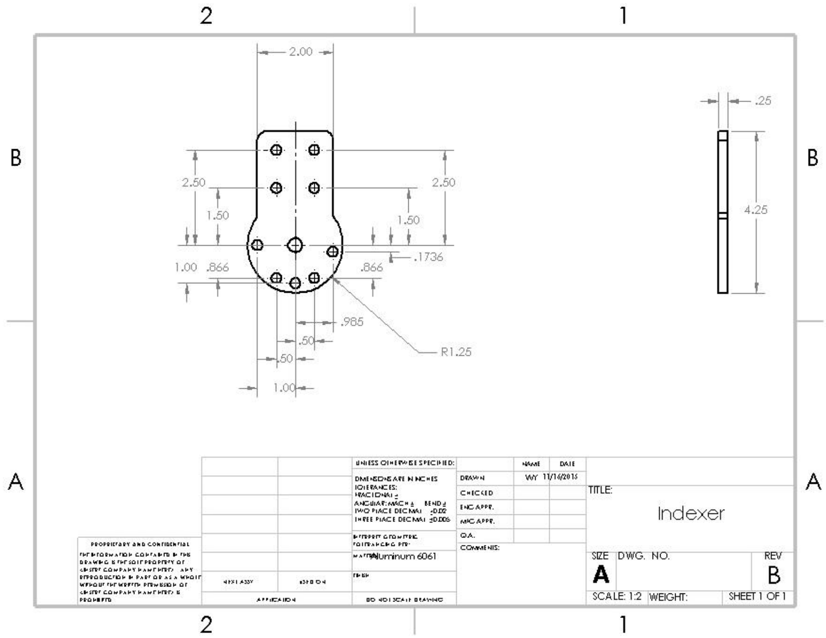


Figure E.8 : Motor Side Axle Support, Part #8

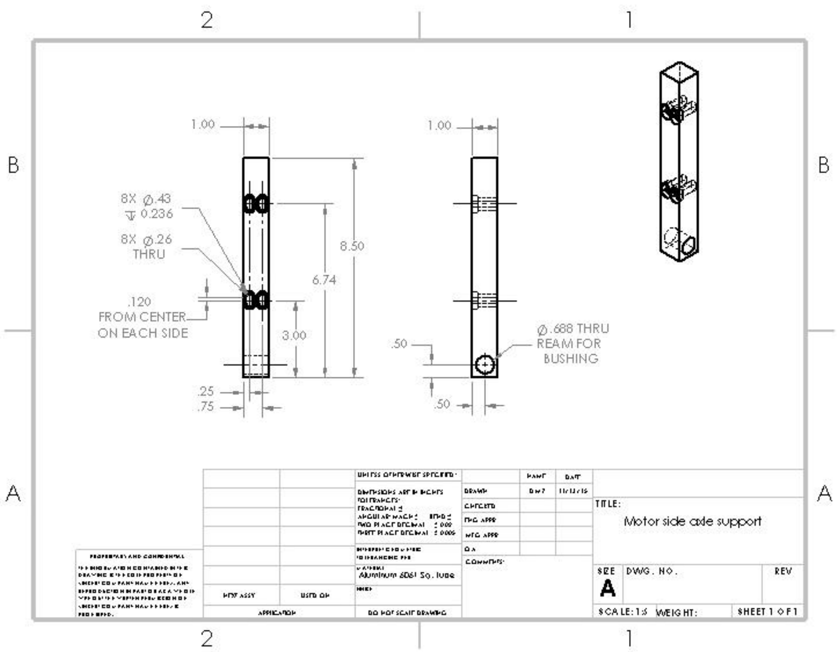


Figure E.9 : Left Side Axle Support, Part #9

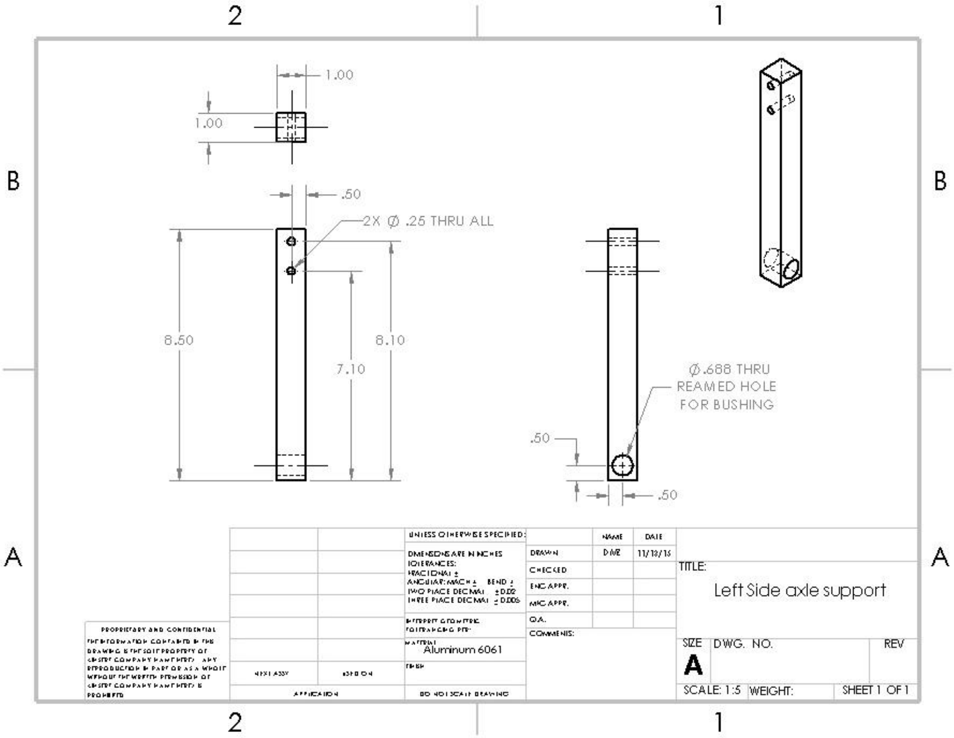


Figure E.10 : Indexer Link, Part #10

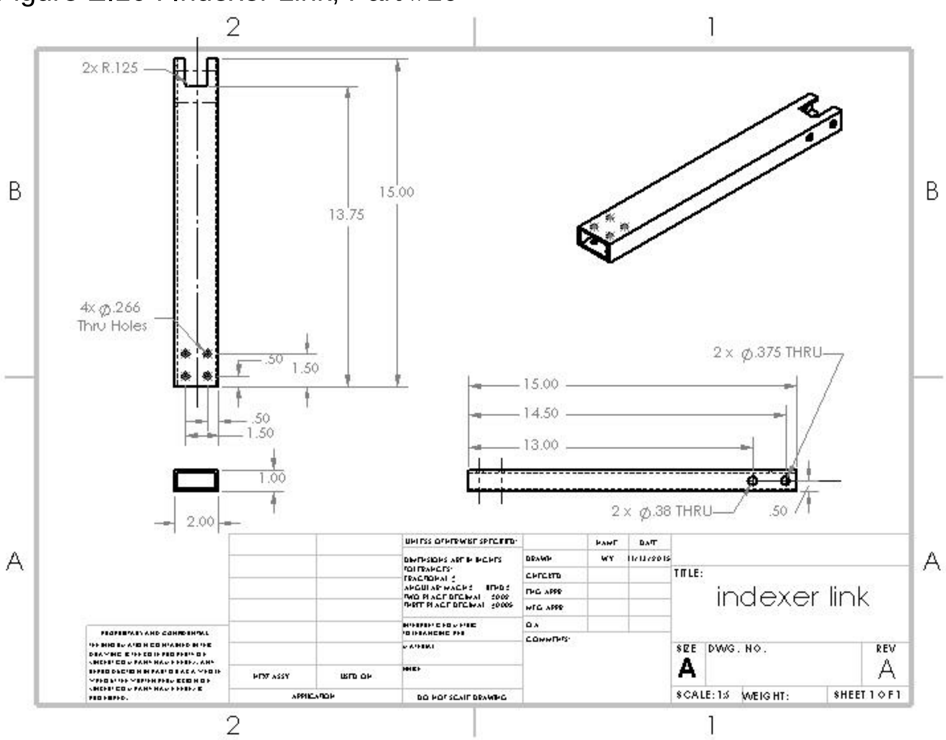


Figure E.11 : Wheel Axle Bracket, Part #11

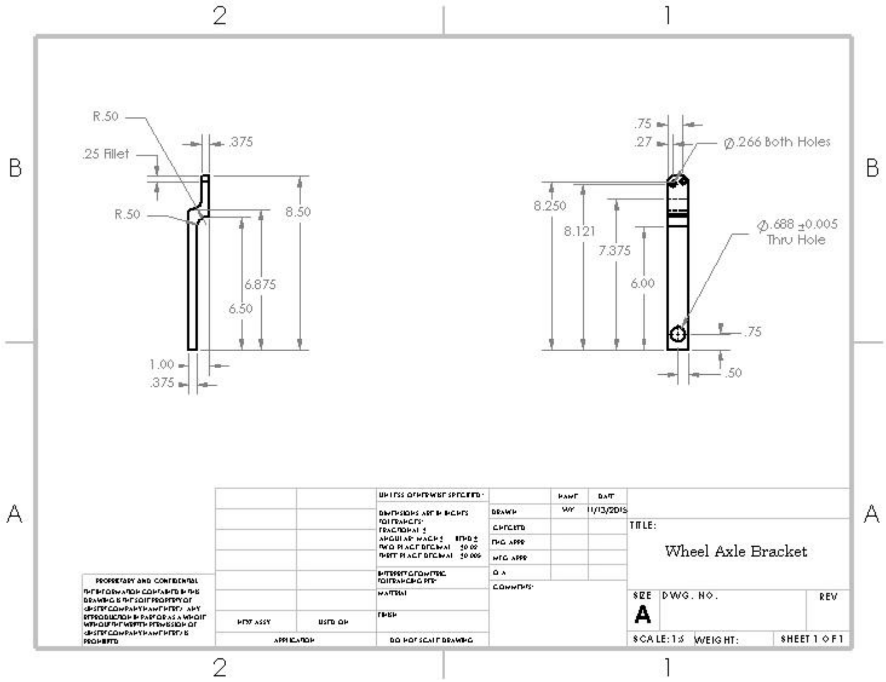


Figure E.12 : Wheel Axle Bracket, Part #12

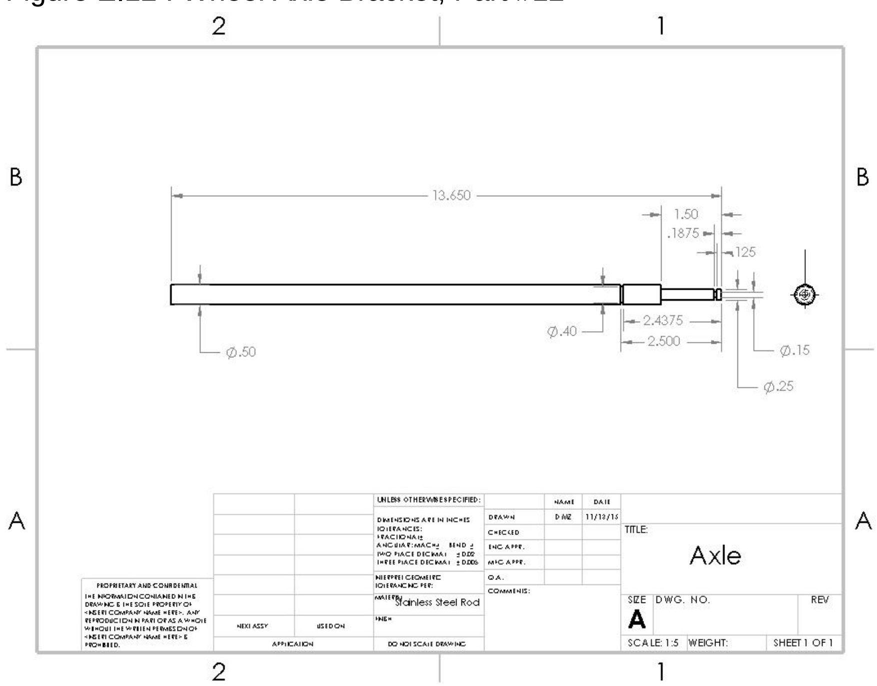


Figure E.13 : Indexer Top Bar Connector, Part #13

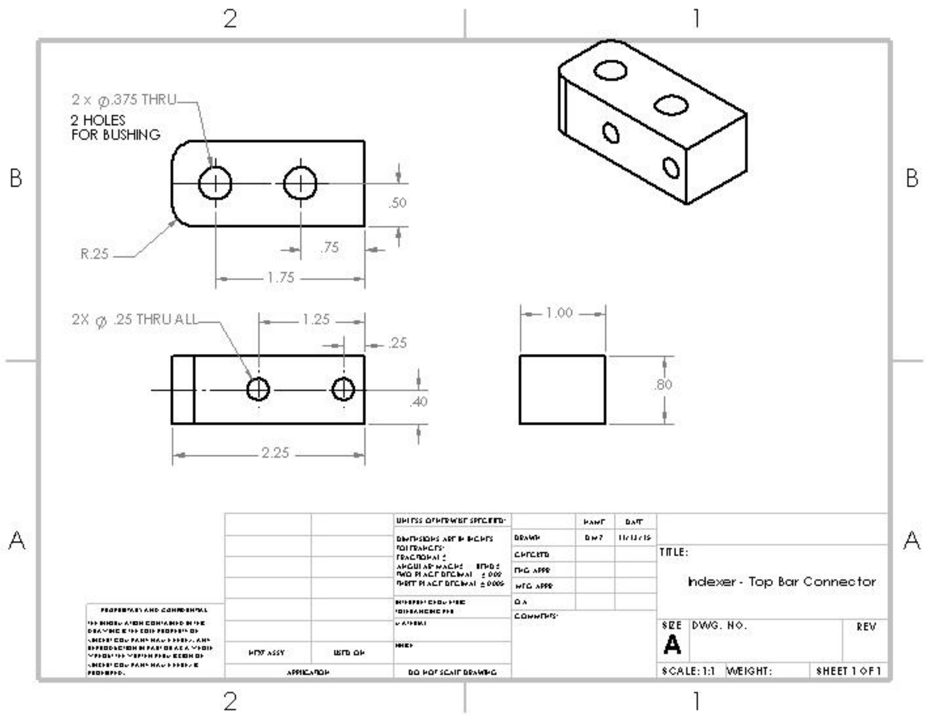


Figure E.14 : Hexagonal Coupler, Part #14

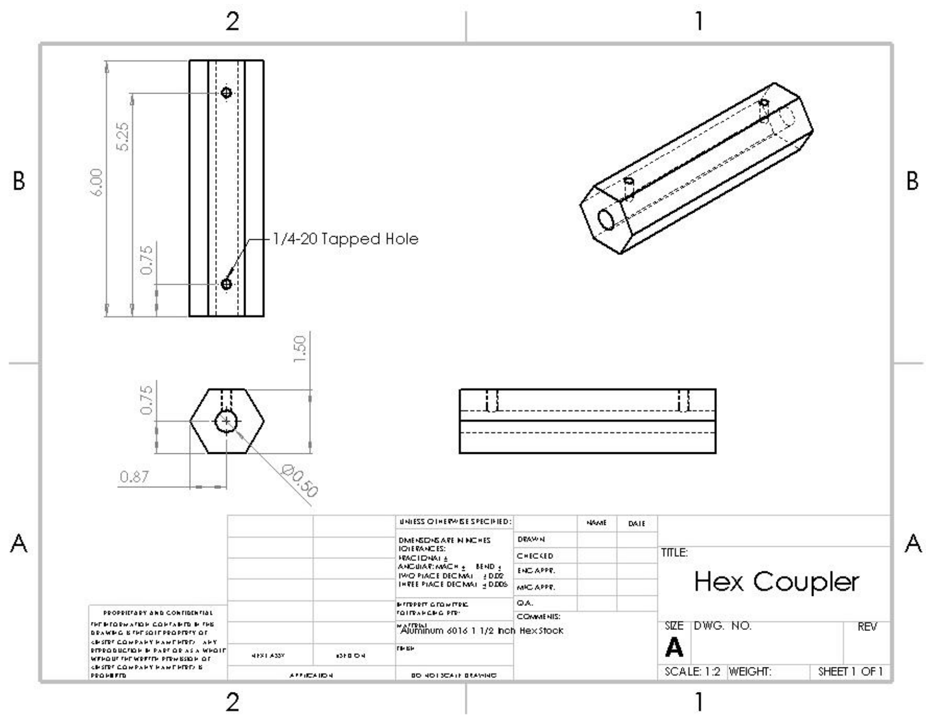


Figure E.15 : Hexagonal Coupler, Part #15

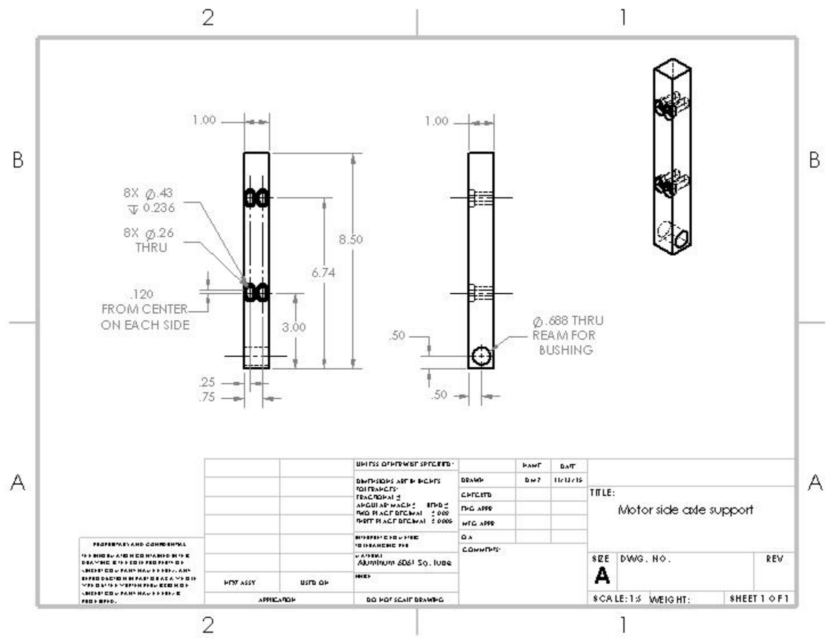


Figure E.16 : Ground Contour Angle Bracket Unthreaded, Part #16

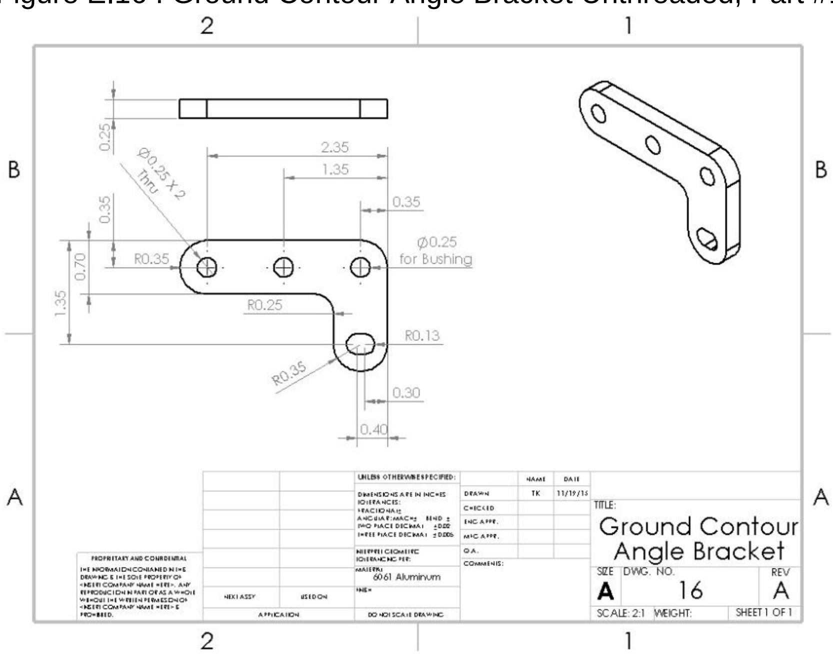


Figure E.17 : Ground Contour Angle Bracket Threaded, Part #17

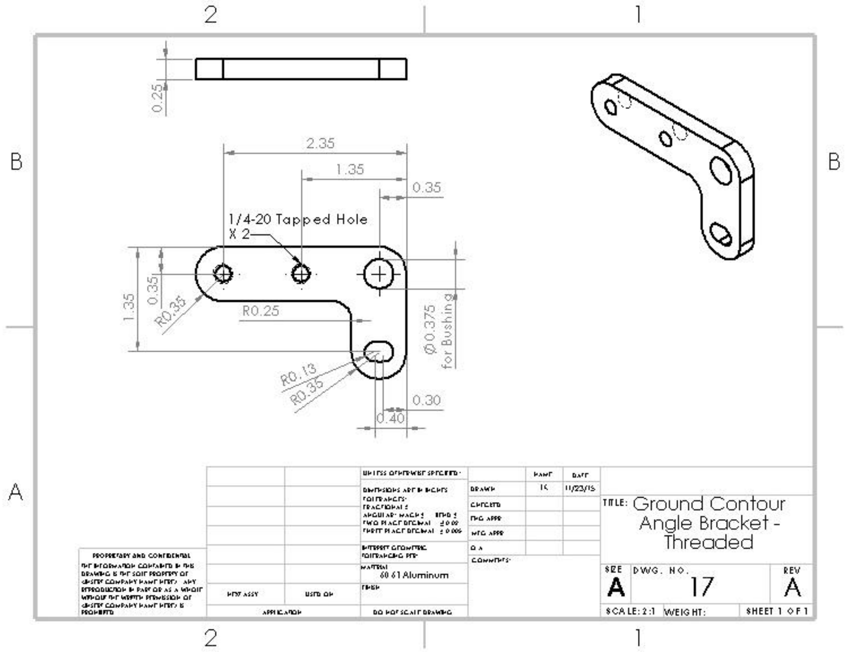
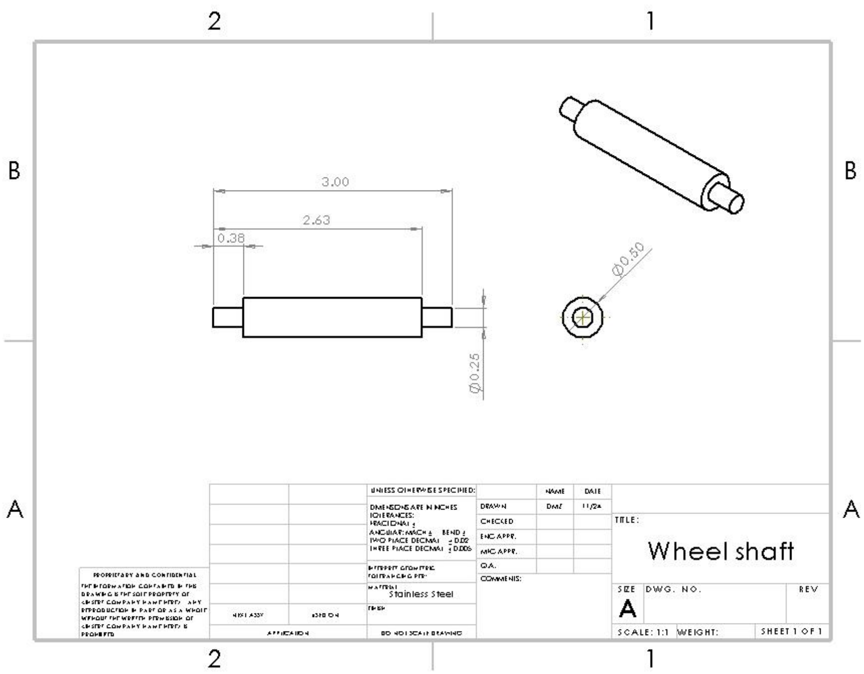


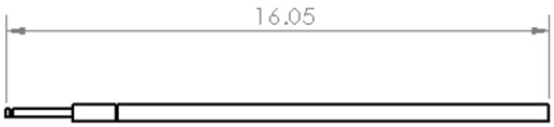
Figure E.18 : Wheel Axle, Part #18



Appendix F : Engineering Change Notices

F.1: Motor Side Axle Engineering Length Change

WAS:



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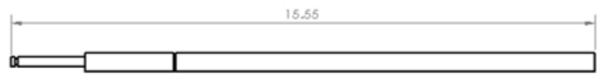


Notes:

Reduced length to make assembly and disassembly of the bristle easier.

ME 450 Team 28	
Project: Bicycle Snow Removal Device	
Ref Drawing: Motor Side Axle	
Engineer: Tyler Kaldobsky	11/29/2015
Proj. Mgr: L. Ni	11/29/2015
Mgmt/Sponsor: M. Strauss	11/29/2015

F.2: Axle Engineering Length Change

WAS:

IS:

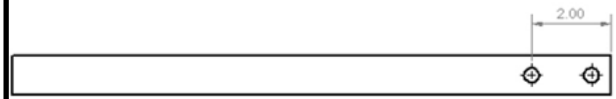
Notes:

Reduced length to make assembly and disassembly of the bristle easier.

ME 450 Team 28	
Project: Bicycle Snow Removal Device	
Ref Drawing: Axle	
Engineer: Tyler Kaldobsky	11/29/2015
Proj. Mgr: L. Ni	11/29/2015
Mgmt/Sponsor: M. Strauss	11/29/2015

F.3: Indexer Link Hole Location Change

WAS:



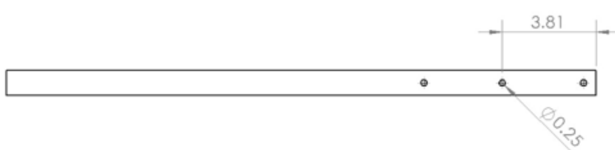
IS:

Notes: Moved location of hole to improve the mechanical advantage of the system.

ME 450 Team 28	
Project: Bicycle Snow Removal Device	
Ref Drawing: Indexer Link	
Engineer: Tyler Kaldobsky	12/13/2015
Proj. Mgr: L. Ni	12/13/2015
Mgmt/Sponsor: M. Strauss	12/13/2015

F.4: Disengagement Lever Slot Change

WAS:



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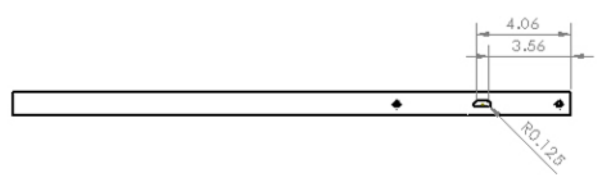
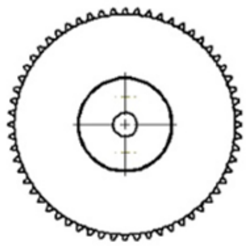


Notes: Added slot instead of hole to allow for a sliding pin spring system to make device easier to disengage.

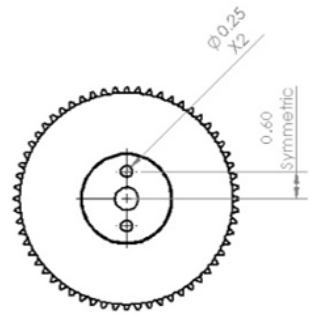
ME 450 Team 28	
Project: Bicycle Snow Removal Device	
Ref Drawing: Disengagement Lever	
Engineer: Tyler Kaldobsky	12/13/2015
Proj. Mgr: L. Ni	12/13/2015
Mgmt/Sponsor: M. Strauss	12/13/2015

F.5: 60 Tooth Sprocket Thru Holes

WAS:



IS:



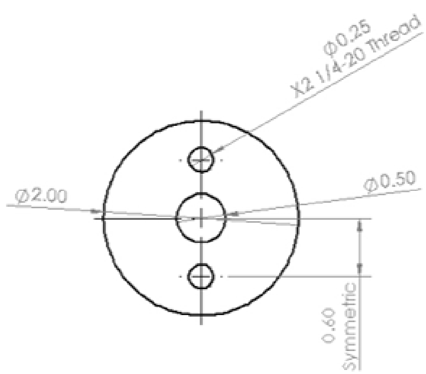
Notes:

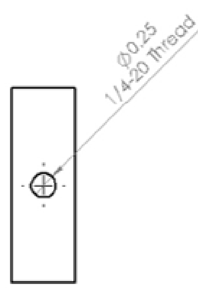
Added clearance holes for axle attachment adapter.

ME 450 Team 28	
Project: Bicycle Snow Removal Device	
Ref Drawing: 60 Tooth Sprocket	
Engineer: Tyler Kaldobsky	12/13/2015
Proj. Mgr: L. Ni	12/13/2015
Mgmt/Sponsor: M. Strauss	12/13/2015

F.6: Gear Adapter with ¼-20 Threaded Holes

IS:





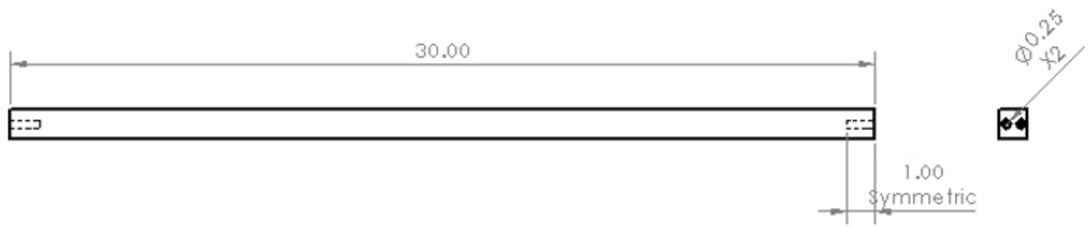
Notes: Was added to fix the 60 tooth sprocket

to the bristle axle.

ME 450 Team 28	
Project: Bicycle Snow Removal Device	
Ref Drawing: Sprocket Adapter	
Engineer: Tyler Kaldobsky	12/13/2015
Proj. Mgr: L. Ni	12/13/2015
Mgmt/Sponsor: M. Strauss	12/13/2015

F.7: Added Disengage Cross Bar

IS:



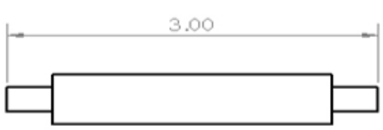
Notes: Added to add stability while disengaged.

Supports the wheel axle.

ME 450 Team 28	
Project: Bicycle Snow Removal Device	
Ref Drawing: Disengage Cross Bar	
Engineer: Tyler Kaldobsky	12/13/2015
Proj. Mgr: L. Ni	12/13/2015
Mgmt/Sponsor: M. Strauss	12/13/2015

F.8: Wheel Shaft Length Change

WAS:



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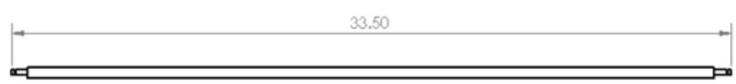


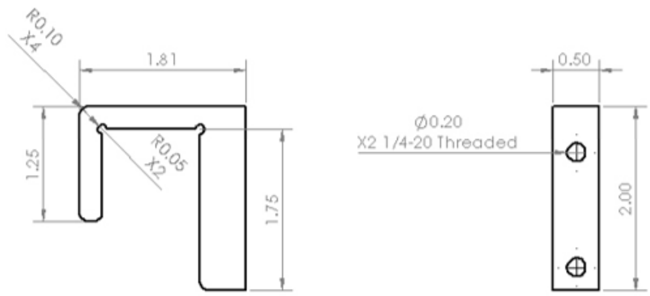
Notes: Was made larger to adapt for the Disengage

Cross Bar and support another wheel.

ME 450 Team 28	
Project: Bicycle Snow Removal Device	
Ref Drawing: Wheel Shaft	
Engineer: Tyler Kaldobsky	12/13/2015
Proj. Mgr: L. Ni	12/13/2015
Mgmt/Sponsor: M. Strauss	12/13/2015

F.8: Added Battery Box Clamp Bracket

IS:



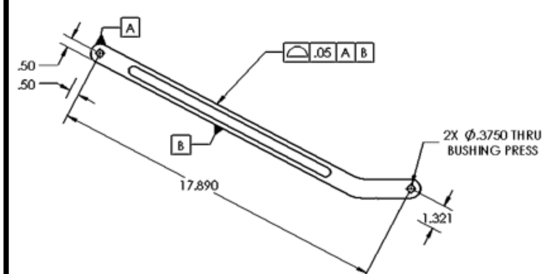
Notes:

Added to attach the battery box to the frame.

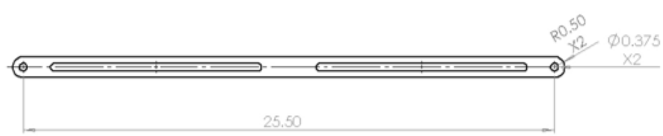
ME 450 Team 28	
Project: Bicycle Snow Removal Device	
Ref Drawing: Clamp Bracket	
Engineer: Tyler Kaldobsky	12/13/2015
Proj. Mgr: L. Ni	12/13/2015
Mgmt/Sponsor: M. Strauss	12/13/2015

F.9: Disengagement Link Length and Geometry Change

WAS:



IS:



Notes: Updated length of links and changed geometry

to improve system mechanical advantage.

ME 450 Team 28	
Project: Bicycle Snow Removal Device	
Ref Drawing: Disengagement Link	
Engineer: Tyler Kaldobsky	12/13/2015
Proj. Mgr: L. Ni	12/13/2015
Mgmt/Sponsor: M. Strauss	12/13/2015

Appendix G : Validation Plans

The purpose of this appendix is to describe the validation plans we will use to test the prototype.

Snow removal

The main function of the device is to remove snow. Therefore, the device will be tested on soil to simulate sense snow and observed if it is able to fling a significant amount of soil when it is operated. No equipment will be needed for this test. The bristles will be tested on loose soil, mud and dense soil to represent different snow densities.

Operation Time at Maximum Power Output

The requirements for this device state that it should run at a maximum power output of 250W for at least 30 minutes. This is a reasonable period of time required for an individual to clear a sidewalk or driveway along with keeping in mind the endurance of a rider biking through snow for extended amounts of time. A stopwatch will be used to record the time. The device will be run in grass, which simulates dense snow, until it loses power. The process will be repeated for 3 times to obtain an average operation time.

Disengage Functionality

The disengage mechanism needs to provide the user with enough mechanical advantage that a majority of operators (50th percentile female and up) are able to comfortably operate it. Our target input force is 30 lbs based on anthropometrics data for an “average” human. A spring gauge will be used to record the force needed to disengage the bristle assembly. The gauge will be attached at the end of lever where the user would grip. The test will be done by pulling on the spring gauge while standing over the bicycle seat to emulate operating conditions.

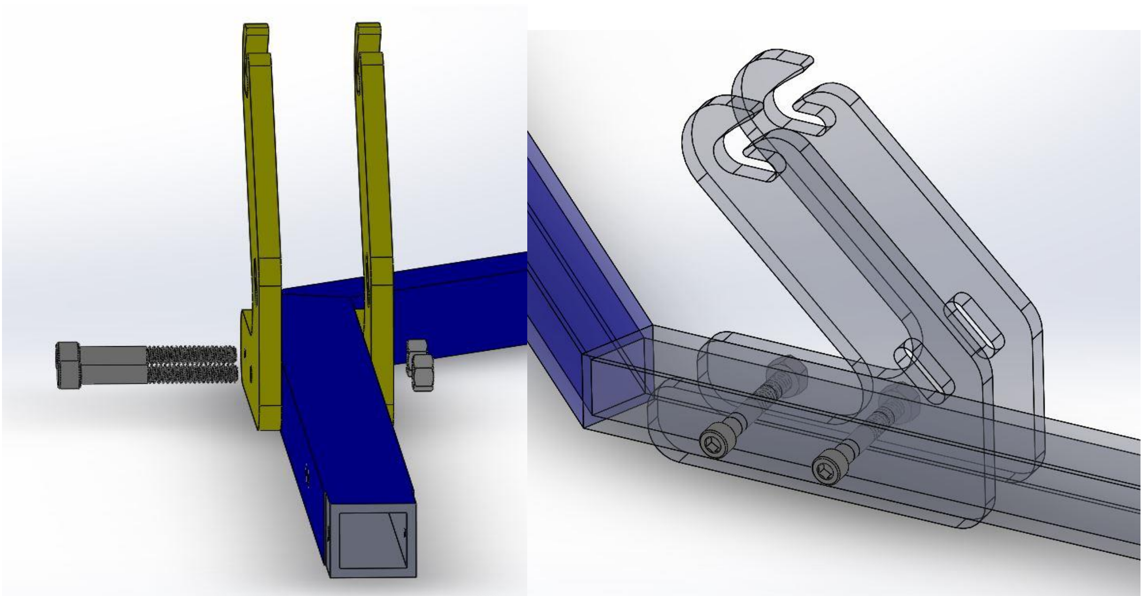
Stability Riding with Device

The device should not hinder the rider with attached to the bike when it is running or when it is in the disengaged position. To test this we will attach the device to our sponsor’s bicycle and have him ride the bike with the bristles spinning and with the device engaged. While he is riding we will get his feedback about how the device affects his ability to ride. This is largely a subjective rating and thus has no “hard” metric to validate its compliance.

Appendix H: Assembly Plan

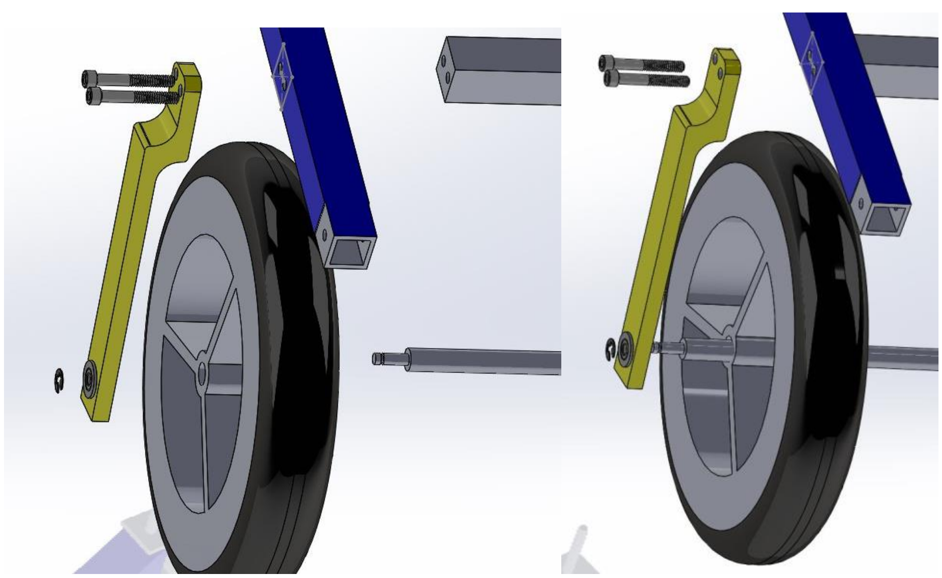
Step 1: Align the disengagement locks with the bent bar holes and insert the ¼-20 screws, fastening them with hex nuts.

Parts Needed - Two 1.5” length, ¼-20 screws, two ¼-20 Hex Nuts



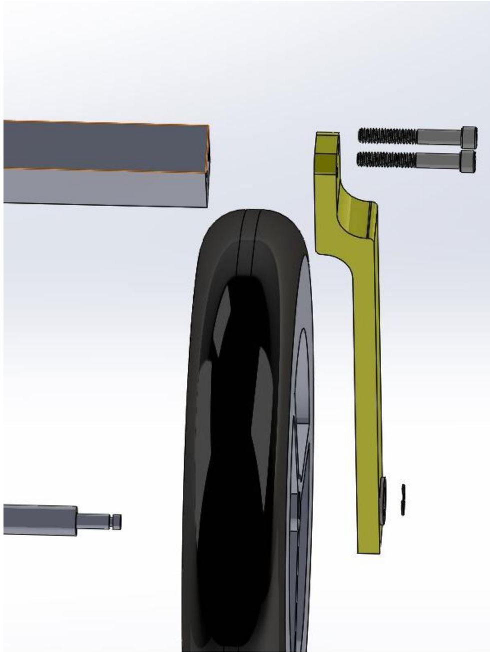
Step 2: Screw in the axle support bracket into the crossbar while supporting the crossbar on the other end. Insert the wheel axle and clamp the E-Clip into the axle as shown below.

Parts Needed - Two 1.75” length ¼-20 screws, ¼” E-Clip, 8” support wheel, wheel axle bracket, wheel axle



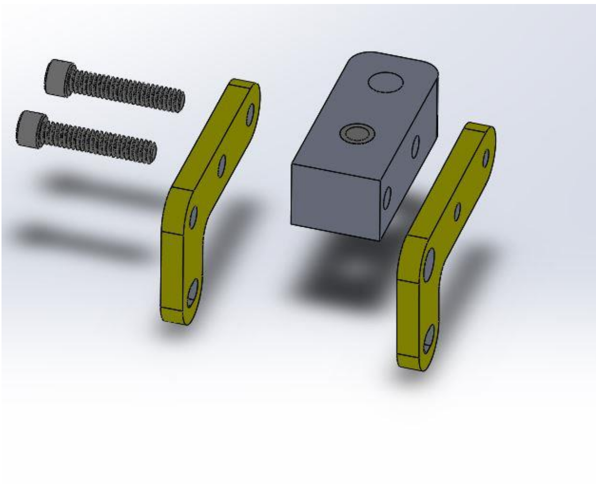
Step 3: Thread in the ¼-20 screws on the other side of the crossbar. Slide the other 8” wheel onto the wheel axle and clamp the E-Clip onto the axle in the location shown below.

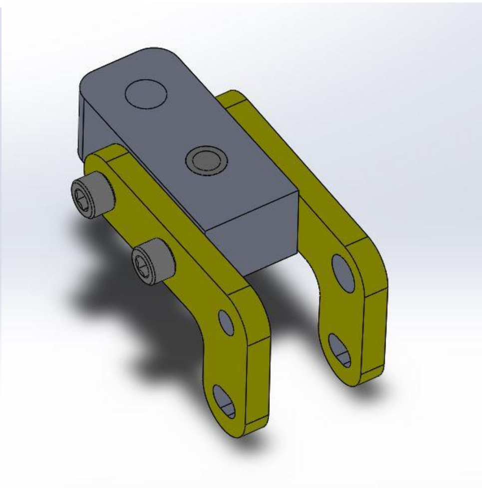
Parts Needed - Two 1.75” length ¼-20 screws, ¼” E-Clip, 8” support wheel, wheel axle bracket, wheel axle



Step 4: Align contour brackets with top bar connector, insert ¼-20 screws through clearance holes and thread into the threaded ground contour bracket.

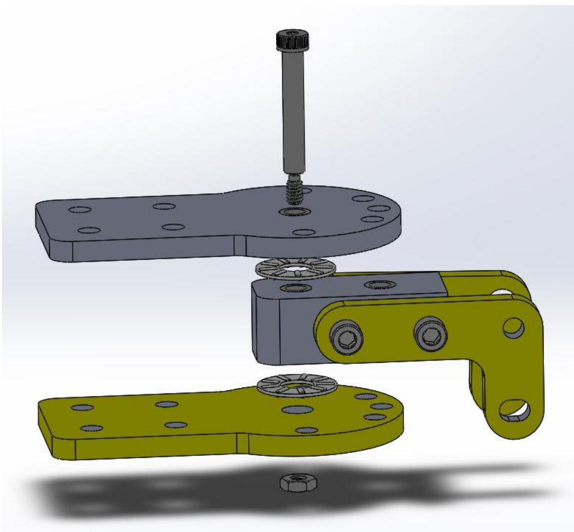
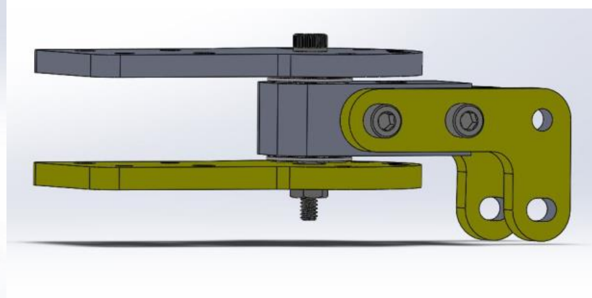
Parts Needed - Two 1.5” ¼-20 Screws, two Ground Contour Bracket, Top Bar Connector





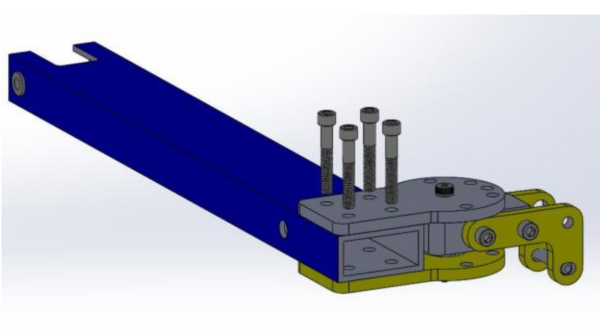
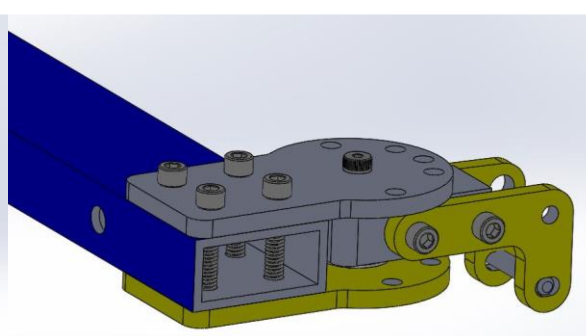
Step 5: Align indexers and needle bearings with the subassembly in Step 5, insert shoulder screw and lock the hex nut using an adjustable or proper sized socket wrench.

Parts Needed - Two needle bearings, 1.5” long, ¼ diameter Shoulder Screw with 10-24 thread, 10-24 Hex Nut, two Indexers, Step 4 subassembly

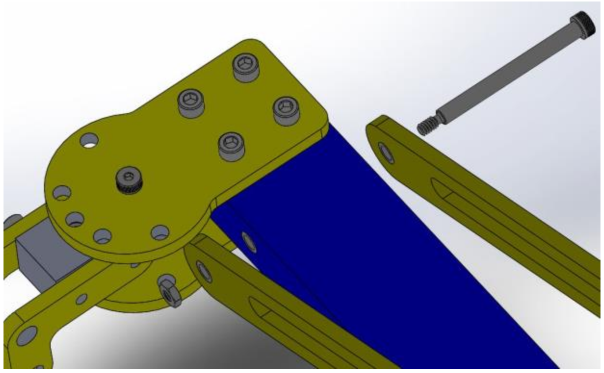
Step 6: Align the subassembly in step 5 on the indexer link as shown in the pictures below. Insert and thread the four ¼-20 screws into the bottom indexer piece.

Parts Needed - Subassembly from step 5, four 1.5” long ¼-20 screws, Indexer Link

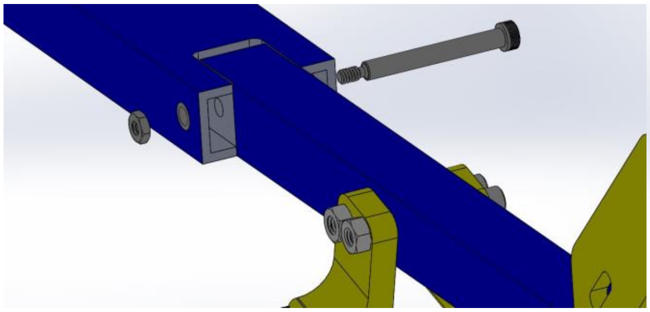
Step 7: Connect the disengagement links with the indexer link using the shoulder bolt.

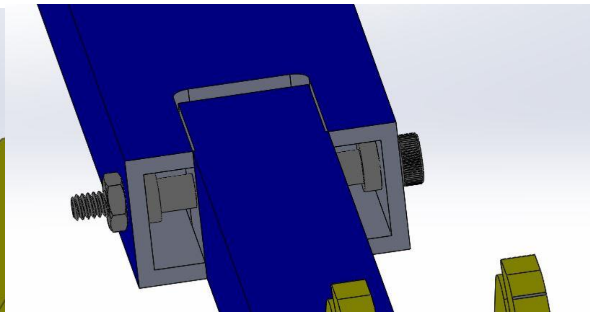
Parts Needed - Disengagement Links, Indexer Link, 2.5" long, ¼ diameter Shoulder Screw with 10-24 thread, 10-24 Hex Nut



Step 8: Align the other end of the indexer link with the bent bar and fasten the shoulder bolt using the 10-24 hex nut.

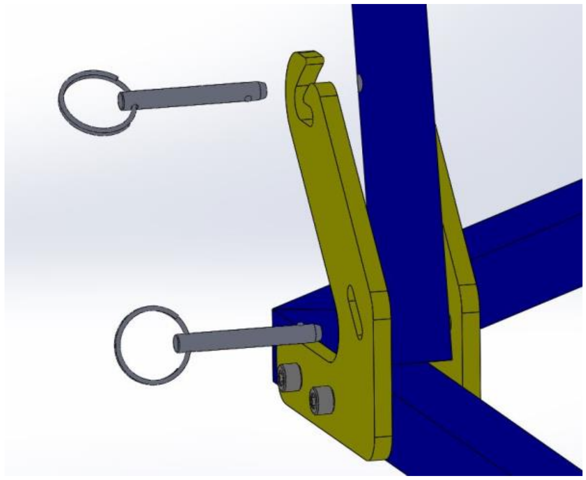
Parts Needed - Subassembly from step 3, Subassembly from step 6, 2" long, ¼ diameter Shoulder Screw with 10-24 thread, 10-24 Hex Nut





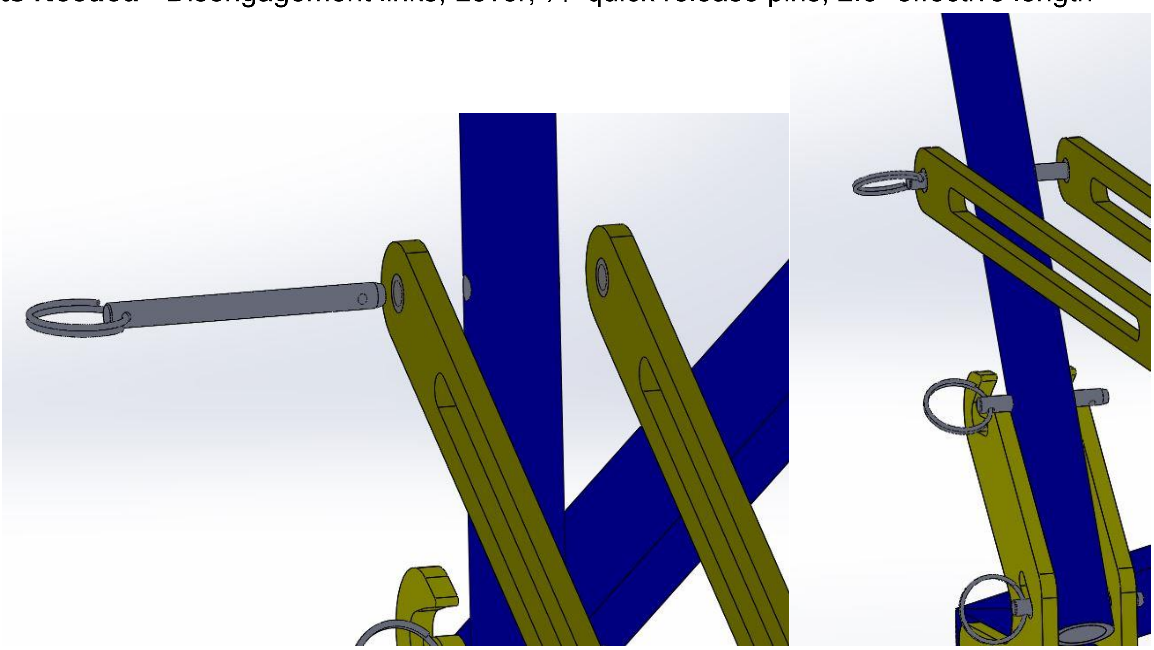
Step 9: Insert the quick release pins in the disengagement locks and lever arm as shown below.

Parts Needed - Lever, Disengagement locks, Two ¼” quick release pins, 1.5” effective length



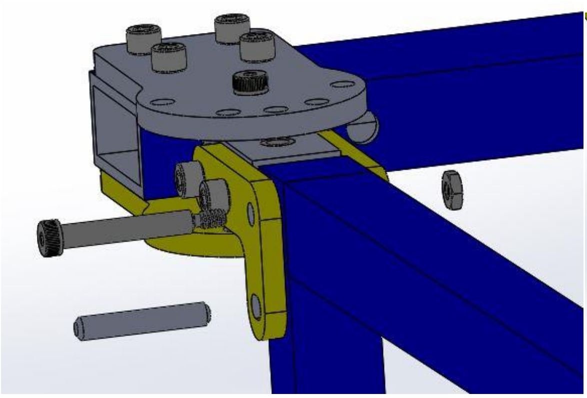
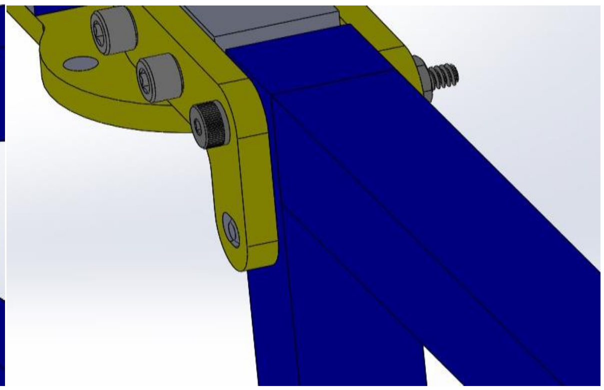
Step 10: Connect the disengagement links with the lever arm using the quick release pin.

Parts Needed - Disengagement links, Lever, ¼” quick release pins, 2.5” effective length



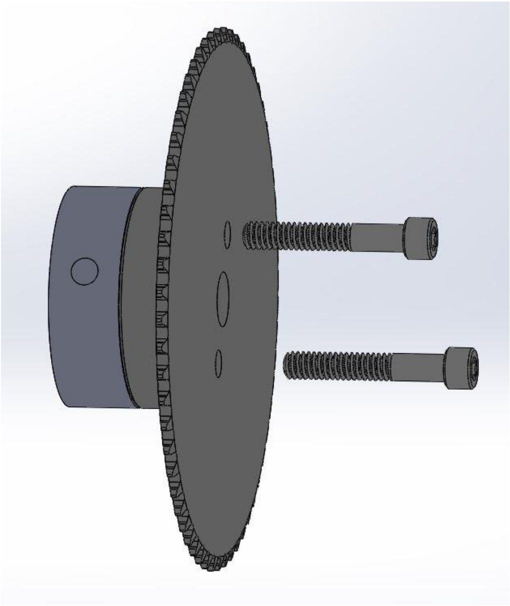
Step 11: Support the bristle support bar and align it with the ground contour brackets. Insert the shoulder screw and fasten the hex nut. Insert the dowel pin, press fitting it through the bristle support bar.

Parts Needed - Subassembly from Step 7, Bristle support bar, 1.5” long, ¼ diameter Shoulder Screw with 10-24 thread, 10-24 Hex Nut, ¼ “ diameter, 1.5” dowel pin

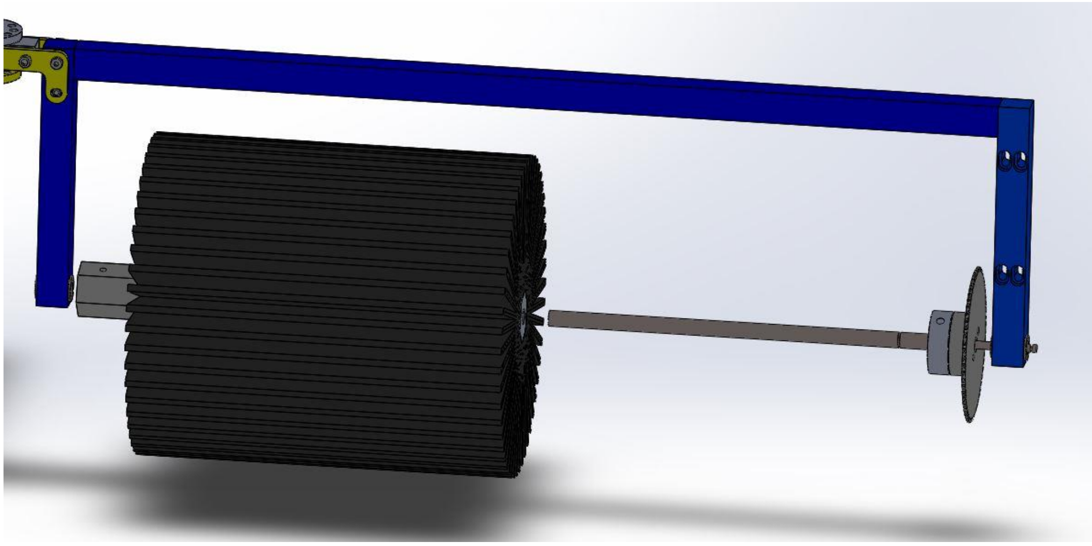
Step 12: Attach the sprocket to the sprocket adapter with the two ¼-20 screws, threaded each into the adapter.

Parts Needed - 60 Tooth sprocket, Sprocket adapter, Two 1.5” length, ¼-20 screws



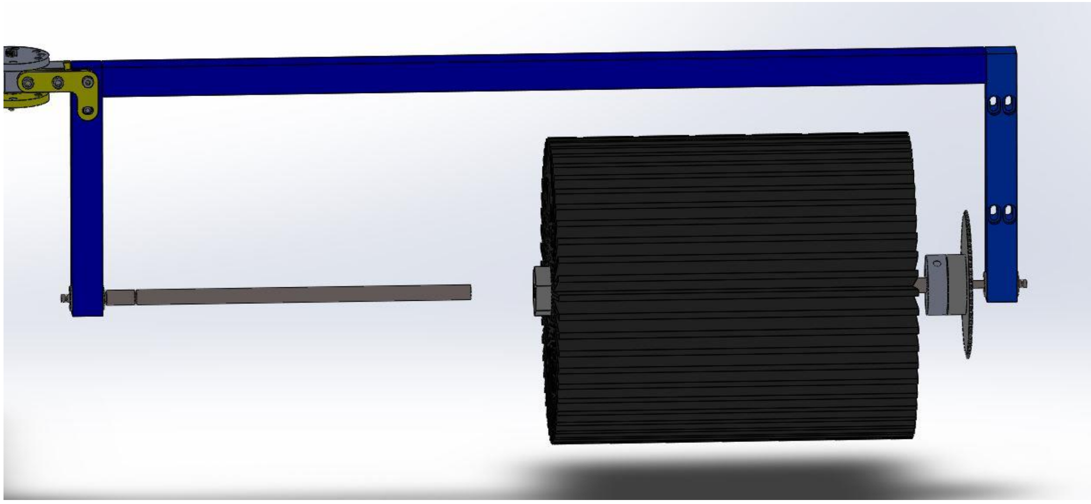
Step 13: Insert the motor side axle piece into the right support and slide the sprocket attachment onto the axle. Insert the hex coupler into the end of one bristle and align the bristle towards the axle with the hex piece on the face directed towards the axle.

Parts Needed - Bristle, Motor Side Axle, Hex Coupler, 60 Tooth sprocket



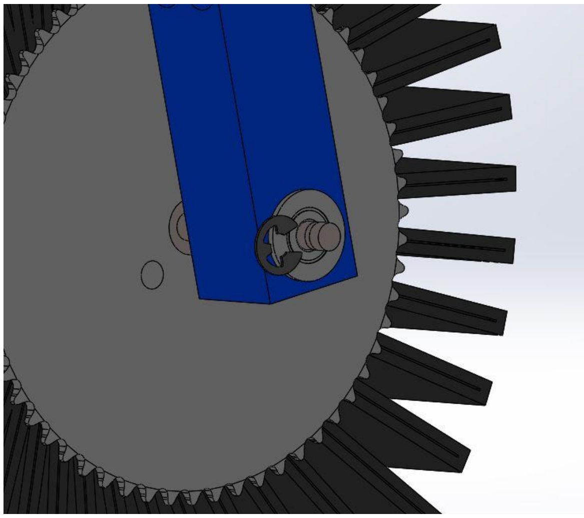
Step 14: Slide the bristle and hex coupler onto the motor side axle. Insert the left axle into the opposite side as shown below.

Parts Needed - Axle



Step 15: Add a 0.25” E-clip to the slot on the motor side axle as shown below.

Parts Needed - 0.25” E-Clip

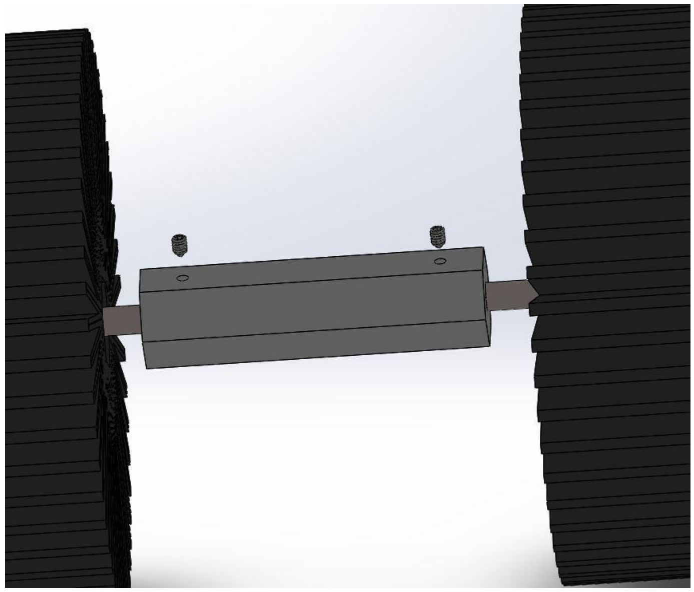


Step 16: Add a 0.25” E-clip to the slot on the motor side axle and slide the other bristle onto the axle as shown below.

Parts Needed - 0.25” E-Clip, Bristle

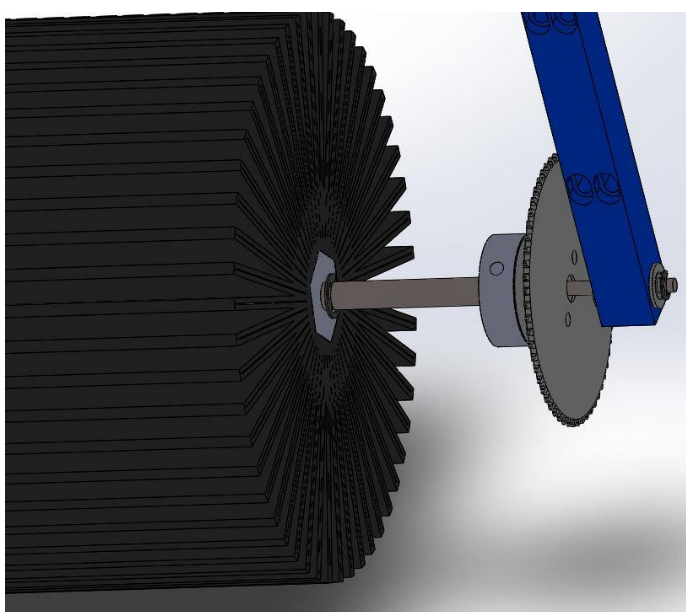
Step 17: Slide the bristles as far onto each axle and place the hex coupler in the center, aligning it with the E-clip slot. Insert and thread two set screws using an Allen wrench.

Parts Needed - Hex Coupler, Two ⅜" length ¼-20 set screws



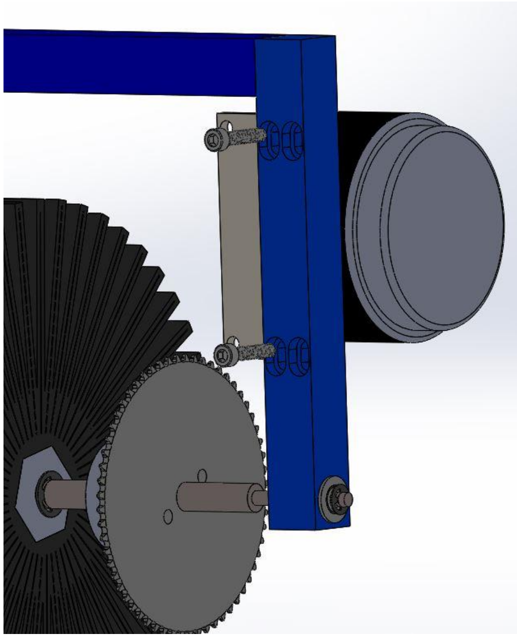
Step 18: Clamp the ½" E-Clip onto the shaft in the location shown below.

Parts Needed - ½ " E-Clip



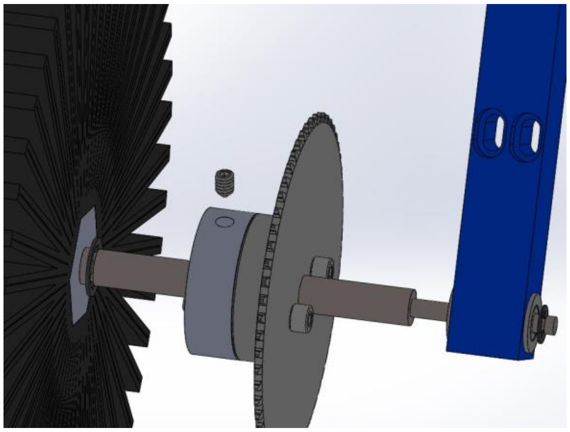
Step 19: Thread the motor onto the bristle support bar, fastening the M6 screws loosely in the slot to allow for the chain to be added.

Parts Needed - Two 30mm M6 screws, Motor



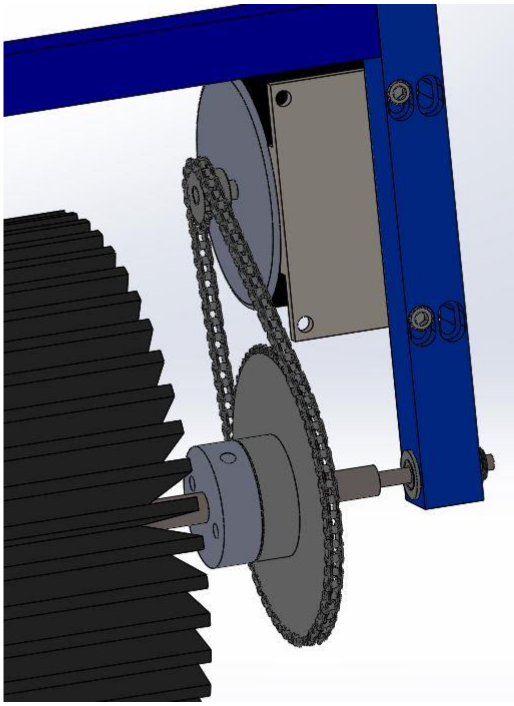
Step 20: Thread the set screw through the sprocket adapter and into contact with the axle. Keep the set screw loose to allow for adjustment of the sprocket while setting up the chain.

Parts Needed - 60 Tooth Sprocket, ⅜" Length, ¼-20 Set Screw



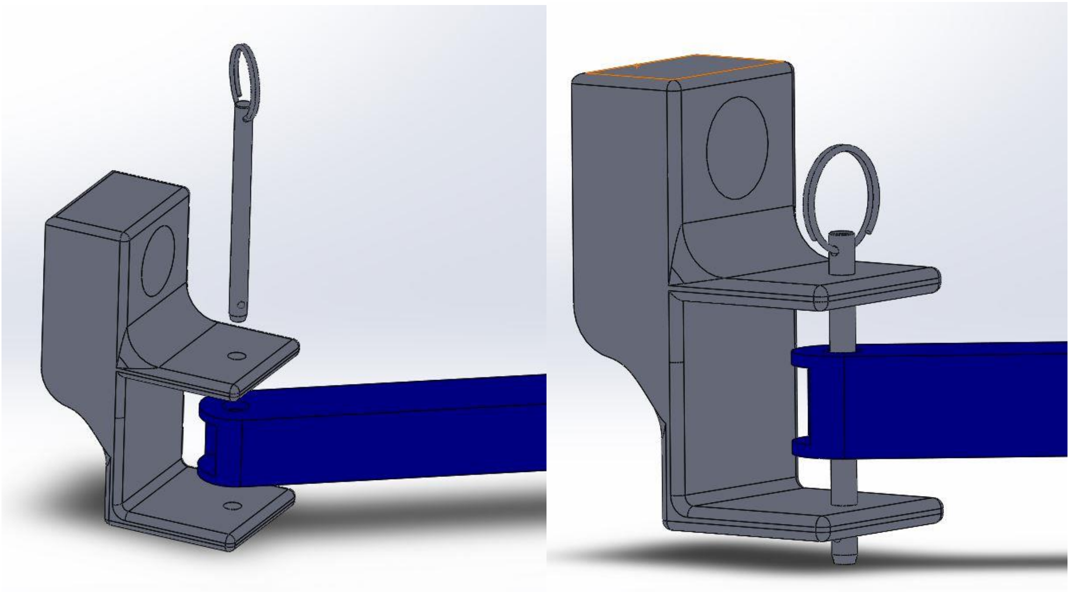
Step 21: Wrap the chain around the sprockets, adjust the height of the motor in the slots by loosening the M6 screws and raising the motor until the chain is in tension. Once the chain is in tension, tighten the M6 screws.

Parts Needed - Two 30mm M6 screws, Motor, #25 Roller Chain



Step 22: Attach the device to the bicycle by inserting the locking pin through the bicycle adapter and the bent bar joint.

Parts Needed - Bicycle adapter, Device assembly, ¼" quick release pin, 2.5" effective length



Bibliography

[1] “Compare US Cities Average Snowfall." *US Cities Average Annual Snowfall*. Web. 21 Sept. 2015. <http://snowfall.weatherdb.com/>.

[2] Pytka, Jaroslaw A. "Snow Stress State under Ground Vehicle Loads."*Dynamics of Wheel-soil Systems a Soil Stress and Deformation-based Approach*. 1st ed. Boca Raton: CRC, 2013. 331. Print.

[3] Hansen, David. Composite Snow Plow Apparatus and Method. David Hansen, assignee. Patent CA 2806030 A1. 12 Aug. 2013. Print.

[4] Landucci, Angelo. Snow Bicycle. Angelo Landucci, assignee. Patent US 5738361 A. 14 Apr. 1998. Print.

[5] McDaniel, Royce A. Bicycle Ski Attachment Assembly. Royce A. McDaniel, assignee. Patent US 8403342 B1. 26 Mar. 2013. Print.

[6] Leibrock, Amy. "6 Eco-Friendly Snow Removal Ideas." *Sustainable America*. Sustainable America, 3 Jan. 2014. Web. 22 Sept. 2015. <http://www.sustainableamerica.org/blog/6-eco-friendly-snow-removal-ideas/>

[7] “Idling Vehicle Emissions for Passenger Cars, Light-Duty Trucks, and HeavyDuty Trucks." *Epa.gov*. United States Environmental Protection Agency, 1 Oct. 2008. Web. 21 Sept. 2015. <http://www3.epa.gov/otaq/consumer/420f08025.pdf>.

[8] “Noise." *Noise*. American Speech-Language-Hearing Association, 2011. Web. 21 Sept. 2015. <http://www.asha.org/public/hearing/Noise/>.

[9] Heimbuch, Jaymi. "Human-Powered Snow Vehicle Zips You Over Hills In Silence." *TreeHugger*. N.p., 10 Dec. 2010. Web. 21 Sept. 2015.

[10] “Average Annual Emissions and Fuel Consumption for Gasoline-Fueled Passenger Cars and Light Trucks." *Epa.gov*. United States Environmental Protection Agency, 1 Oct. 2008. Web. 20 Sept. 2015. <http://www3.epa.gov/otaq/consumer/420f08024.pdf>.

[11] “Noise." *Noise*. American Speech-Language-Hearing Association, 2011. Web. 21 Sept. 2015. <http://www.asha.org/public/hearing/Noise/>.

[12] Blumenthal, Ivan. "Carbon Monoxide Poisoning." *Journal of the Royal Society of Medicine*. The Royal Society of Medicine, 1 June 2001. Web. 23 Sept. 2015. <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1281520/>.

[13] "BOSS UTV PLOWS « Master Truck & Trailer, Waukegan: Hitch, Repair, Bike Racks, Snow Plow." *BOSS UTV PLOWS « Master Truck & Trailer, Waukegan: Hitch, Repair, Bike Racks, Snow Plow*. Web. 22 Sept. 2015. <http://mttllc.net/boss-utv-plows>

[14] "Designing Sidewalks and Trails for Access." *Chapter 4*. U.S. Department of Transportation Federal Highway Administration, 10 Feb. 2014. Web. 23 Sept. 2015. <http://www.fhwa.dot.gov/environment/bicycle_pedestrian/publications/sidewalks/chap4a.cfm>

[15] Georg, Ramgraber. Coupling for Hitching Trailer to Bicycle. Ramgraber Georg, assignee. Patent DE19705554 (A1). 28 Aug. 1997. Print.

[16] Hallett, Richard. *The Bike Deconstructed: A Grand Tour of the Modern Bicycle*. New York: Princeton Architectural Press, 2014. Print.

[17] "How Loud Is Too Loud? How Long Is Too Long?" *[Noisy Planet]*. NIH Publication No. 09-6433, 3 Dec. 2014. Web. 20 Sept. 2015. <http://www.noisyplanet.nidcd.nih.gov/info/Pages/howloud.aspx?nav=npeml>.

[18] Kenneth. "Velomobiles." *Velomobiles*. Kenneth, 4 Feb. 2015. Web. 21 Sept. 2015.

[19] Lee, Jonah H., et al. "Simulation of Tire-Snow Interfacial Forces for a Range of Snow Densities with Uncertainty".Warrendale, PA: SAE International , 2006. Print.

[20] Otwell, Bob. "The Traverse City Bike Plow: A DIY Instructional." *Norte*. Norte, 21 Dec. 2013. Web. 21 Sept. 2015.

[21] Rivas, Ernesto, and Kazuhisa Mitobe. "Development of the Intake System for the Snow Eater Robot." *Mechatronics* 28 (2015): 27-34. Print.

[22] Shaw, Stephanie L., Stephen B. Reid, Erin K. Pollard, and Dana C. Sullivan. "Improvements to Lawn and Garden Equipment Emission Estimates for Baltimore, Maryland." Improvements to Lawn and Garden Equipment Emission Estimates for Baltimore, Maryland (1993): n. pag. 29 Sept. 2010. Web. 20 Sept. 2015.

[23] "Snow Engineering V: Proceedings of the Fifth International Conference on Snow Engineering, 5-8 July 2004, Davos, Switzerland". *Snow engineering 5; Snow engineering five; Proceedings of the fifth International Conference on Snow Engineering; Proceedings of the 5th International Conference on Snow Engineering; Fifth International Conference on Snow Engineering; 5th International Conference on Snow Engineering.* Leiden: A.A.Balkema , 2004. xii, 382 p. Print.

[24] Tracy, Sam. "Frames." *Bicycle!: A Repair & Maintenance Manifesto*. 2nd ed. Oakland, Calif.: PM, 2013. 117. Print.