Duck Dolly 2.0

Phase 3 Report

December 7, 2021

I pledge my honor that I have abided by the Stevens Honor System.

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Project Statement

For this senior design project, the group is continuing the research and development of a project from the previous year and will be designing and prototyping an attachable cargo storage device for bikes in a city environment. In urban areas, a large demographic of people use bikes as a primary form of transportation for commuting, errands, and delivery services. The most common solutions to this are backpacks and panniers, but these often are either not enough storage or expensive, bulky, and hard to quickly attach or detach from the bike. The group's primary goal is to create a design that efficiently targets these needs and create a functional prototype that can be brought to market. The design will consist of a storage device attached to the bike's rear and trail behind the bike on its wheels. The design will be modular and allow the user to collapse and reorient the attached device from its trailing position to a folded position above the rear wheel, where it can function as a secondary storage type.

In implementing this design, a few challenges will need to be overcome. The main issue is creating a design with high storage capacity that can also be collapsed into a very compact form. Another challenge is making sure that the product is weather-resistant, sturdy, and safe from theft. These challenges can be addressed by looking at how some competitors have resolved similar issues, and consulting with potential customers to see what issues they have and what their current solutions are. The competitors' designs and user inputs will provide concepts to be incorporated into the generated design solutions. These derived solutions will be rigorously tested in the prototyping and experimentation phase to ensure that the product meets all the set requirements. Experiments may include analysis on shock resistance, how the product performs on different terrain, and the time it takes the user to attach and detach the device. Through this method of design and testing, the group is confident in creating a design that meets all the customers' needs and is competitive in the market.

State of the Art Technology

Burley Travoy Bike Trailer

The group identified seven different bike storage products. Of the seven, four of the products were evaluated. The first product reviewed was the Burley Travoy Bike Trailer. The bike cargo trailer costs $300. This trailer attaches underneath the bike seat and can support a weight of up to 60 pounds. The trailer has a size of 43x22x14 inches. The trailer has a quick hitch for easy installation and detachment. It can be folded up much like a suitcase for easy transportation. The trailer can be used as a hand cart when detached from the bike. A picture of the trailer is included in Figure 1.

Figure 1: Burley Travoy Bike Trailer (Left) with Additional Bags (Right)

The picture shows the bike trailer connected to the bike in its functional form as well as the bike trailer with extra bags added. One drawback to this trailer is that the base trailer does not have any sides to keep things from falling off. The trailer also cannot be folded up while it is still attached to the bike. Another drawback is that the trailer is too wide to leave attached to the bike while the bike is stored at a bike rack with other bikes. Another issue with this trailer design is that it would be difficult to stack things on top of each other in the trailer because the trailer is slanted and does not have anything on the sides. The travoy device is also very expensive, which may sway customers away from purchasing this device.

Wald Folding Rear Bicycle Basket

The next product reviewed was the Wald Folding Rear Bicycle Basket, depicted in Figure 2. The wired basket costs $37. It hooks onto a bike rack and can be folded up while attached. The basket's size is 12.75x7.25x8 inches and can hold up to two grocery bags. The basket can be unhooked from the rack very easily.

Figure 2: Wald Folding Rear Bicycle Basket

Figure 2 on the left shows what the basket looks like when on the bike rack in “storage mode.” The left picture also shows what the basket looks like when it is folded up. The picture on the right shows what the basket looks like connected to the bike rack. One drawback to the basket is that there is not much storage space. Another drawback is that a bike rack needs to be purchased in order to be able to use the basket.

Zizzo Trailer

After looking at the wire basket, the group also looked at other bike trailer designs. One of them was the ZiZZO trailer. The ZiZZO bike trailer costs between $170 to $200, depending on where it is bought. This product comes with three main parts: the hitch, the frame, and the bags. The hitch is installed underneath the seat of the bike and extends 22 inches. The trailer’s frame has a hand truck design and can attach to the hitch or be used independently. It is made from aluminum tubing for a lightweight design. In Figure 3 below, the product can be seen with and without two bags that optionally attach to the frame.

Figure 3: ZiZZO Trailer

The large bag at the bottom of the frame is a shopping bag for large items. It also has two straps on the back for use as a backpack. The smaller bag on top is intended as a tote bag and has a shoulder strap. One drawback is that while the frame itself has detachable wheels for minimal storage space, the product is not meant for regular folding and unfolding on the bike with ease. Another drawback is that it would be too wide to leave on the bike while stored at a bike rack with other bikes.

Trenux Foldable Bike Trailer

The final product examined was the Trenux Foldable Bike Trailer, seen in Figure 4. The bike trailer costs $587. The trailer comes with other bicycle attachments, including a bag, a lockset, and a hand-pull extension. The trailer's size is 40 cm x 60 cm and can support an upward weight of 40 kg. After installing the bike attachments, the trailer can be attached and unattached to the bike within 10 seconds. The trailer can be folded up above the back wheel when not being used.

Figure 4: Trenux Foldable Bike Trailer

The picture shows the two positions of the trailer overlaid on the same bike. When the trailer is unfolded with its wheels on the ground it is in its “storage mode.” When it is raised and resting behind the bike seat, it is in its “folded mode.” The product is too bulky to fit in a crowded bike rack. The wheels on the trailer are thick and would not be able to fit in between bikes. Another potential drawback of the trailer is that items cannot be stacked. Like the Travoy, the Trenux device is also very expensive, which may sway customers away from purchasing it as well.

State of the Art Review Conclusions

The team learned from the research conducted that there are more than a few products already on the market that provide cyclists with the means of transporting cargo with their bicycle. Each has a few drawbacks, however, that the team aims to eliminate with a new design. First, the Travoy Trailer and the Trenux Trailer offer two of the best solutions. Their main drawbacks are their cost. The Trenux Trailer costs almost $600 and while the Burley costs half that at $300, the team believes it can develop a new product at a more affordable price than that. The ZiZZO Trailer is another promising solution at a more affordable price of $170 at its lowest. Unfortunately, the ZiZZO cannot collapse to reduce its size and bulk. This prevents bicycles to which it is attached to be stored at bike racks. A collapsible design, like the one the team will develop, will be an advantage over the ZiZZO. The rear folding basket from Wald also provides cyclists with convenient storage, however the amount of storage is limited compared to what trailers or trolleys similar to the Burley, Trenux, and ZiZZO can provide. The team will draw inspiration from the folding basket to develop a product that also can fold or collapse and is as convenient, while providing a larger volume of storage at a more affordable price than existing trailers or trolleys.

Customer Needs and Specifications

Potential Customers

In urban environments, bicycles are a typical mode of transportation used to commute from place to place. Bicycle commuters often need to transport cargo or gear of some kind while on their bike, but find this problematic as bicycles rarely come equipped with built-in cargo storage. This project aims to design a product that will satisfy this need and allow bicycle commuters to transport different types of cargo with a bicycle easily. As there are already a few existing solutions to this problem, a tighter focus of this project will be to create a more affordable and versatile design than existing products. The potential customers include:

- commuters who carry backpacks or large items like sports equipment or an instrument,
- people going grocery shopping who will have several bags of food to transport, and
- restaurant delivery workers transporting takeout food.

Customer Needs List

The team created a customer information survey to learn more about bicycle commuters' challenges while carrying belongings. A link to the survey was posted in an online forum for cyclists. A QR code was also posted around the Stevens Institute of Technology campus and Hoboken's bicycle racks. The survey asked respondents what type of bike they use, how often they cycle, what kind of storage solution they currently use and how satisfied they are with it, what sort of items they carry, and what ideal storage capacity would be for them. The survey can be accessed here: Customer Information Survey. A copy of the questions and the results from the survey are attached in the appendix. With the information gathered from the survey, the team assembled a list of customer needs the project design would aim to satisfy, included below in Table 1.

Table 1: Customer Needs List

	Scale: 1 to 5 least important to most important			
Category	**Index**		**Need**	**Weight**
Convenience	C1	The dolly	is lightweight	2
Convenience	C2	The dolly	is quick to set up	4
Convenience	C3	The dolly	can attach to different bikes	3
Convenience	C4	The dolly	folds compactly	4
Convenience	C5	The dolly	is expandable/collapsable	5
Convenience	C6	The dolly	can be locked for security	3
Convenience	C7	The dolly	is able to be stored with bike at standard bike rack	4
Convenience	C8	The dolly	is easy to attach and detach	2
		The dolly		
Cost	Co1	The dolly	is affordable	5
		The dolly		
Durability	D1	The dolly	protects gear/goods from weather	3
Durability	D2	The dolly	is durable	4
Durability	D3	The dolly	has a long useful lifetime	2
		The dolly		
Performance	P1	The dolly	has a large volume for storage	3
Performance	P2	The dolly	can travel over multiple terrains	4
Performance	P3	The dolly	can navigate narrow sidewalks	2
Performance	P4	The dolly	can handle heavy loads	3
Performance	P5	The dolly	can absorb shocks to protect stored goods	4
		The dolly		
Safety	S1	The dolly	is safe	5

Each need was given a weight based on how important it was to customers. A "1" represents a weight of least importance and a "5" represents most important. The two highest weighted needs were the device's safety and cost. It is unlikely that anyone would use the device if it posed a danger to the rider or passersby, so ensuring the device will not make the bicycle more difficult to ride and will not cause accidents will be given the highest priority during design. As aforementioned, there are already products that offer cargo storage solutions for cyclists, albeit at a high price, such as the Burley and Trenux trailers. Thus, minimizing the product's cost below the current price of those existing products will be a high priority. Some of the next highly weighted needs following cost and safety include expanding or collapsing the device, storing the bicycle with it at a standard bike rack, absorbing shocks to protect the cargo, and traveling over different terrains. The device must not make cycling more inconvenient by being too bulky or cumbersome to prevent the bike from being stored at bike racks and other locations, so designing the device to fit within the profile of a standard bike will be necessary. The team aims to accomplish this by making the device expandable and collapsible to reduce its profile. Likewise, the team hopes this will also allow customers to carry more when the device is in its expanded configuration. Finally, from the customer survey, feedback indicated that cyclists use their bikes on a variety of different terrains, such as dirt/grass paths, cobblestone, or pavement with occasional potholes and speed bumps. The team will focus on the device's design on being able to traverse these different types of terrain and ensuring that the device is capable of absorbing the shocks and jolts that such terrain can impart without incurring damage to itself or its cargo.

Target Specifications

After establishing the customer needs, the next step was to identify the metrics and target specifications the design would have to meet to satisfy the customer needs. Each metric was given a target value the team would like the design to achieve and a limit value that it would have to achieve at a bare minimum. As with the customer needs, each metric identified was assigned a numerical weight of design importance. Some of the highest weighted metrics include the cost, dimensional width in the expanded configuration, width in the collapsed configuration, weather rating, storage volume, and weight capacity. A complete list of the metrics and target specifications is in Table 2.

Table 2: Metrics and Target Specifications

Scale: 1 to 5
least important to most important

Metric No.	Need No.	Metric	Target Value	Limit Value	Weight
1	C1	Weight of dolly	<10 lbs	<20 lbs	2
2	C2	Initial Install Time	<5 min	<10 min	4
3	P4	Storage Load Capacity	>50 lbs	>25 lbs	3
4	C4	Folded width	<12 in	<18 in	4
5	C4	Collapsed height	<4 in	<7 in	2
6	C6	Lockable	> Grade 2	> Grade 1	3
7	P1	Storage Volume	>3 paper bags	>2 paper bags	3
8	Co1	Cost	<150 $	<300 $	5
9	P2,P3	Max Traversable obstacle	>8 in	>6 in	4
10	C7	Expanded width	<20in	<30 in	4
11	C7	Expanded height	<16 in	<19 in	3
12	D1	Weather rating	>66 IP Rating	>64 IP Rating	3
13	D3	Total Lifetime	>3 yrs	>2 yrs	2
14	C8	Attachment/Detachment time	<5 s	<10 s	2
15	C3	Compatibility to bikes	90% of bikes	75% of bikes	3

From the customer survey, 30.8% of respondents are looking to transport a backpack or briefcase, while 30.8% would like to transport 1-2 grocery bags. 11.5% answered that storage for 3-4 grocery bags would be ideal. Additionally, 53.8% answered that a weight capacity of 0-25 pounds would be helpful, and another 34.6% answered with 25-50 pounds. As a result, the team set the target value for the storage volume at 3-4 paper shopping bags and the limit at 1-2 bags. The target value was set at 50 pounds for the storage weight capacity, and the limit became 25 pounds. The customer survey also informed the team that it is vital that the design not be too broad or bulky, both while expanded and collapsed. To that end, the team set a target value for the width of the expanded device at 20 inches and a limit value of 30 inches. These were based on the average end-to-end distance of handlebars on bicycles to allow the device to fit on the same narrow sidewalks or streets as the bike. For the collapsed width, the target value was set at 12 inches and the limit 18. These were based on the average width of bicycle pedals, which the team concluded is the most limiting factor when fitting the bike in a bike rack. Customers also wrote in the survey that protection from weather would be an essential feature for the device. Realizing this, the team set a weather IP rating of 66 as the target value and 64 as the limit. The goal is to create a cart that could protect its cargo from dust and medium/heavy rain, but at the bare minimum protect against water splashes and light rain. In the state of the art review, the existing solutions that closely resemble a trailer or trolley cost as low as $170 and as high as $587. The team is looking to design a similar product but wants it to be slightly more affordable. Thus, the target value for the cost was decided to be $150, with a limit value of $300.

Concept Designs

Concept Design 1

To brainstorm ideas on how to satisfy the customer needs, the team generated several concept designs for the final product. The first concept is depicted in Figures 5 and 6 below.

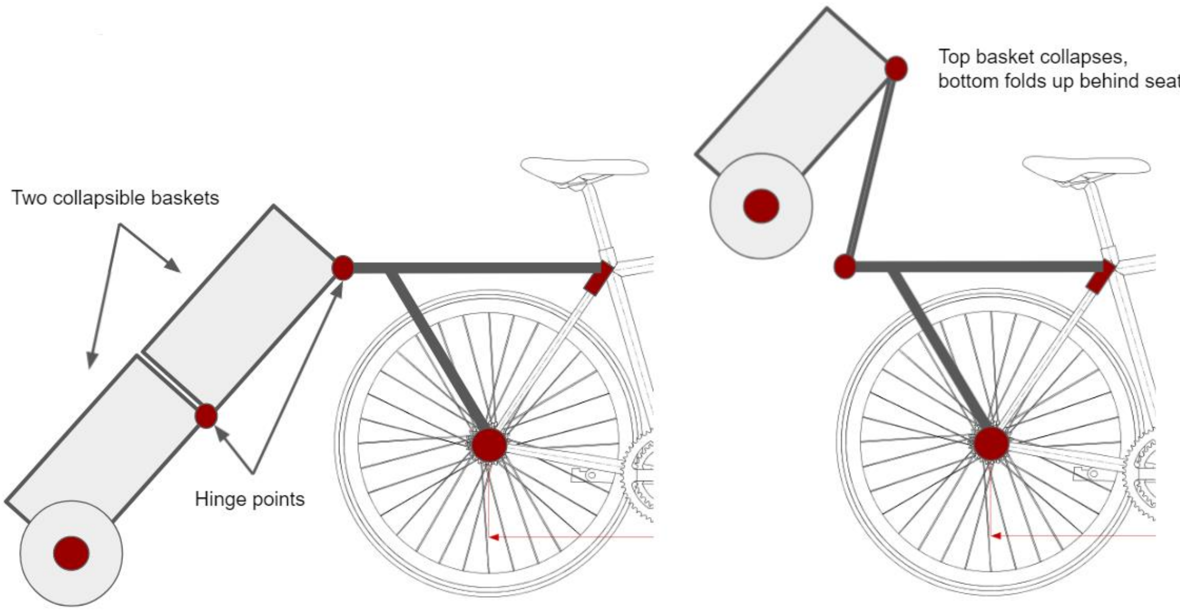

Figure 5: Concept 1 Diagram A

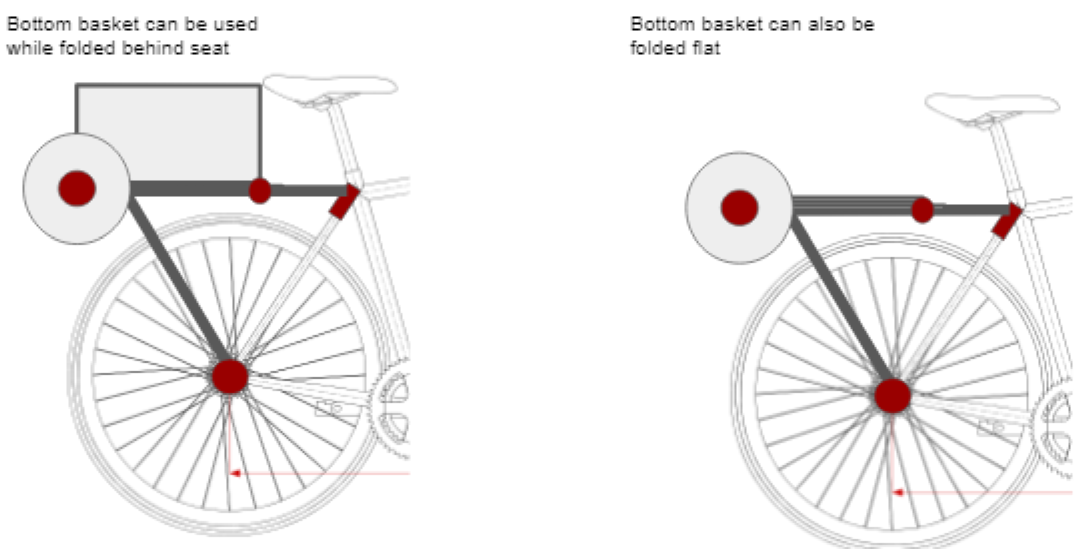

Figure 6: Concept 1 Diagram B

Concept 1 would consist of two baskets or crates. They would be hinged together at the bottom edge of one of their sides so they could fold from being inline and upright together to having their bottom planes flat against one another. One of the baskets would also have wheels on its bottom edge, opposite from the edge where it is hinged to the other basket, so it can roll along the ground. The second basket would be hinged to a bracket or rack that is mounted on the back of the bicycle behind the seat. The bracket would be mounted to the bicycle's rear wheel axle and the bicycle frame below the seat. When both baskets are unfolded, they would be pulled along behind the bike on the wheels affixed to the bottom basket. To collapse the device, the top basket would collapse flat and it would be folded up and inverted behind the bicycle seat. The bottom basket would be folded up behind the seat as well, its bottom plane resting on the bottom plane of the top basket. It can stay unfolded behind the seat to provide the rider with storage while partially folded. Alternatively, the bottom basket can also collapse flat behind the seat.

Concept Design 2

Figures 7 and 8 depict the second concept design.

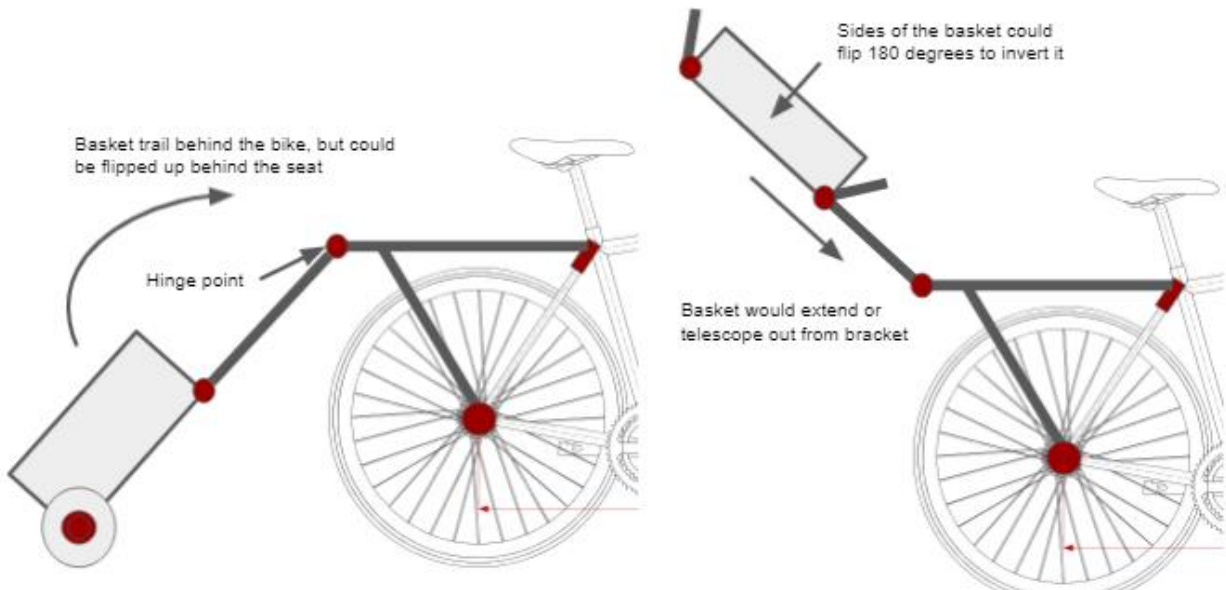

Figure 7: Concept 1 Diagram A

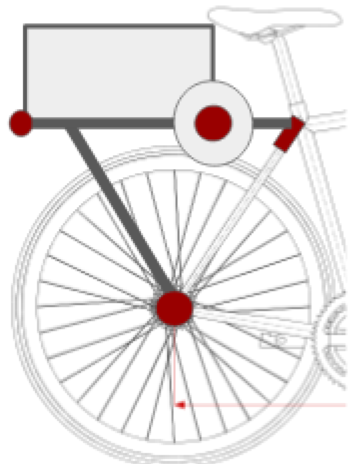

Figure 8: Concept 1 Diagram B

Concept 2 contains a basket that would telescope out from a bracket mounted to the back of the bike. The telescoping bars would be hinged to the bracket so the whole device could flip up behind the bicycle seat. In addition to this, the sides of the basket would flip 180 degrees to invert the basket. The inverted basket would sit behind the bicycle seat to provide the rider with storage while the device is folded up.

Concept Design 3

For the third concept, the group came up with a design that transforms from a hand truck when expanded to a pannier when collapsed. This design is a hand truck that is attached to the back of the bike frame at two points and will collapse onto the back of the bike. There are two pouches that are secured to the side of the hand truck. This can be seen in Figures 9 and 10 below.

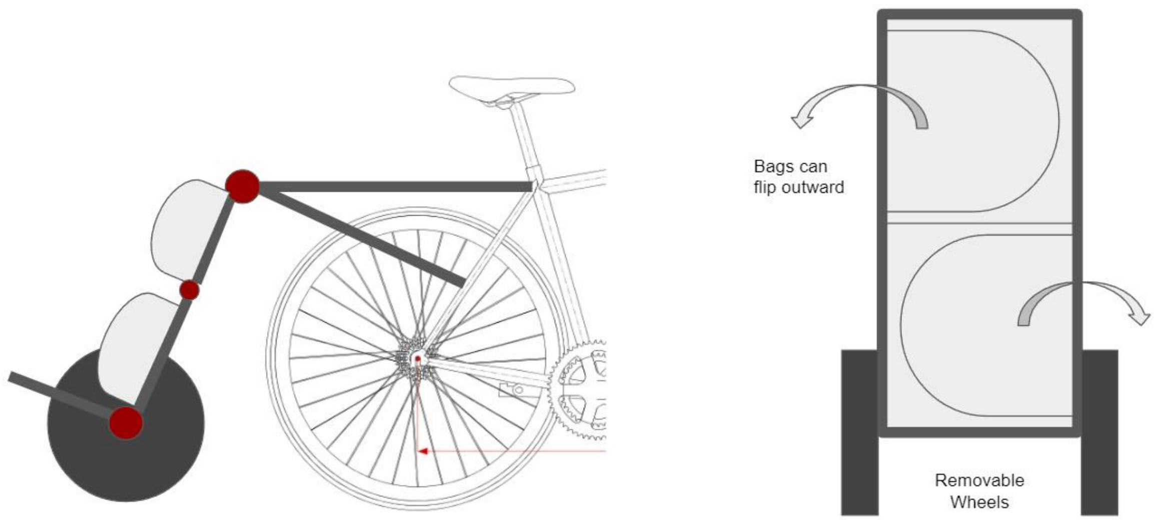

Figure 9: Concept 3 Unfolded Side View (Left) and Front View (Right)

Heavily influenced by the Burley Travoy trailer, the hand truck will fold up in a similar fashion, utilizing hinges shown by the red circles in the figures. Like the Travoy, this requires the wheels to be removed and tucked into the folds and the entire design will be resting on the top frame. Due to the fact that the pouches are attached only on the side, when folded up, the pouches can flip outward to transform into a pannier design. This allows the design to continue to have storage capacity even when collapsed. This aspect of the design can be seen in Figure 10 below.

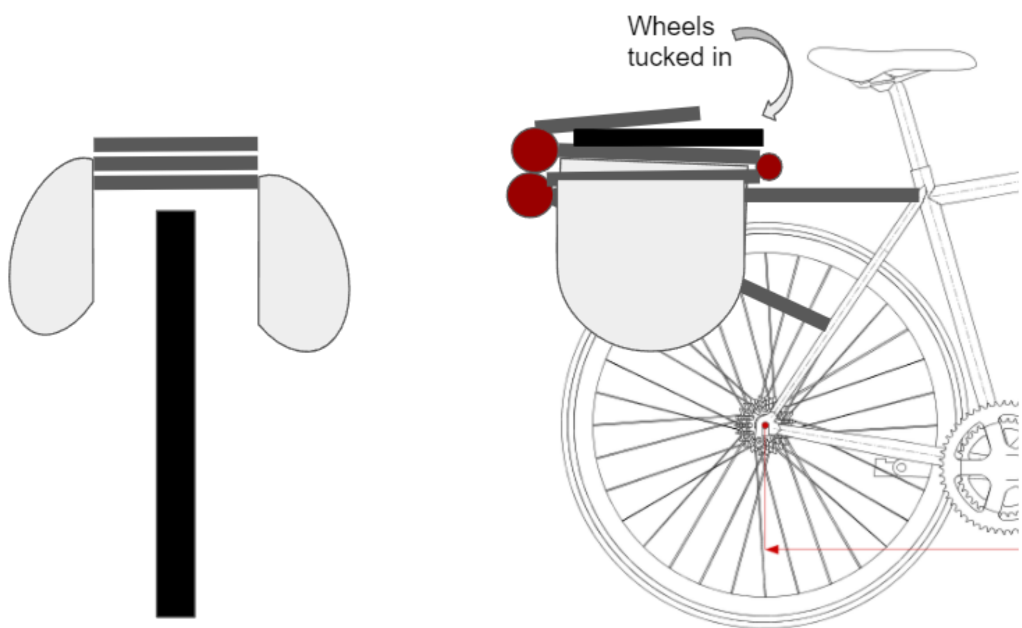

Figure 10: Folded Back View (Left) and Side View (Right)

Concept Design 4

The fourth design for the bike cargo storage solution involves having a similar frame attachment system to the previous design, but with the sides of the dolly being made of a metal grate that can be folded from a box to form a 2D plane. The design can be seen in Figure 11.

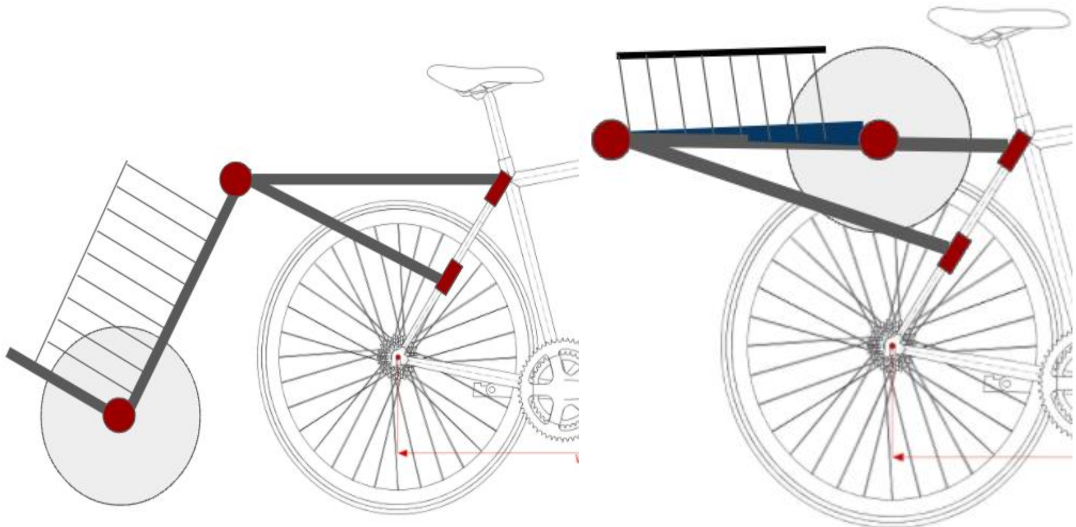

Figure 11: Concept 4 Expanded (Left) and Folded (Right)

The design uses a secure dolly frame attached to the bike frame at two points with flexible joints seen on the red circles. The sides of the dolly are metal grating similar to that of a Wald rear folding basket from the state of the art review. This would allow it to be lightweight and also rotate around the sides of the dolly where it is connected. This can be seen in Figure 12.

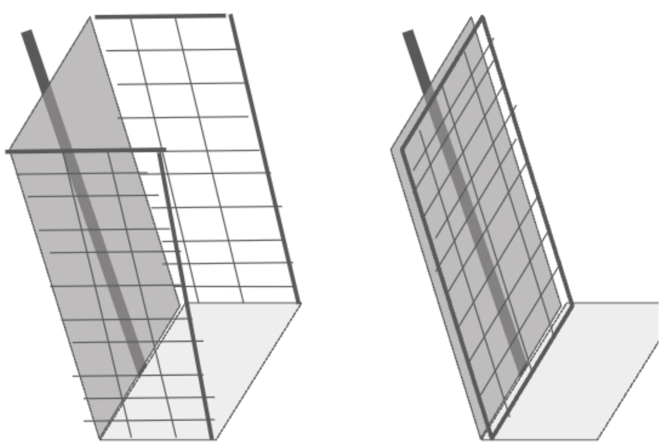

Figure 12: Concept 4: Folding Sides Demo

This folding allows the dolly to be a flat plane for strapping something onto it or a basket for storing goods in it. Once the dolly sides are folded in and the foot of the dolly is folded up, the entire trailing system can be flipped up onto the support. The side grates can also be folded 180 degrees to the other side of the dolly to create a basket behind the seat of the bike. This idea performs well in storage volume and being modular, however may be lacking in the security. Even if this design is not chosen the sub elements of the frame attachment and the side rotating completely around the dolly can be implemented in other designs.

Concept Design 5

The fifth design involves a telescoping storage system connected to the bike by linkage systems. The storage device is connected to two linkages that are connected to the bike in two locations. The first connection location is on the bike frame below the seat. The second connection location is at the center of the back wheel. The design can be seen below in Figure 13.

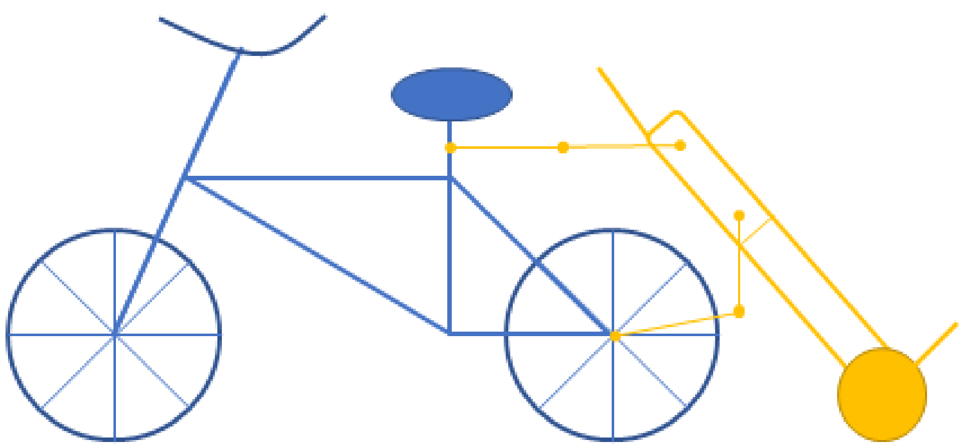

Figure 13: Concept 5 Expanded View

In the expanded setting, the storage section is slid out and maneuvered down until the wheel hits the ground. When the dolley function is not in use, the system can be moved up to sit behind the bike seat as a small storage basket. The bottom half of the storage section can be slid up into the first half, then locked into position. Then, the basket can be maneuvered to an upright position behind the bike seat. The collapsed version of the system can be seen below in Figure 14.

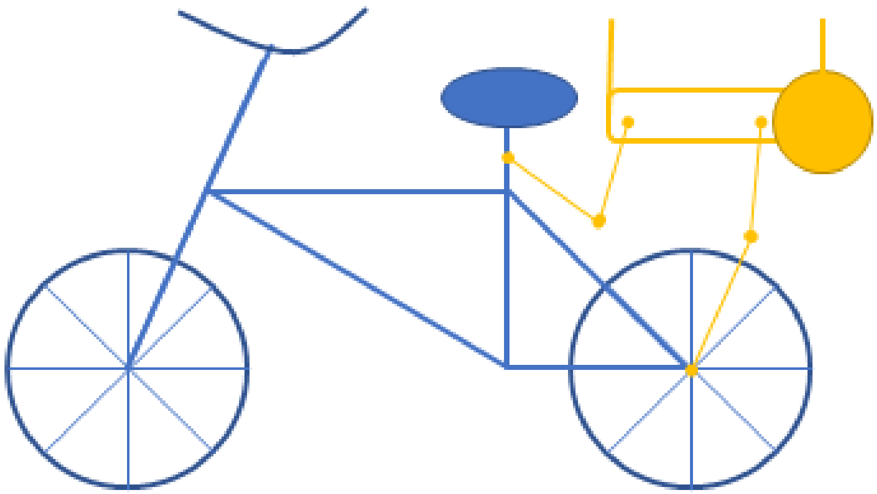

Figure 14: Concept 5 Collapsed View

Concept Design 6

The final concept design is a bicycle trolley that detaches from the bicycle seat and doubles as a shopping cart. Concept 6 was strongly inspired by the ZiZZO Trailer from the state of the art review. Concept 6 has two forms. "Trolley Mode" refers to the cart when attached to the bicycle seat for transport. When the bicycle is no longer in motion, the two links attaching the cart to the bicycle seat could unclasp and pivot away from each other. The links would then lock into a horizontal position and double as handlebars for the consumer to push or pull the cart; this is called "Cart Mode." Thus, the consumer would not have to carry shopping bags or find a typical grocery cart while running errands. The main cargo would be constructed out of an insulated fabric-like material to store and transport foodstuff safely. The metallic frame of the cart has two large wheels for easy movement and turns. A concept diagram for this cart is included in Figure 15.

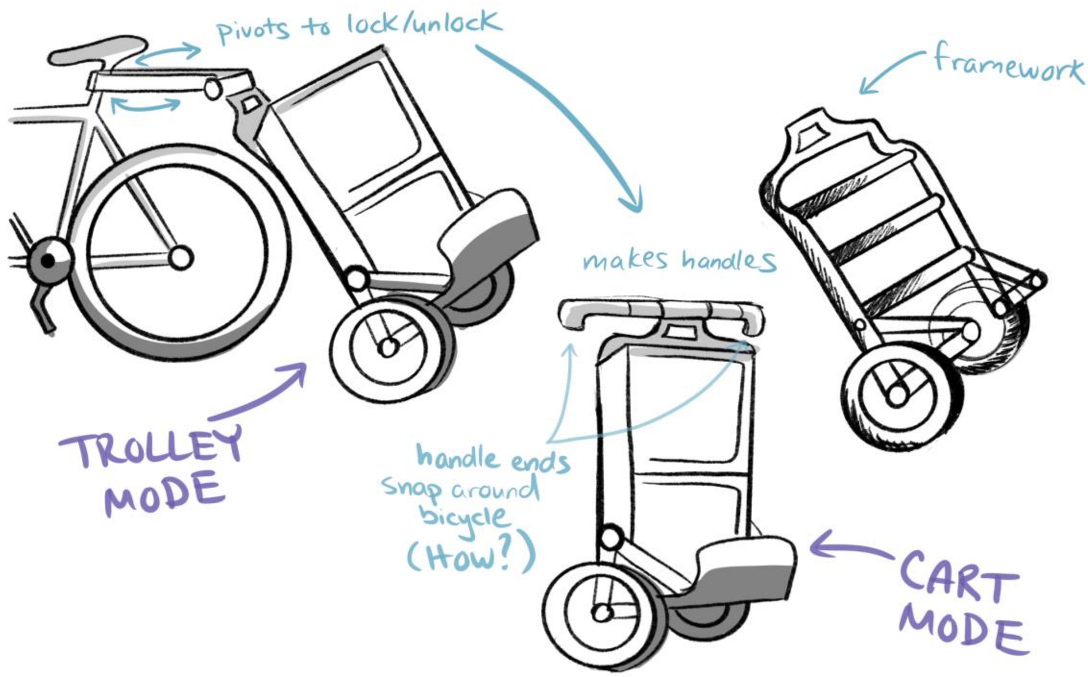

Figure 15: Concept 6 -- Shopping Cart

Concept Screening

After the team finished generating different concept designs, the next step was to screen and narrow them down. To accomplish this, the team constructed a screening matrix to compare the designs against a reference product chosen from among the existing solutions. From the state of the art review, the Trenux trailer was chosen as the reference to compare against. The selection criteria for comparison included the weight of the dolly, the time it would take to install on the bike, its load capacity and storage volume, its dimensions while folded up and while expanded, its cost, its security, and its ability to traverse obstacles, such as the curbs of sidewalks. Within the screening matrix, a plus or double plus was given to each concept for each selection criteria, based on how much better the team believed the concept would be compared to the Trenux. Similarly, a minus or double minus was given if the team believed the concept would compare worse or much worse than the Trenux. A zero was given if the team believed it would compare similarly to the Trenux. The full selection matrix is displayed in Table 3 below. The concepts chosen for final consideration are highlighted in yellow.

Table 3: Concept Screening Matrix

	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6	Ref
Selection Criteria	Rating	Rating	Rating	Rating	Rating	Rating	Rating
Weight of dolly	0	+	+	-	0	-	0
Install Time	0	0	0	+	-	0	0
Storage Load Capacity	-	0	0	0	0	0	0
Folded width	0	0	0	-	-	-	0
Collapsed height	+	0	0	0	+	-	0
Lockable	0	0	0	0	0	0	0
Storage Volume	++	0	+	++	+	++	0
Cost	+	++	+	+	++	+	0
Max traversable obstacle	+	0	+	0	0	0	0
Expanded width	+	+	+	+	+	0	0
Expanded height	0	0	0	0	0	0	0
Storage Capacity (collapsed)	+	+	++	+	+	0	0
Pluses	7	5	7	6	6	3	0
Sames	4	7	5	4	4	5	7
Minuses	-1	0	0	-2	-2	-3	0
Net	6	5	7	4	4	0	0
Rank	2	3	1	4	4	6	
Continue?	Yes	Yes	Yes	No	Yes	No	

Above all, the team believes that each concept considered can be developed for a more affordable price than the Trenux. Each one was given a plus or double plus in the cost category. Similarly, all but one of the concepts would likely offer a greater storage volume than the Trenux, both while in the expanded and collapsed configurations. Concept 2 was the only one that seemed like it would offer a similar amount of space. The team also concluded that concepts 1-5 would likely have a smaller expanded width than the Trenux, allowing them to better navigate narrow sidewalks, streets, or other spaces. As a result of the screening matrix, concepts 1, 2, 3, and 5 were considered for the final design while concepts 4 and 6 were discontinued.

Concept Selection

To narrow down the concepts chosen for final consideration, the team constructed a selection matrix. Within this matrix, weights were assigned to the selection criteria and the concepts were scored for each criterion. Scores ranged from 1 to 5, a “1” being the lowest rating and a “5” being the highest. The weights and ratings were multiplied and the sum of the products for each concept created a score the team could use to identify which concept would be best and should be developed. Concept 1 came out with the highest score between it, concepts 2, 3, and 5, and the Trenux trailer, with concepts 3 and 5 very close behind. Concept 2 will be discontinued and during phase 2 of the project, concepts 1, 3, and 5 will be evaluated further during the technical analysis to finally decide which one would be the best to develop. The full selection matrix is included in Table 4 below, with the final concepts chosen for further considering highlighted in yellow.

Table 4: Concept Selection Matrix

Scale: 1 to 5	1 = Worst	Reference		Concept 1		Concept 2		Concept 3		Concept 5	
	5 = Best	Trenux Trailer		E: Folding Boxes		E: Telescope		R: Saddle Bag		S:Linkage	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Weight of dolly	5.0%	3	0.15	4	0.2	4	0.2	4	0.2	3	0.45
Install Time	5.0%	3	0.15	3	0.15	3	0.15	3	0.15	2	0.1
Storage Load Capacity	10.0%	3	0.3	2	0.2	3	0.3	3	0.3	3	0.3
Folded width	10.0%	3	0.3	4	0.4	3	0.3	3	0.3	2	0.2
Collapsed height	5.0%	3	0.15	5	0.25	3	0.15	3	0.15	4	0.2
Lockable	5.0%	3	0.15	3	0.15	3	0.15	3	0.15	3	0.15
Storage Volume	10.0%	3	0.3	5	0.5	3	0.3	4	0.4	4	0.4
Cost	15.0%	3	0.45	4	0.6	5	0.75	4	0.6	5	0.75
Max Traversable obstacle	15.0%	3	0.45	4	0.6	3	0.45	4	0.6	3	0.45
Expanded width	10.0%	3	0.3	4	0.4	4	0.4	4	0.4	4	0.4
Expanded height	5.0%	3	0.15	3	0.15	3	0.15	3	0.15	3	0.15
Storage Capacity (collapsed)	5.0%	3	0.15	4	0.2	4	0.2	5	0.25	4	0.2
sum	100.00%										
	Total Score	3		3.8		3.5		3.65		3.75	
	Rank			First		Fourth		Third		Second	
	Continue?	No		Yes		No		Yes		Yes	

In order to narrow down the concept selection further, the team created SolidWorks models and specifications for Concept 1, Concept 3, and Concept 5. The team then compared the specifications for each concept, and started to eliminate the concepts that did not hit the team's original specifications. The specifications for each concept can be found in Table 5 below.

Table 5: Estimated Specifications for Concept 1, Concept 3, and Concept 5

Metric	Target Value	Limit Value	Concept 1 Estimates	Concept 3 Estimates	Concept 5 Estimates
Weight of dolly	<10 lbs	<20 lbs	~19.8 lbs	12 lbs	45 lbs
Initial Install Time	<5 min	<10 min	<10 min	5 min	5-10 min
Storage Load Capacity	>50 lbs	>25 lbs	100 lbs	60 lbs	70 lbs
Folded width	<12 in	<18 in	~20 in	20 in	14 in
Collapsed height	<4 in	<7 in	~9 in	8 in	8 in
Lockable	> Grade 2	> Grade 1	Grade 1	Grade 1	Grade 1
Storage Volume	>3 paper bags	>2 paper bags	2 or 4 bags	2 bags	2/6 bags
Cost	<150 $	<300 $	~$140	~$120	~$300-350
Max Traversable obstacle	>8 in	>6 in	~8 in	~8 in	6 in
Expanded width	<20in	<30 in	~20 in	~20 in	14 in
Expanded height	<16 in	<19 in	~6 in	2 in	8 in
Weather rating	>66 IP Rating	>64 IP Rating	64 IP Rating	66 IP Rating	64 IP Rating
Total Lifetime	>3 yrs	>2 yrs	>3 yrs	3 yrs	~2 yr
Attachment/Detachment time	<5 s	<10 s	~10 s	~10 s	~10 s
Compatibility to bikes	90% of bikes	75% of bikes	<75%	75%	~75%

Concept 5 was the first concept eliminated due to the fact that it was double the limit value for the overall weight, and cost more than the other concepts as well as the limit value. Concept 1 and Concept 3 were very similar in their over specifications. In order to select which concept to use, the group looked at the highest valued specification criteria. These criteria were cost, max traversable obstacle, storage load capacity, storage volume, and the folded/expanded widths. The values for each concept for the cost, max traversable obstacle, and the widths were about the same. However, Concept 1 had a storage load capacity of 100 lbs and a storage volume of 2-4 bags, while Concept 3 had a storage load capacity of only 60 lbs and a storage volume of just 2 bags. Because of this, the team decided to move forward with Concept 1. The Solidworks models for Concept 1 can be seen below in Figure 16.

Figure 16: Concept 1 CAD Models

Technical Analysis

Phase 1 Technical Analysis

In phase 1 the group studied the contending concept designs and identified areas of technical analysis that would be critical to selecting a final concept. One area of technical analysis identified for further investigation was the maximum load ratings at critical points on the dolly. The group set a target of supporting 50lbs of cargo in addition to the weight of the dolly itself. The group can use free body diagrams and weight equations to derive the forces applied to the dolly from its cargo as well as static analysis in solidworks. The material properties of the supporting beams of the dolly, including yield strength, can be used to determine how much weight can be applied to the dolly before it breaks. Through simulation and experimentation, gradually heavier loads can be applied to the dolly and its performance can be measured to test its maximum load capabilities. From the experimental data of last year's project it is known that the joints are the areas of the dolly most susceptible to damage and therefore they are the areas that should be analysed thoroughly.

The second area of analysis is the results of shock and impact of the dolly. The dolly will be moving at high speeds on uneven terrain which will cause some high impacts to be applied to the wheels as they navigate these obstacles. The sudden impact on the wheels can transfer to the rest of the frame and cause the dolly to break at a weak point. To avoid this, the shock absorbency of the wheels can be measured and suspension can be added in the wheels to avoid damage. A shock dynamometer can be used to get readings on the performance of the implemented suspension, as this is typically how a bike's shock absorbency is tested. Depending on these results the group can change to use pneumatic wheels or add shock absorbance to the system.

The third crucial area of analysis is sizing the dolly wheels. The main concern with wheel size is to make sure that the wheels are big enough to be able to traverse large objects while also being small enough to fit into the compact folded position. The radius of the wheel and the height of an obstacle are related various that can provide very helpful data. Wheel sizes are labeled with ISO mm and standard sizing charts will relay information about the properties of these wheels. Testing the wheels will involve running them over various terrain and seeing how they react in a solidworks simulation and in a physical prototype down the line.

Phase 2 Technical Analysis

Phase 2 technical analysis involved using hand calculations to determine some preliminary data on the forces acting on the dolly in a worst case scenario. The worst case scenario for the dolly was defined by the customer data about what sort of terrain urban cyclists encounter in their rides. Common situations included small curbs and inclines in terrain. Both of these scenarios add stress to the bike and combined create the worst possible scenario for the dolly. It is important to test the worst possible scenario to establish a good factor of safety when riding in more normal conditions.

With the worst case scenario established the group was able to derive a FBD of the dolly wheel. This was done to determine the force of the wheel axle as advised by the group's advisor as it was noted that the previous year's team experienced failure under loading.

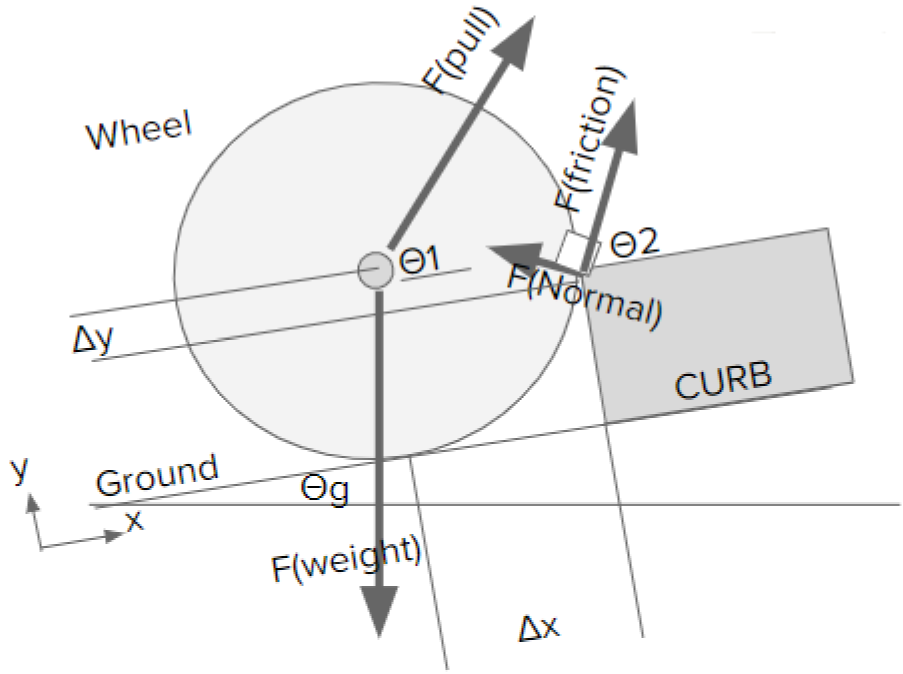

Figure 17: Dolly Wheel FBD (Worst Case Scenario)

In Figure 17 above, all of the variables can be seen on the free body diagram. Θg represents the angle of the inclined ground which, for this scenario, was set to 10 degrees. Δy represents the vertical distance between the top of the sub and the center of the wheel. There are four forces interacting in this system when the wheel has just left the ground. The weight is pulling down on the wheel, and the bike is pulling up on the wheel at an angle of Θ1. At the corner of the curb, the curb exerts a normal force on the wheel where contact is made and a frictional force in the direction of the wheel's motion at the same point. With these variables defined, an equation was derived for the pulling force on the wheel using torque equations. By analysing at the corner of the curb, the normal and friction force cancel out and the group was left with Tf(pull)x+Tf(pull)y = Tf(weight)x + Tf(weight)y. Breaking this down further, the group ended up with this equation:

$$f = \frac{mg(\,(cos\theta_1\sqrt{2Rh - h^2}\,) + (sin\theta_1(R-h)\,)}{(cos\theta_2(R-h) + (sin\theta_2\sqrt{2Rh-h^2}\,)}$$

where Θ1 is the ground incline, Θ2 is the pulling angle, R is the radius of the wheel, h is the height of the curb, and mg is mass*gravity.

With the equation defined, the pulling force was calculated in various scenarios. For this analysis as only one side of the dolly was being analyzed half of the loading weight was used. The worst case scenario had a 10° incline, a pulling angle of 66°, a curb at 6 inches high, a wheel radius of 6 inches, and a weight of 55 lbs which resulted in the resulting pulling force being approximately 150 lbs. This is very helpful data as if the group only accounted for the pulling load on flat terrain, the pulling force would be from the weight of cargo and dolly which would be much lower and the design would've failed when subjected to the more realistic loads.

	in/deg/lbs		lbs
Height of curb =	6.00	**F=**	**151.4019883**
Radius of wheel =	6.00		
weight = mg =	55.00		
Theta1 =	10.00		
Theta2 =	60.00		

Figure 18: Excel Calculations of Pulling Force on Wheel

Another hand calculation done for this analysis was the approximate impact force on the wheels when the dolly wheels hit an obstacle. Similar to the previous analysis, variables were defined for this situation and then varied in order to test the worst case scenario.

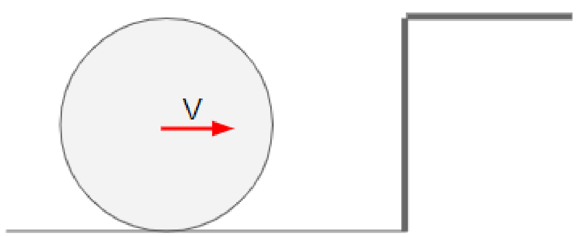

Figure 19: Dolly Wheel Impact on Obstacle

The impact equation, $F(avg) = \frac{.5\, m\, v^2}{d}$, was used to calculate impact force where mass was 55lbs, velocity was 5 mph, and the distance that the rubber pneumatic wheel deforms was 1cm. The excel calculation below in Figure 20 shows the resulting data.

Impact force on Wheels					
	m / m/s / kg	F=	0.5 m v^2 /d		
Depth deformed	0.01	F=	6050	N	1360 lbs
velocity (5mph)	2.2				
mass (55 lbs)	25				

Figure 20: Excel Calculation of Impact Force

The resulting impact force was calculated to be 1360 lbs in the worst case scenario. Most situations will have a smaller force than this. However, it is good to have the worst case scenario data so that the dolly has the ability to function under any conditions and have a large factor of safety in normal conditions.

Phase 3 Technical Analysis

Phase 3 technical analysis used solidworks to run both a static and a dynamic analysis on the dolly to determine the stresses acting on key points of the dolly. Feedback from phase 2 presentations led to the group determining that a motion analysis was important for determining realistic stresses on the key joints in the dolly. There were too many factors to account for in a hand calculation so a solidworks motions analysis could accomplish this better. Many terrain the group compared the forces to the max forces that can be applied to the custom 3D printed joints the group designed. A static analysis on the joints could gather this information, and the comparison of the data would confirm the viability of the design.

Motion Analysis of Simplified Dolly Assembly

The CAD model of the alpha prototype design was highly detailed and complex, therefore unsustainable for a motion analysis in solidworks. Therefore the group created an accurate but simplified model for the purpose of motion analysis in solidworks. This model has accurate material properties and dimensions and uses physical stoppers at the hinge joints to restrict motion. It also includes the back wheel of the bike to assist in realistic motion. Two 50 lb boxes are attached to the dolly with one in the center of each the lower and upper frame. The parts are connected with pin type hinge joints that are concentrically mated. A snapshot of the model can be seen in Figure 21 below.

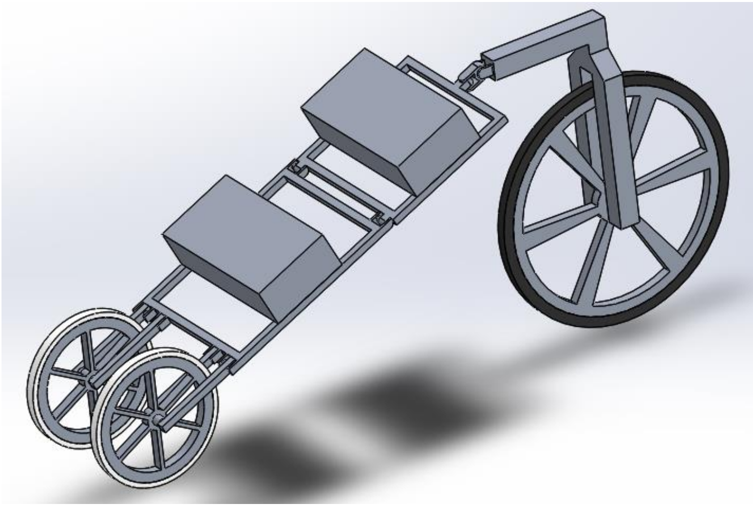

Figure 21: Simplified Model of Alpha Prototype Dolly with Back Wheel of Bike

The set up of the motion analysis included a few main parts. First, the ground was created as a separate part with terrain obstacles like a speed bump, incline, decline, and curb. These parts were combined in an assembly where the motion analysis took place. The part mounting the bike rear wheel needed to be constrained with plane mates to stay vertical and move straight along a plane. The setup can be seen below in Figure 22.

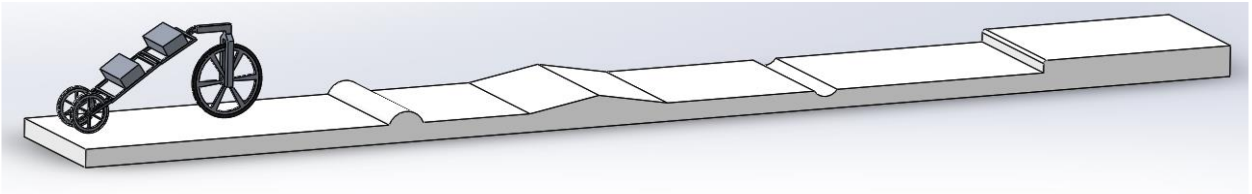

Figure 22: Motion Analysis of Simplified Dolly Layout

When setting up the motion analysis, gravity was applied and solid body contacts were made between all parts with the appropriate material friction properties. A rotational motor was applied to the bike wheel that revolved at 30 rpm, which is roughly 2 mph for the wheel size used. This was an appropriate speed considering cyclists will generally slow down when approaching obstacles. A video of the analysis can be found on the Duck Dolly 2.0 website or on youtube at the following link: Video of Analysis

Upper-Lower Frame Joint Analysis

After running the motion analysis, contact force readings were measured at the two joints most susceptible to failure. The first joint is the joint connecting the upper and lower frames of the dolly. A close up of this joint can be seen below in Figure 23.

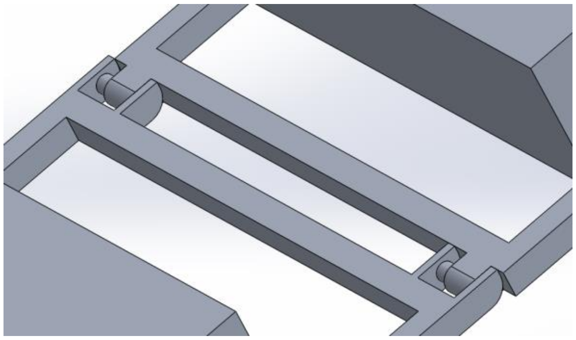

Figure 23: Upper-Lower Frame Joint

The first obstacle in the simulation is the speed bump. It is 4 inches tall to reflect standard speedbumps. The data from the motion analysis in Figure 24 shows the force readings on the joint as it goes over the bump.

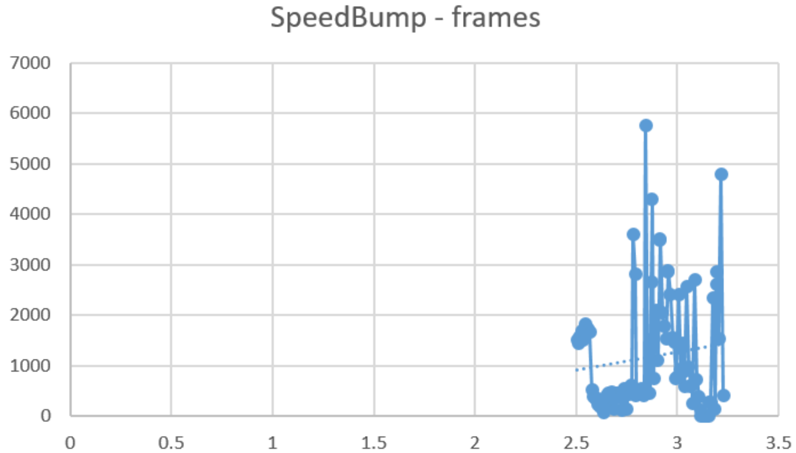

Figure 24: Force on Upper-Lower Frame Joint over Speed Bump (lbf vs time)

The graph above shows that the force spikes throughout the motion and reaches a maximum of almost 6000 Pound force. While there are high spikes the data tends to gather closer to the 3000 pound force mark which may represent a more realistic maximum force on the pn in this situation. Because this experiment is done to test the worst case scenario however it is safer to assume a maximum force of approximately 5,500 pound force.

The second obstacle is the incline and decline which each were 10 degrees. The force results can be seen in Figure 25 below.

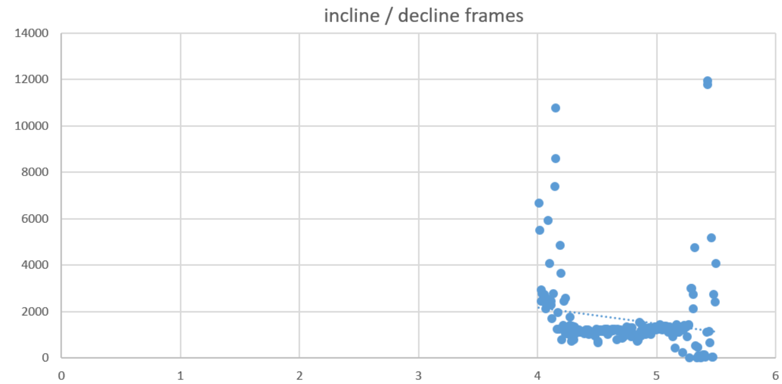

Figure 25: Force on Upper-Lower Frame Joint over Incline/Decline (lbf vs time)

In this graph two clear peaks can be seen at the start of the incline and end of the decline. These peaks reach up to 12,000 pound force while in the middle of the motion the force stays very constant at approximately 1,000 pound force. To ensure that the worst case scenario is being accounted for the group will assume that 12,000 is the max force on the joint hinge at this point.

The last obstacle was the curb which was 4 inches high to reflect standard curb height that a bike would be traversing. The force results can be seen in Figure 26 below.

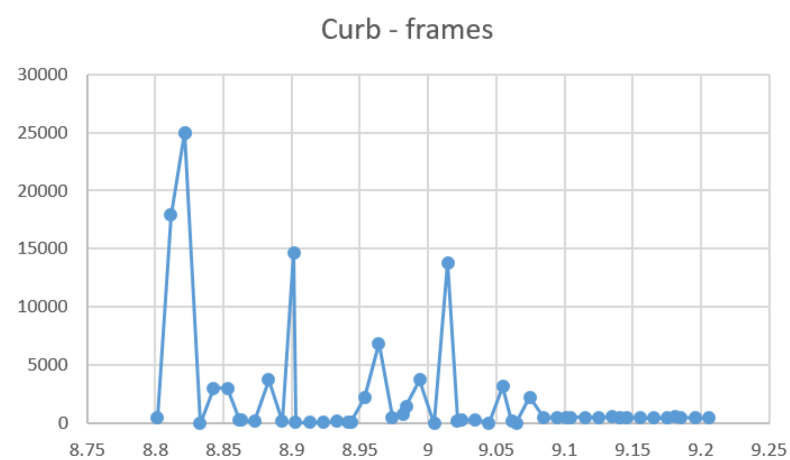

Figure 26: Force on Upper-Lower Frame Joint over Curb (lbf vs time)

This graph has a spike in data just as the wheel hits the curb and starts to lift off the ground. This sprike is around 25,000 lbs which represents the worst case scenario for the dolly going over a curb while fully loaded. While this is a situation that would hopefully be avoided by the dolly operator it is good to have this data to ensure that the dolly will not break in a situation like this.

Summarizing the data, the max force for the speed bump was approximately 5,500 lbf, the incline/decline was 12,000 lbf, and the curb was 25,000 lbf. While these were the peak forces the trend lines show much lower forces so it is possible that the high points are outliers and the actual max force is closer to the average. Taking the worst case scenario though it can be assumed that 25,000 lbf is the worst case pound-force on the joint connecting the two frames.

Wheel Holder-Lower Frame Joint Analysis

The other joint analysis was the joint connecting the wheel supports to the lower frame. Those joints can be seen in Figure 27 below.

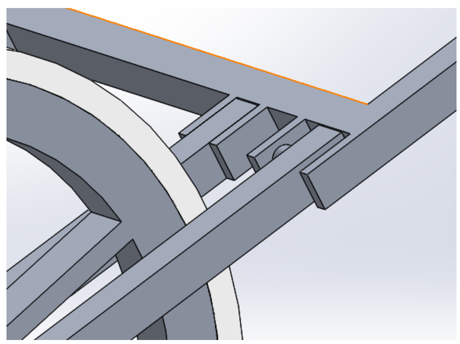

Figure 27: Wheel Holder-Lower Frame Joint

The first obstacle in the simulation is the speed bump. It is 4 inches tall to reflect standard speedbumps. The data from the motion analysis in Figure 28 below shows the force readings on the joint as it goes over the bump.

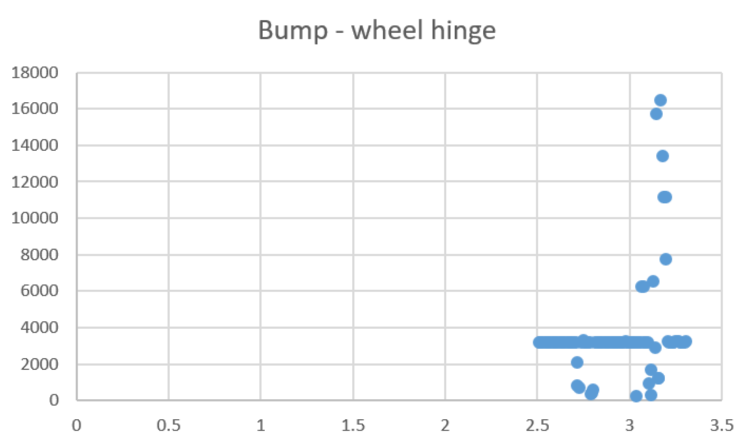

Figure 28: Force on Wheel Holder-Lower Frame Joint over Speed Bump (lbf vs time)

The graph above shows that the force spikes towards the end of the motion and reaches a maximum of almost 16,000 pound force. While there are high spikes the data tends to gather closer to the 3000 pound force mark which may represent a more realistic maximum force on the pn in this situation. Because this experiment is done to test the worst case scenario however it is safer to assume a maximum force of approximately 16,000 pound force.

The second obstacle is the incline and decline which each were 10 degrees. The force results can be seen in Figure 29 below.

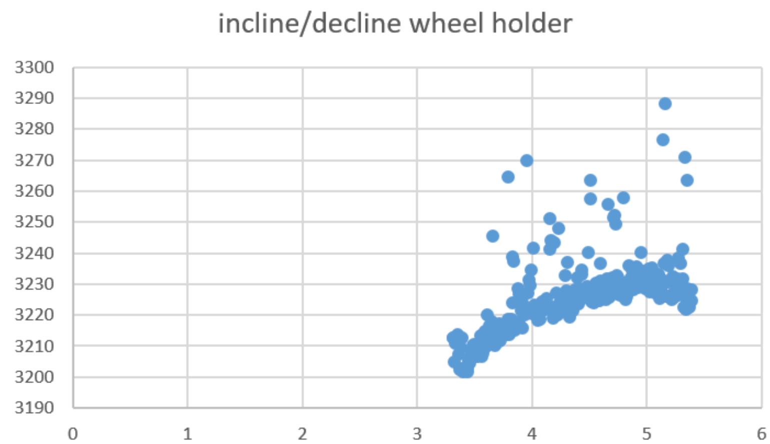

Figure 29: Force on Wheel Holder-Lower Frame Joint over Incline/Decline (lbf vs time)

In this graph a parabolic trend can be seen on the force with random spikes occurring throughout. These peaks reach up to 3,300 pound force while in the middle of the motion the force trend shows a force of approximately 3,250 pound force. These forces are very similar so this is not an issue. To ensure that the worst case scenario is being accounted for the group will assume that 3,300 is the max force on the joint hinge at this point.

The last obstacle was the curb which was 4 inches high to reflect standard curb height that a bike would be traversing. The force results can be seen in Figure 30 below.

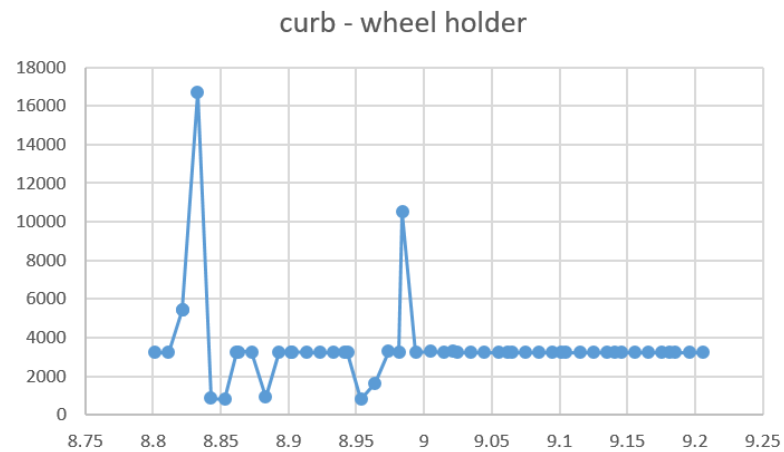

Figure 30: Force on Wheel Holder-Lower Frame Joint over Curb (lbf vs time)

This graph has a spike in data just as the wheel hits the curb and starts to lift off the ground. This sprike is around 17,000 lbs which represents the worst case scenario for the dolly going over a curb while fully loaded. While this is a situation that would hopefully be avoided by the dolly operator it is good to have this data to ensure that the dolly will not break in a situation like this.

Looking at the data the max force for the speed bump was approximately 16,000 lbf, the incline/decline was 3,300 lbf, and the curb was 17,000 lbf. While these were the peak forces, the trend lines show much lower forces so it is possible that the high points are outliers and the actual max force is closer to the average. Taking into consideration the worst case scenario, it can be assumed that 17,000 lbf is the worst case lbf on the joint connecting the two frames.

With the data gathered from this motion analysis the group has determined that the 100 pound cargo load and significant terrain obstacles may produce too much stress for the physical prototype to handle. There are multiple directions that the group can go in with the beta prototype to reduce these forces. First the maximum cargo load can be reduced. While 100 pounds was the target goal, 50 would meet the majority of customer requirements. Another option is to redesign the joints to be stronger to ensure that they can handle these high loads. The 3D joints are currently being printed with ABS plastic but if necessary the beta prints can be done with a stronger material to account for high forces.

Static Stress Analysis of Subassemblies

In SolidWorks, stress analysis was conducted on various subassemblies of the model without the bicycle attached. Before analysis, the model parts had to be modified to account for the force of the screws on the actual prototype. A cut extrude feature was used to represent the screw-heads on the assembly parts. The screw-heads have a diameter of 9.5 mm, and the cut-extrude was set to a 1 mm depth. Figure 31 shows an example of the alteration on a SolidWorks part.

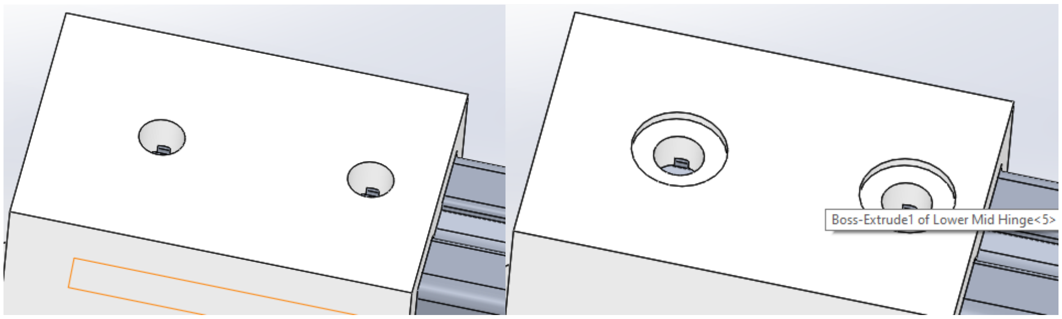

Figure 31: Original Holes on Assembly (left) and Holes After Cut-Extrude Change (right)

All of the subassemblies were located on either the upper or lower frame of the trolley. For instance, Figure 32 illustrates Subassembly #1, located on the right side of the upper frame. Note that additional subassemblies did not have to be created for mirroring components. That is, if a subassembly for the right side exists, a subassembly for the mirroring left side does not have to be made (and vice-versa).

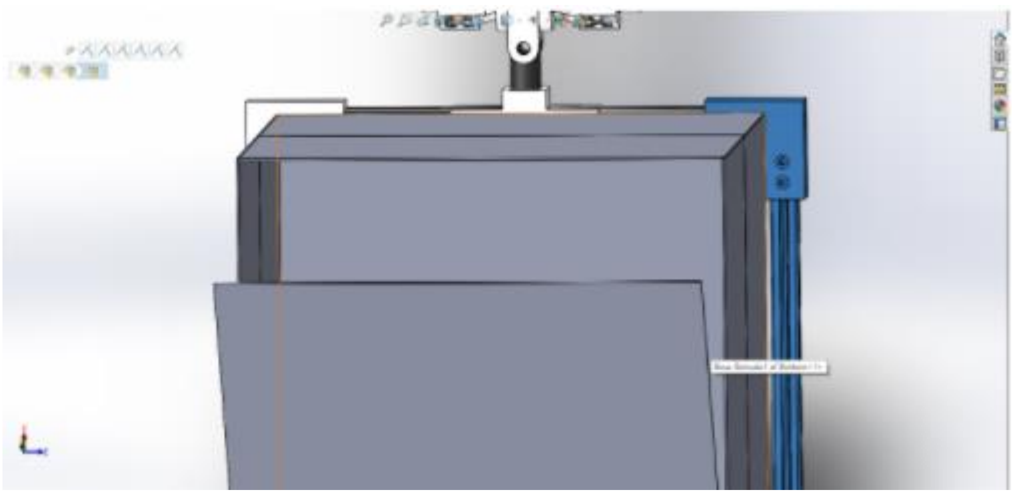

Figure 32: Subassembly #1 (Upper Frame, Upper Right 90D Bracket & Side Piece) (in blue)

Figures 33-39 illustrate the (von Mises) stress analysis results of various subassemblies. The minimum stress for all subassemblies was located at the point(s) furthest from the bracket/hinge. Stress also increases as you approach the bracket/hinge from the end of the linkage. The maximum stress for each subassembly was always located at the fixed screw holes. Table 6 contains the resulting stresses for all of the subassemblies.

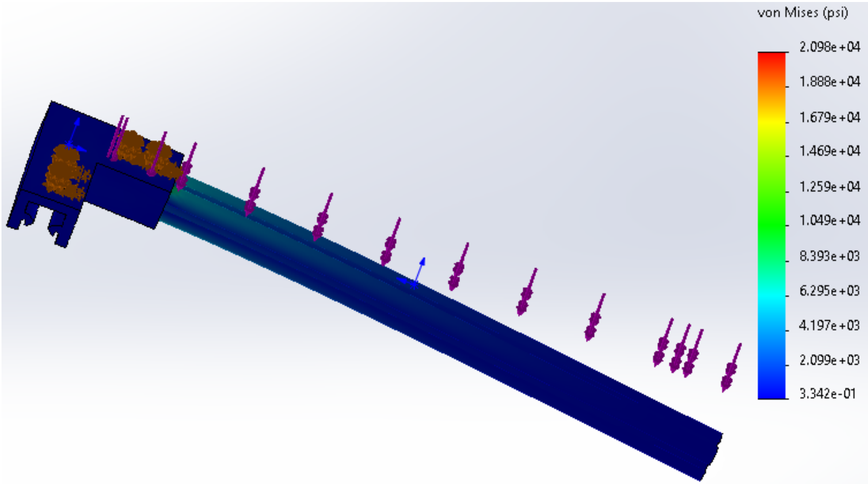

Figure 33: Subassembly #1 Stress Analysis-Upper Frame;Upper Right 90° Bracket & Side Piece

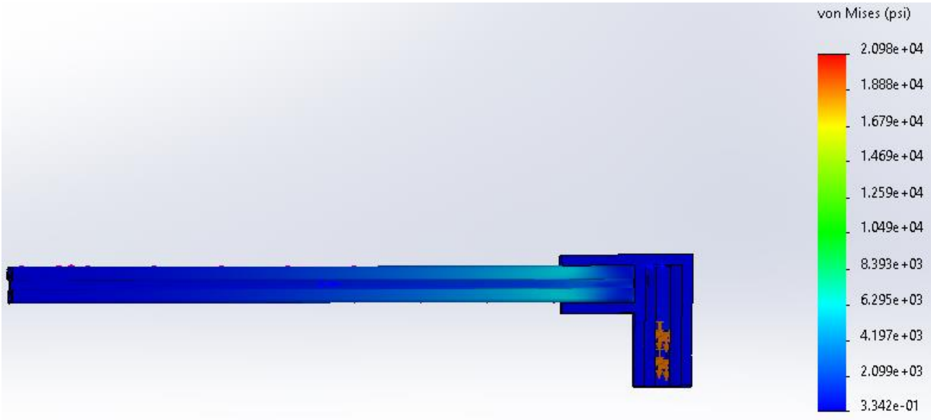

Figure 34: Stress Analysis for Subassembly #1 (bottom view)

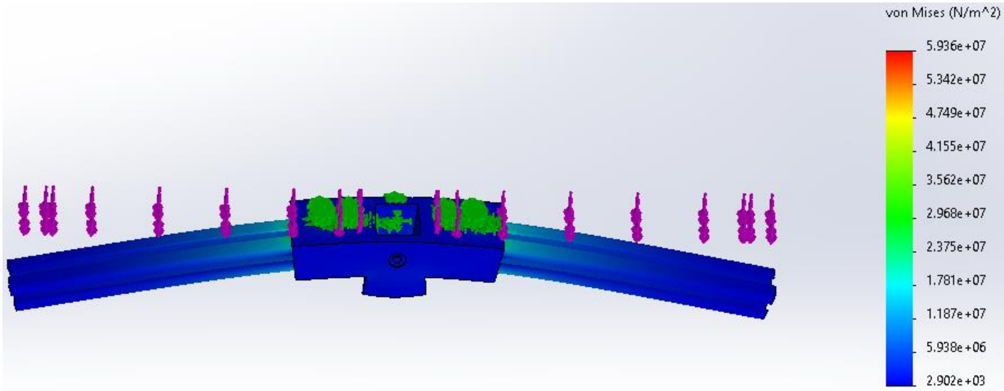

Figure 35: Stress Analysis for Subassembly #2-Upper Frame; Custom Tow Arm & 2 Side Pieces

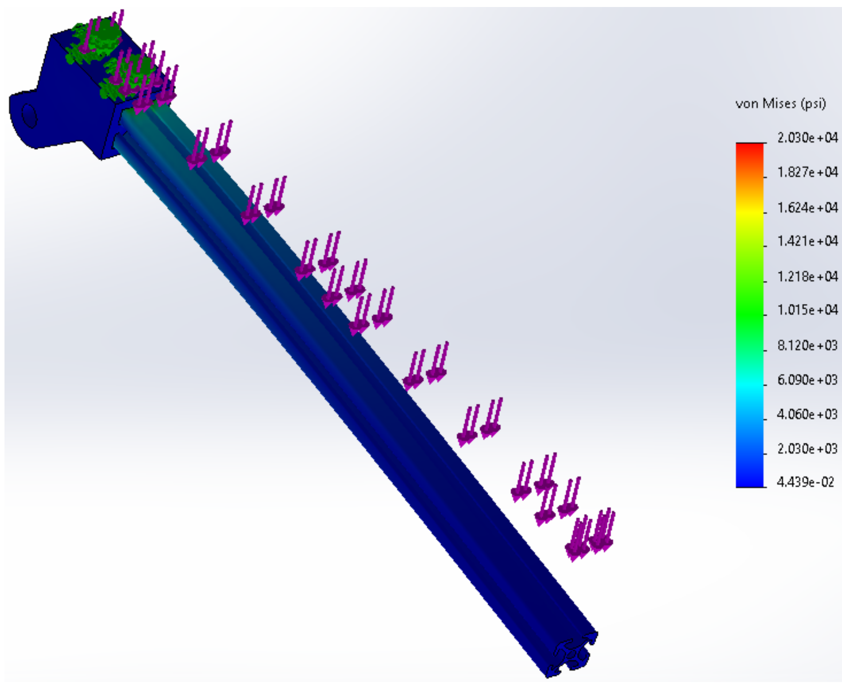

Figure 36: Stress Analysis for Subassembly #3-Lower Frame; Upper Mid-Hinge & Side Piece

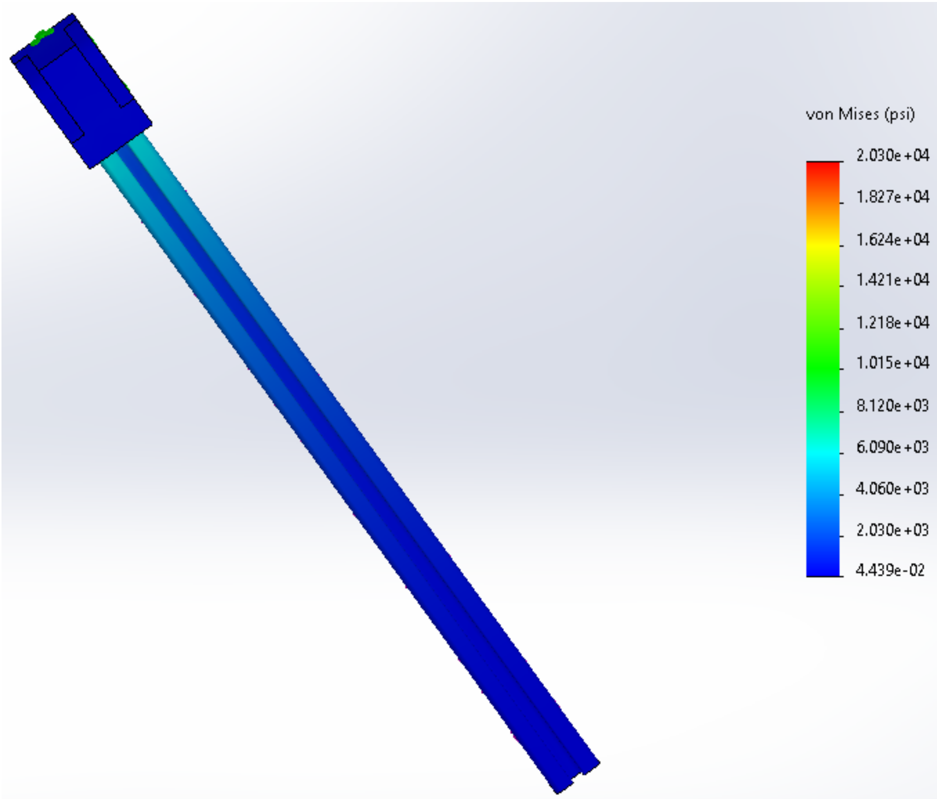

Figure 37: Stress Analysis for Subassembly #3 (bottom view)

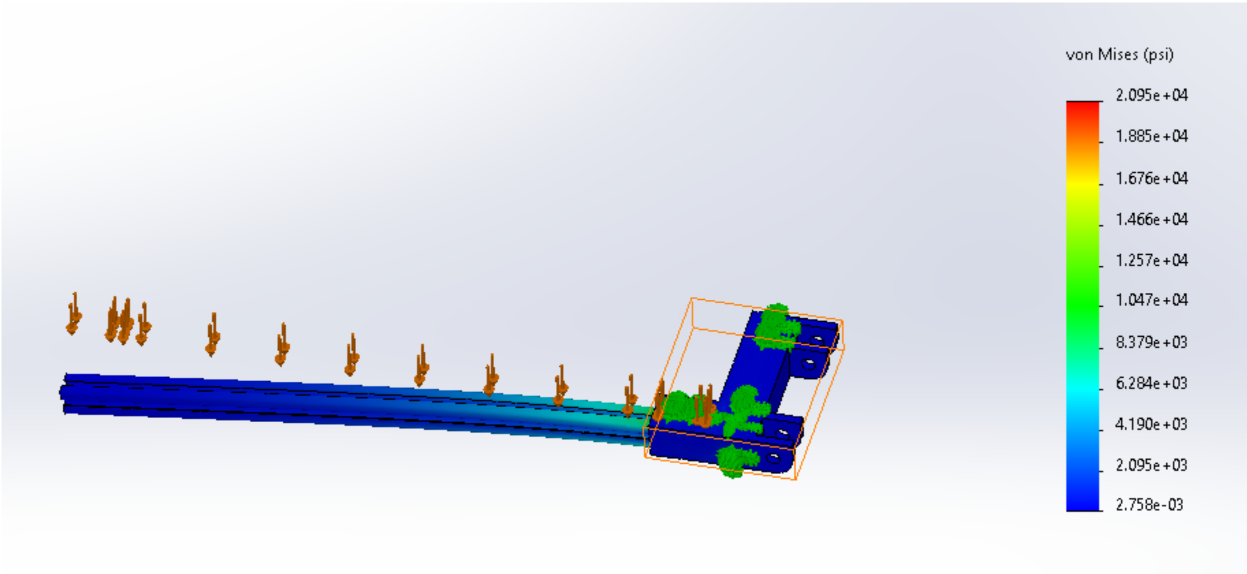

Figure 38: Stress Analysis for Subassembly #4 (Lower Frame; Left Wheel Hinge & Side Piece)

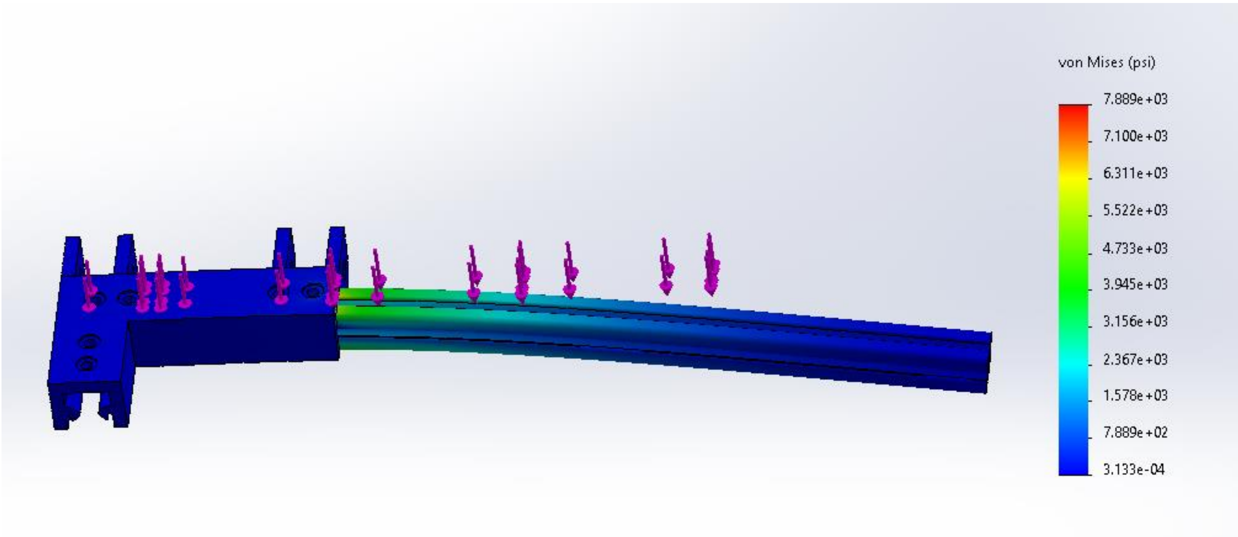

Figure 39: Stress Analysis for Subassembly #5 (Lower Frame; Right Wheel Hinge & End Piece)

Table 6: Minimum & Maximum Stresses of Subassemblies in SolidWorks Simulation

	Location on Model	**Components**	**Minimum Stress (psi;psf)**	**Maximum Stress (psi;psf)**	**Factor of Safety**
Subassembly #1*	Upper Frame, Right Side	Upper Right 90° Bracket & Side Piece	0.3342; 0.00232	20980; 145.694	0.381
Subassembly #2	Upper Frame, Middle	Custom Tow Arm & Two Side Pieces	0.4208; 0.00292	8609; 59.784	0.9291
Subassembly #3*	Lower Frame, Left Side	Upper Mid-Hinge & Side Piece	0.004439; 3.08E-6	20300; 140.972	0.2955
Subassembly #4*	Lower Frame, Left Side	Left Wheel Hinge & Side Piece	0.002748; 1.908E-6	20950; 145.486	1
Subassembly #5	Lower Frame, Right Side	Right Wheel Hinge* & End Piece	0.0003133; 2.17E-6	7889; 54.784	1

*Subassembly or component has mirroring counterpart on model

The highest maximum stress is 20980 psi (145.694 psf), located at the upper frame's right and left brackets. The maximum stress at the end of the lower frame is similar -- 20950 psi (145.486 psf) at each corner. At an applied load of 50 lbf, the factor of safety (FoS) for Subassembly #4 and Subassembly #5 is 1; the design load and safety load are equal. Notably, both assemblies are also located in the model's lower frame. Unfortunately, the FoS is significantly lower than 1 for Subassembly #1 (0.381) and Subassembly #3 (0.2955). It can be inferred that a load of 50 lbf will cause the subassemblies to fracture. Based on the results, it is likely that the trolley's lower frame has a higher maximum load than the upper frame. For the beta prototype, the team may need to either a) consider using different material(s) for the frames or b) rerun the simulation using an applied load less than 50 lbf for the upper frame.

Engineering Design

Design Changes

The design of the Duck Dolly has undergone several changes during phases 2 and 3. The first major change was made to how the wheels were to be mounted on the dolly. The original design had one long axle that fit through both wheels and was held on its ends by two 20 mm square 80/20 aluminum T-slot frame bars, as seen in Figure 40 below.

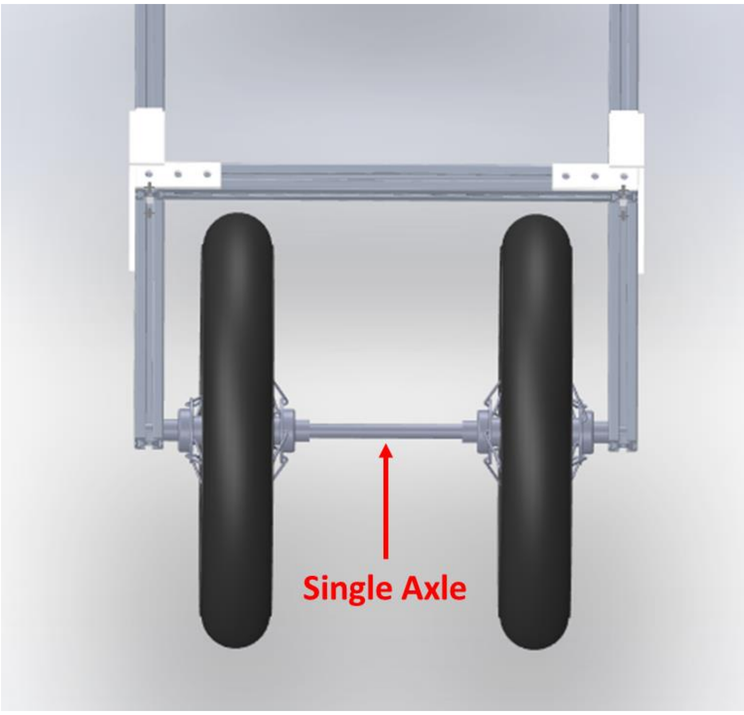

Figure 40: Single Axle Wheel Mount Design

The single axle design was redesigned to be two axles, one for each wheel, with frame bars straddling the wheels to hold onto the axle ends. This change was made after examining the CAD model and noticing that the wheels would extend out past the rear bicycle wheel less if allowed to fold down farther while the dolly was in the collapsed configuration. The single axle prevented the wheels from straddling the rear bicycle wheel and therefore limited how far down the wheels could fold. The images in Figure 41 show how the single axle prevented the straddling in the old design and how the double axle permitted it in the new design.

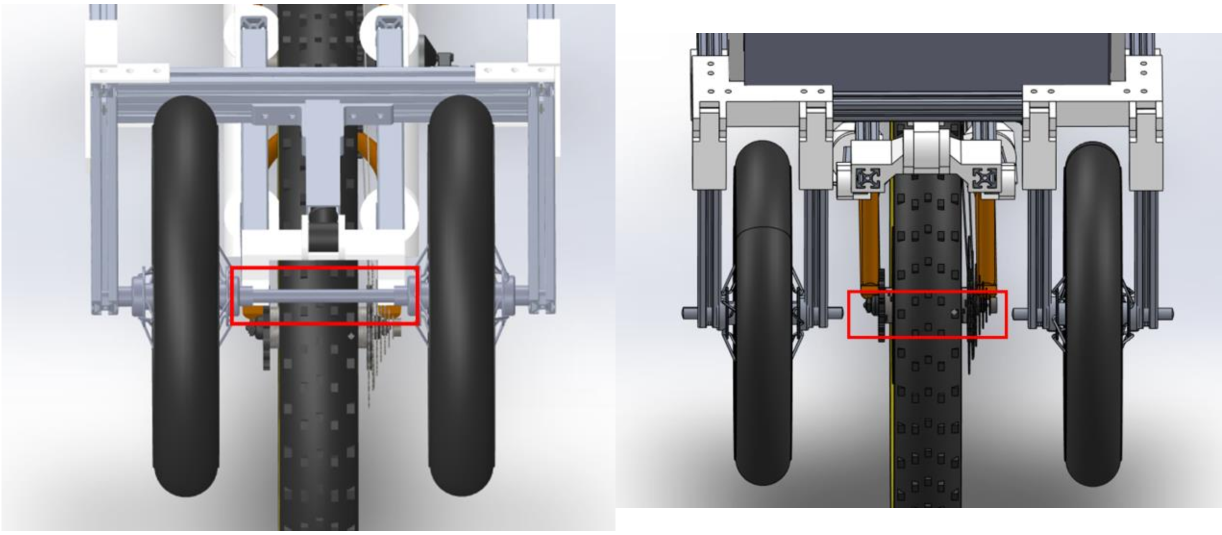

Figure 41: Single Axle (left) Vs. Double Axle (right) Design

The second major redesign was made to the brackets joining the ends of the frame bars and the hinges. The team believed the components would not be strong enough to support the dolly due to single-side contact they made with the frame bars and in the case of the hinges, right corners present in the parts to which force would be directly applied. Figure 42 depicts these two weaknesses.

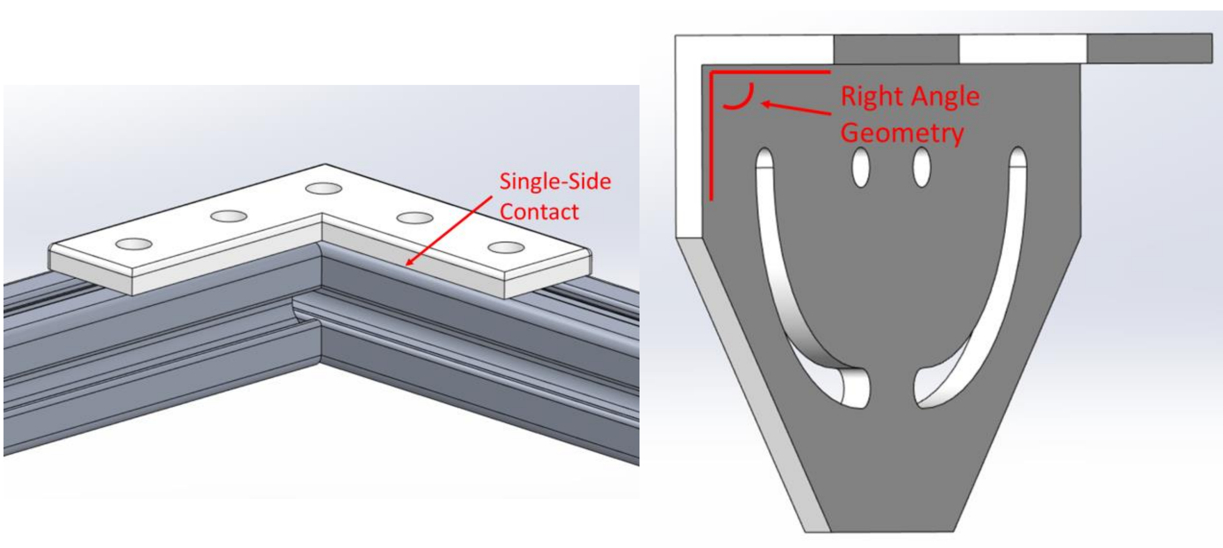

Figure 42: Single-Side Contact (left) and Right Angle Geometry (right)

The brackets and hinges were redesigned to be more like caps that the frame bars would fit into, which provide three or four-side contact. The hinge redesigns also created a pin joint that eliminated the ninety degree corners. The new designs are shown in Figure 43.

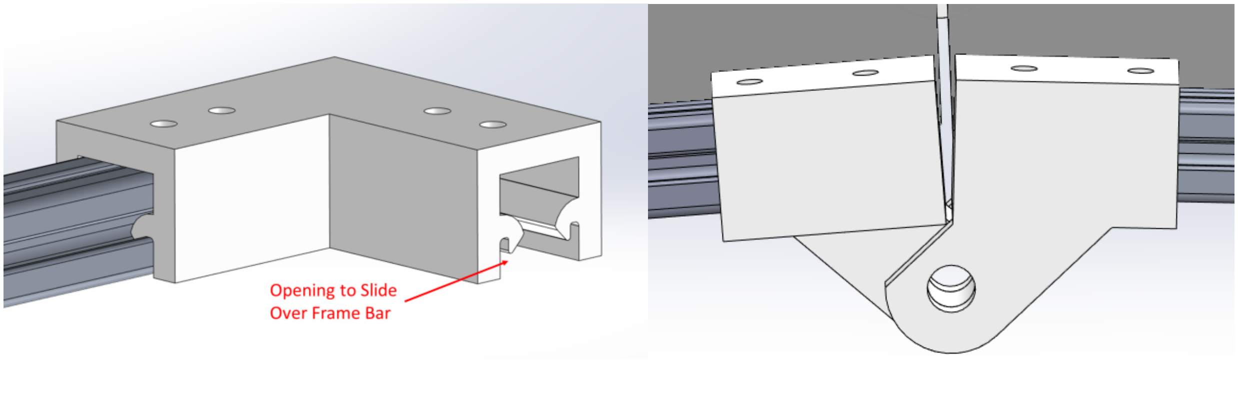

Figure 43: New Bracket (left) and Hinge Designs (right)

The next redesign involved the method by which the dolly hooked up to the mounting bracket on the bicycle. In the original design, a flexible connector was pinned to a hinge point on the mounting bracket with a degree of freedom in the vertical direction to allow the dolly to fold up onto the rear of the bicycle. The team noticed the hookup lacked, however, a degree of freedom in the horizontal direction that would keep the dolly's wheels from skidding when the bike was turning, as can be seen in Figure 44. The flex connector would also experience a great amount of stress from repeatedly bending when turns are made.

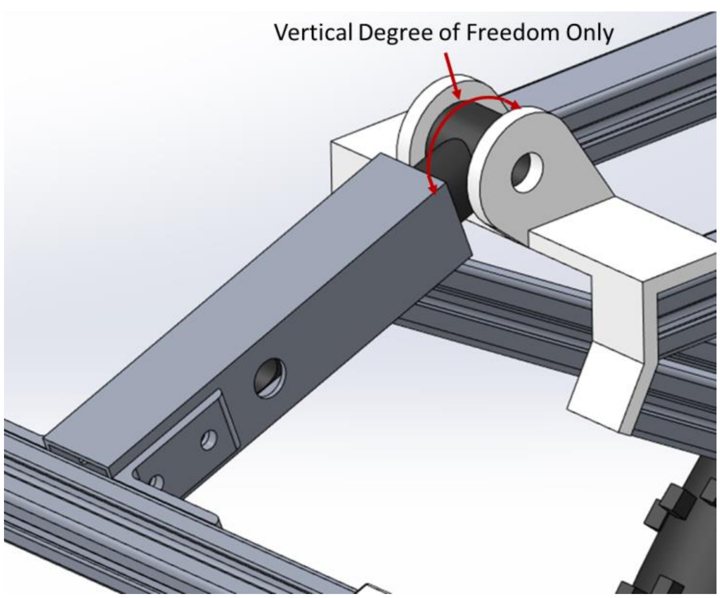

Figure 44: Original Hookup Design

To add the horizontal degree of freedom and reduce the stress on the flexible connector, an adapter component was designed that would still have a vertical degree of freedom between it and the mounting bracket hinge point and allow a horizontal degree of freedom between it and the flexible connector. This new part, and its connections to the hinge point and flex connector, are displayed in Figure 45.

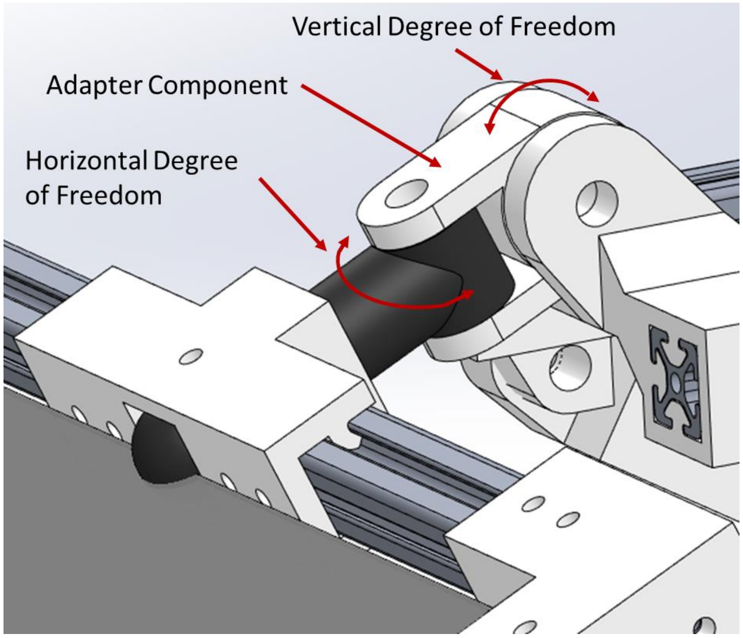

Figure 45: New Hookup Design and Adapter Component

The next major set of changes were made to the mounting component that clamps onto the bike itself and holds the bracket to which the dolly hooks up. Pictured in Figure 46, the part was simply a half cylinder that would fit onto one of the bike's struts, and have two inserts for frame bars to extend up and hold the rest of the mounting bracket. The clamping action would be carried out by two strips of metal that would be screwed into the half cylinder of the part once it was fitted over the strut, sandwiching the strut between them and the half cylinder

Figure 46: Original Mounting Component Design

Instead of using the clamping strips, the new design for the component is almost a full cylinder with a gap. Flanges extend off the part around the gap to make it possible to push the part onto the strut. The flanges can then be bolted closer together to clamp the part tighter. As shown in Figure 47, material was removed from the interior of the part to make it more flexible for pushing it onto the bike strut.

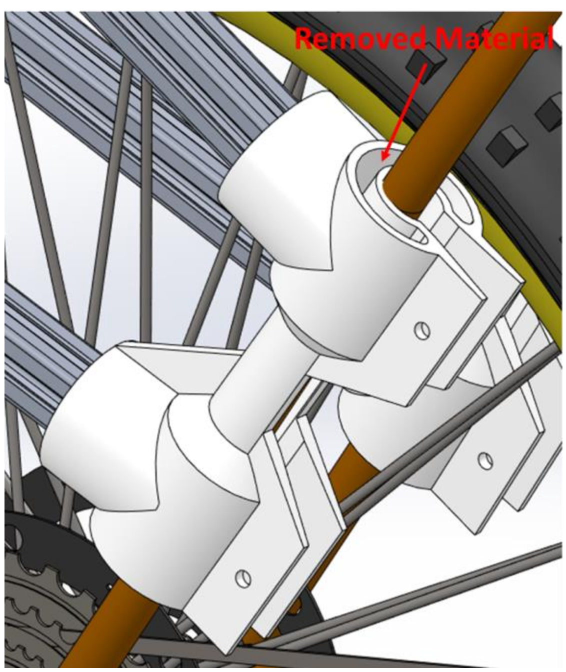

Figure 47: New Mounting Component Design

The last significant redesign was made to the dolly's frames. The lower frame was made longer to accommodate a Smartcart, as opposed to the original dimensions, which were to fit a container bag that is 14 in in length, width, and height. Additionally, during the redesign of the hinges, a crossbar for both the upper and lower frame were removed. After adding to the model the platforms to which the container bags are to be mounted, the crossbars were considered redundant as the platforms will provide the same structure and stability for the frames. The changes made to the frames are depicted in Figure 48.

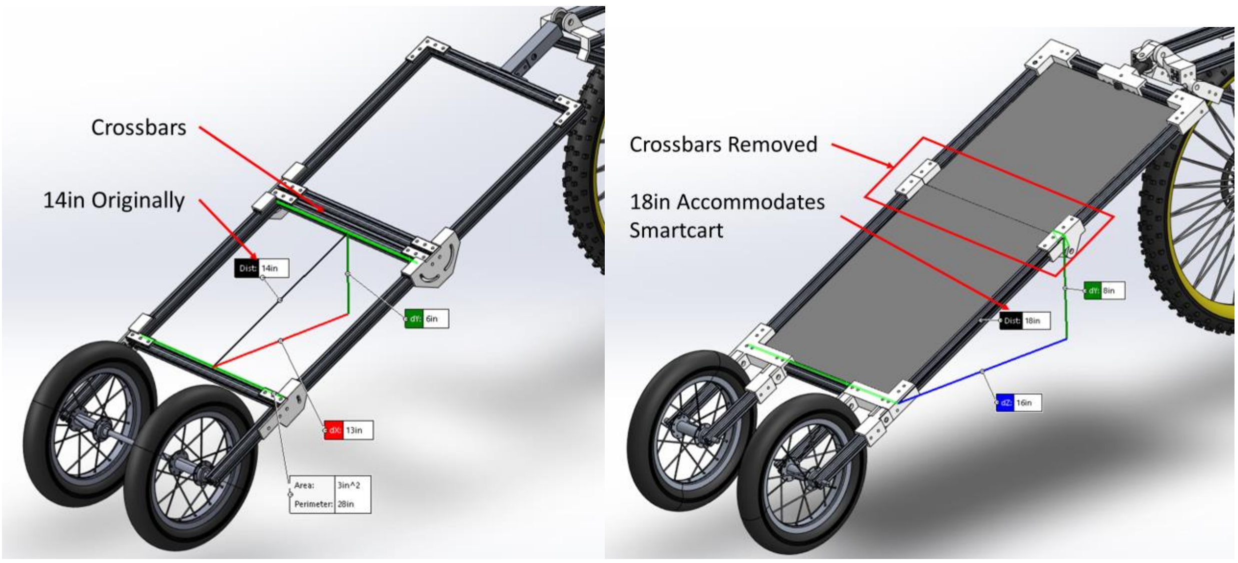

Figure 48: Original (left) Vs. New (right) Frame Design

Design Impact

The goal of this project is to provide cyclists with a convenient method for transporting cargo with a bicycle. In the customer feedback survey distributed, respondents answered that they would be more likely to use bicycles for commuting around urban areas if this goal could be achieved. As bicycles do not have any emissions that leave a carbon footprint, this would have a positive impact on the environment.

The materials used for the dolly may not be so environmentally friendly, however. While aluminum, such as the frame bars of the dolly, is often recycled, plastic, such as the custom joints and hinges between the frame bars, is not. The parts are made of ABS, which does not break down in the environment. ABS contributes to microplastic pollution in the ocean, which is harmful to sea life. The team is using ABS in the design currently due to its availability to 3D print with and its durability under different weather conditions. Other more environmentally friendly options, such as PLA, are not as strong as ABS and will deform when loaded in warm weather around 80 degrees Fahrenheit. As the project moves forward, the team will likely continue to use ABS because of its availability, but will be looking into other material options that exhibit similar mechanical properties as ABS while being more environmentally friendly.

As stated earlier, respondents to the customer feedback survey answered that they would be more likely to use their bike for commuting, if a convenient bicycle cargo storage solution could be offered to them. While the Duck Dolly alone may not bring this about, it and other products that encourage citizens to use their bikes more often could bring about a societal change. Citizens in America rely heavily on cars for commuting, but as the responses in the survey indicate, people would be more willing to use bicycles if it was more convenient. Not only does the convenience apply to transporting cargo, but also to simply being able to get around cities on a bike. Many American cities provide bike lanes on the same roads that cars use, instead of dedicated paths for cyclists that do not allow cars. Additionally, these bike lanes often get covered with the snow that is removed from the roads in the winter, making it difficult for cyclists to use. Once again, the Duck Dolly would not bring about this change on its own, it would contribute to the increased convenience for cyclists that could get citizens off their reliance on cars and riding bikes more often.

During the design of the Duck Dolly, the team has also been focused on the ethical impacts of the design by ensuring the product is reliable and safe to use. With the results of the current technical analysis and future analyses, the team aims to design the dolly to hold twice the load capacity outlined in the target specifications. These results will be further confirmed through testing of the dolly's capabilities with the alpha and beta prototypes. Additionally, while another goal for the dolly is to make it as environmentally friendly as possible, if a more sustainable material that can closely match the strength provided by ABS cannot be identified, ABS will continue to be used, despite its environmentally unfriendliness, to ensure the dolly's safety and reliability.

Design Standards

Wherever possible, the team made an effort to use standard components for the dolly. To that end, much of the dolly's structure is composed of standard 20 mm square 80/20 aluminum

T-slot frame bars. These frame bars are readily available for purchase from McMaster-Carr and several other hardware vendors, and will be the same regardless of where they are purchased. The same can be said for the bolts and fasteners used, a majority of which are M5 by 10 mm long and 3/8 in-16 by 1.5 in long bolts, and corresponding T- and lock nuts. That said, any modifications to be made of these standard parts, such as holes that need to be drilled or bars that need to be cut, will be documented in engineering drawings that meet ASME Y14.5-2018 for Dimensioning and Tolerancing. Custom design parts, such as the joints and hinges between the frame bars, will also be documented in engineering drawings that meet this standard. This will ensure quality parts can be produced and that parts will be interchangeable, so that they can be individually replaced in the event of a broken or lost component.

Alpha Prototype

Prototype Subsystems

With the Alpha Prototype, the team wanted to test the initial designs for different components and subsystems, and test form and functionality of the design for any issues that are not apparent in CAD models of the dolly. Due to the availability of materials from the previous Duck Dolly team and other past design projects completed at Stevens Institute of Technology, the team decided to build the prototype full scale.

The first general subsystem tested and refined was the connection between the custom components that were to be 3D printed and the 20 mm square 80/20 aluminum T-slot framing bars that were to be utilized. The goal was to determine what tolerance the parts would need to be printed at so as to allow them to fit onto the frame bars. To accomplish this, test pieces were printed out of PLA that were dimensioned 0.1, 0.15, and 0.2 mm larger than the frame bars. These pieces are pictured in Figure 49 below. The bar could not fit into the 0.1 or 0.15 mm pieces, but fit snugly into the 0.2 mm piece. This tolerance was used to print the rest of the custom pieces for the prototype.

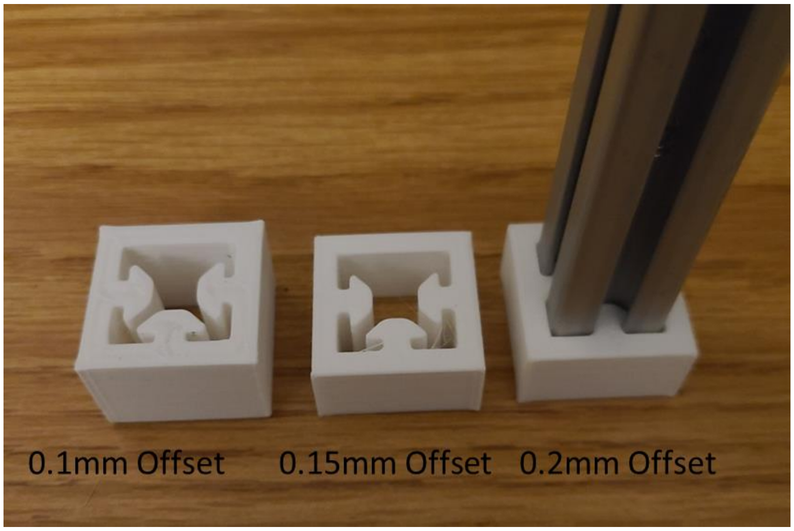

Figure 49: Test Prints

The next major components and subsystems to test were the hinges between the wheels and the lower frame, and between the lower and upper frame. Physical limits to the range of the hinges are incorporated directly into the geometry of the hinges, so the team felt it was important to see if the limits would work as they were designed and would be strong enough to support the dolly. In Figures 50 below are the CAD models components of the wheel hinge.

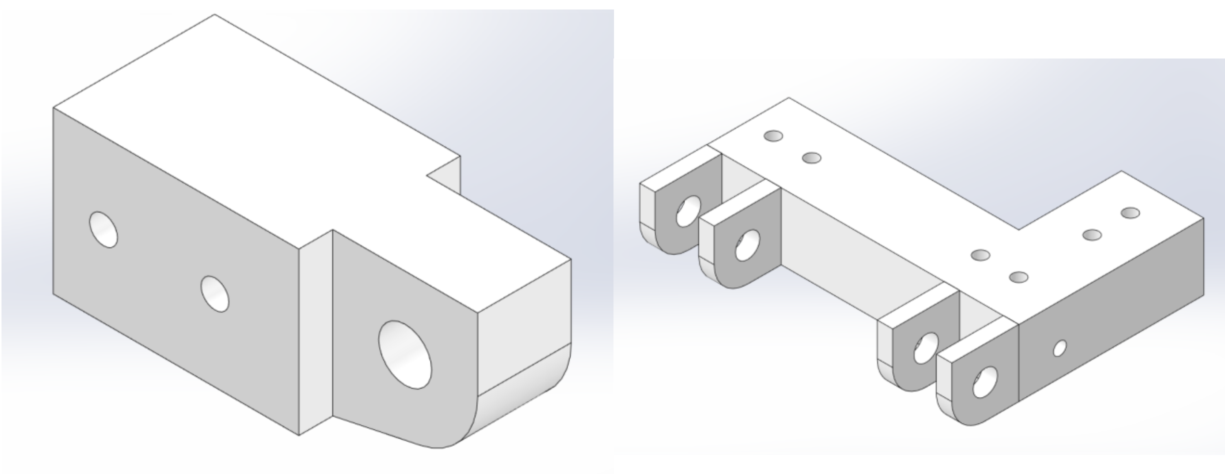

Figure 50: Wheel Hinge Components CAD Models

The part on the left fits onto the frame bars through which the axles for the wheels are mounted. The part on the right holds the lower corners of the lower frame together. Pictures of the actual 3D printed pieces and the way they connect are shown in Figure 51.

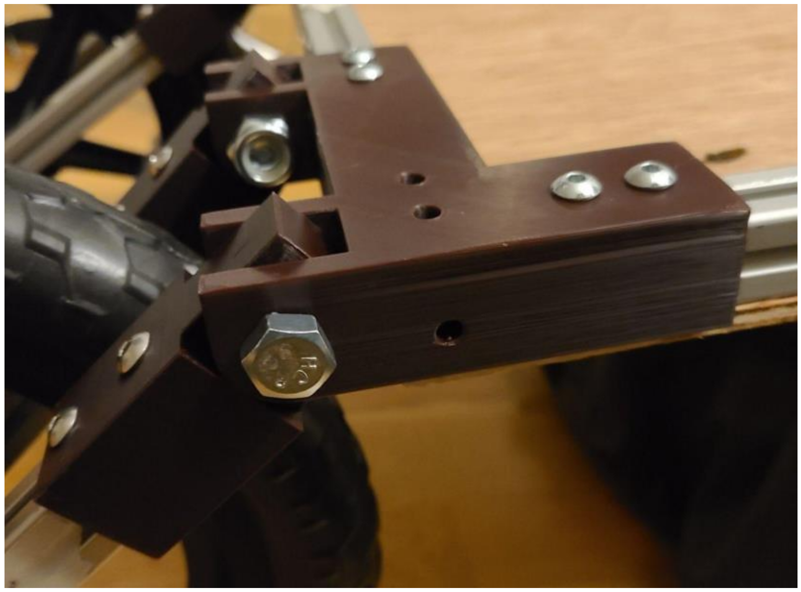

Figure 51: Connection Between Wheel Hinge Components

This wheel hinge allows the wheels to fold down almost 90 degrees with respect to the frame so that when the dolly is in its collapsed configuration, the wheels do not extend farther off the back of the bike than the bike's own rear wheel. While in the extended configuration, however, the hinge locks the wheels inline with the frame so the dolly can roll on the wheels behind the bike. Below in Figure 52 are the CAD models of the hinge between the frames. Figure 53 shows printed components and how they connect.

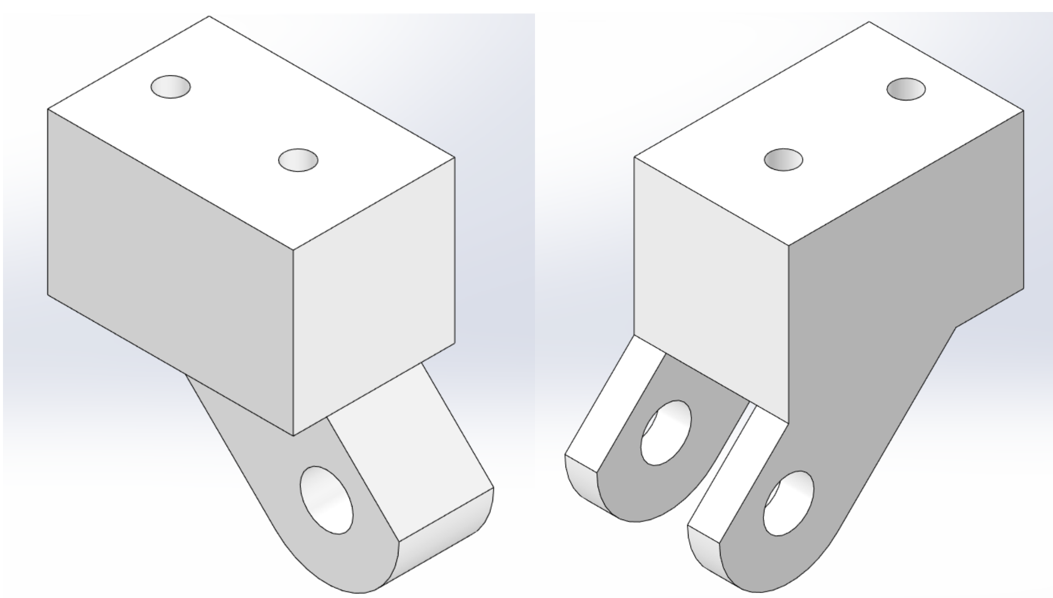

Figure 52: Frame Hinge Components CAD Models

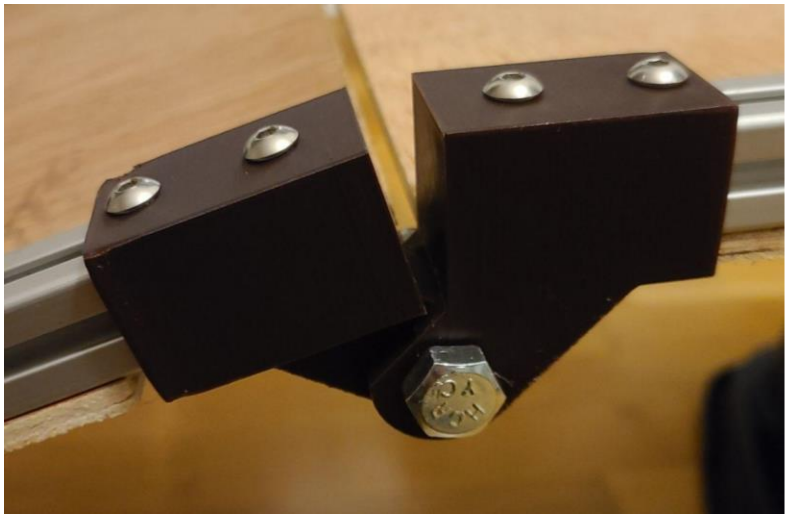

Figure 53: Connection Between Frame Hinge Components

In a similar fashion to the wheel hinge, these components allow the frames to fold 180 degrees with respect to one another so the dolly can be folded up onto the back of a bike. In the expanded configuration, they lock the frames of the dolly inline with each other to provide a platform to hold the cargo.

The pieces of each respective hinge subsystem did fit well together, and both allowed and limited rotation as they were intended, but the strength of the parts was called into question when one part broke. The break, pictured in Figure 54 below, occurred along 3D printed layers of the part. The team will be considering design changes to the components in phase 4, but also intend to print future parts in an orientation that will make the layers of the print parallel to the internal forces the components are expected to experience, as opposed to perpendicular, to give the parts increased strength.

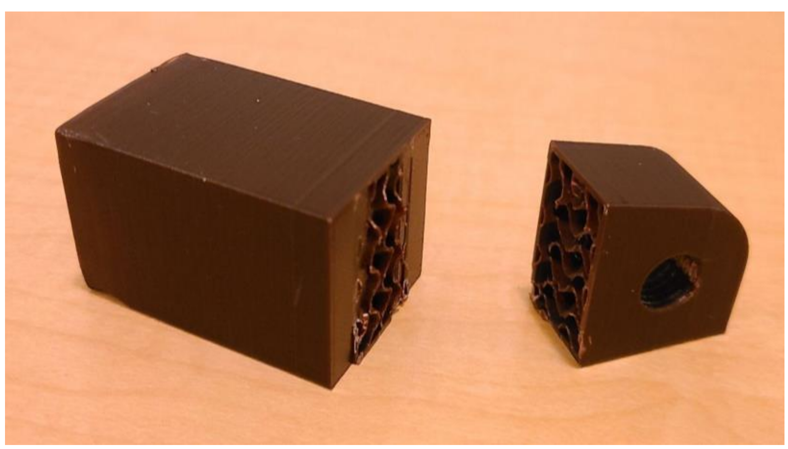

Figure 54: Break Between 3D Printed Layers of Hinge

The third major subsystem tested for fit and functionality was the hookup between the dolly and the mounting bracket on the bicycle. The system mainly consists of three components: a hinge point on the mounting bracket itself, an adapter that adds a degree of freedom to the dolly, and a flexible connector that attaches to the dolly and the adapter, and also gives the dolly an additional degree of freedom. In Figure 55, the CAD model of the hinge point on the mounting bracket is shown.

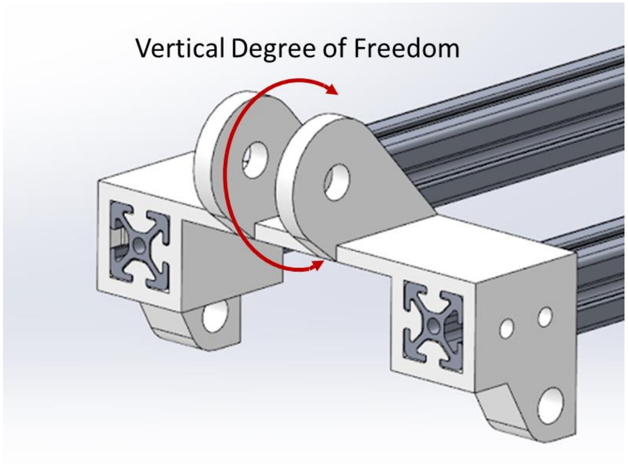

Figure 55: Mounting Bracket Hinge Point Vertical DoF

The component holds the two sides of the mounting bracket parallel and its hinge point gives the dolly its degree of freedom in the vertical direction to fold up onto the back of the bike. Below in Figure 56, the adapter component can be seen.

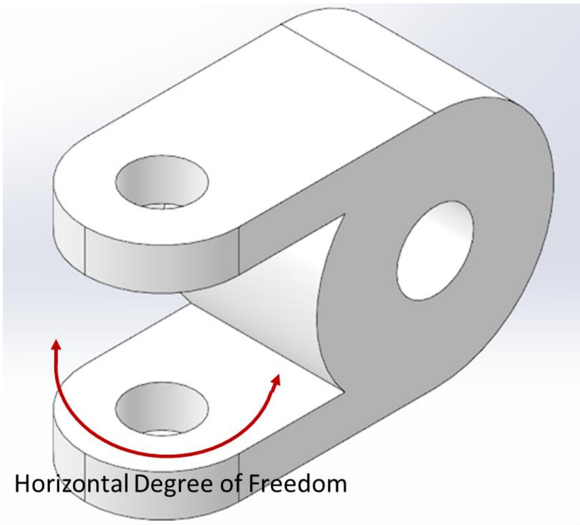

Figure 56: Adapter Horizontal DoF

This adapter fits into the hinge point on the mounting bracket and allows the flex connector, which fits into and attaches to it, to rotate in the horizontal direction. This reduces the likelihood of the wheels of the dolly skidding and the dolly tipping while the bike is turning. Additionally, it reduces the stress on the flex connector as it does not have to bend when the bike turns, instead being allowed to rotate in the adapter. The model flex connector itself is pictured in Figure 57 below.

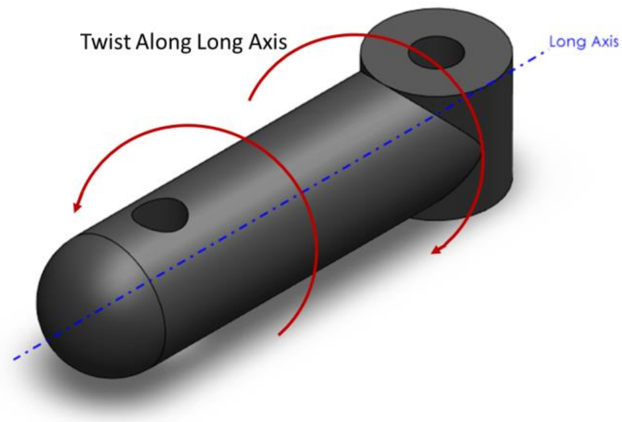

Figure 57: Flexible Connector Twist DoF

The flex connector fits into the top frame of the dolly and the adapter piece. It is made of flexible TPU so as to allow rotation along its long axis. When riders tilt their bikes to one side, or lay them flat on the ground, this degree of freedom will keep the dolly from tipping. The hookup between the mounting bracket and the dolly with these three components are shown in Figure 58.

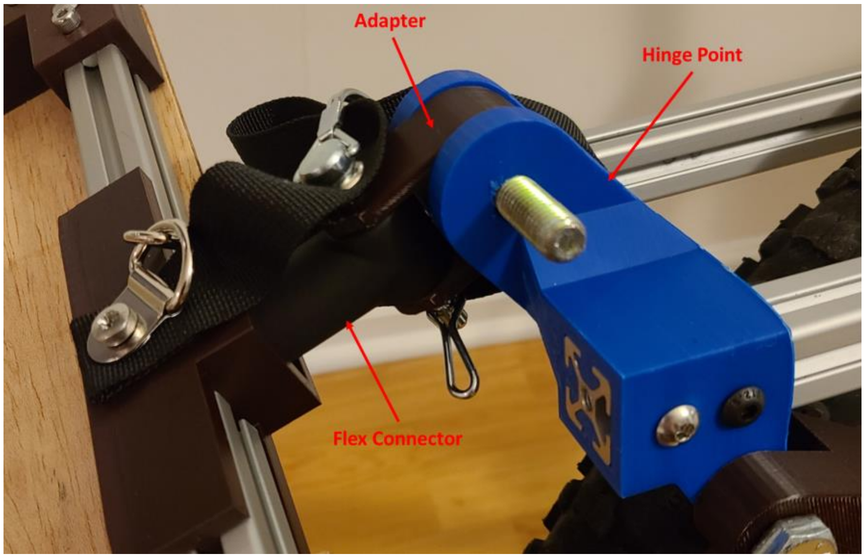

Figure 58: Dolly to Mounting Bracket Hookup

The hookup subsystem was a success, allowing all three degrees of freedom between the mounting bracket and the dolly, however, it revealed some weaknesses in the parts that will need to be addressed. In twisting the flex connector, the hinge points on the mounting bracket flexed and began to break, as can be seen in Figure 59.

Figure 59: Flex (left) and Break (right) in Mounting Bracket Hinge Point

Some redesign has already been completed on the hinge points, such as increasing thicknesses and adding chamfers to corners, but further redesign will be considered in phase 4, as well as printing the piece in a different orientation for increased strength, as is being considered for the other hinge components. The redesigns already carried out can be examined in Figure 60, which shows the original part on the left and the new part on the right.

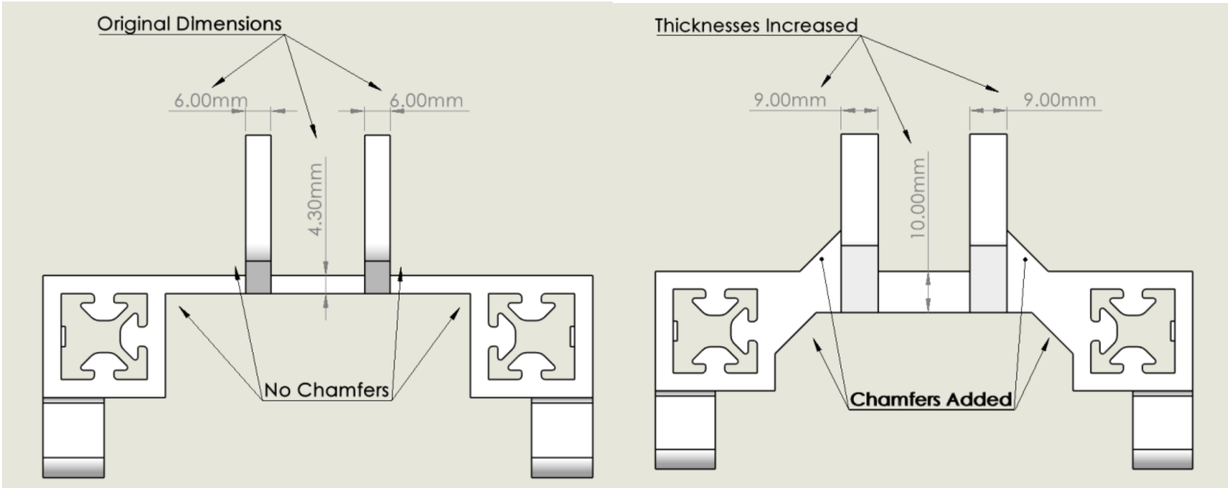

Figure 60: Design Changes Made to Mounting Bracket Hinge Point

The last major subsystem to test was the method by which the mounting bracket would be attached to the bike. The team designed a part that could be pushed onto one of the bike's struts. The part would hold two frame bars that would extend up and hold the hinge point to which the rest of the dolly would hookup. The part and how it holds up the rest of the mounting bracket are depicted in Figure 61 below.

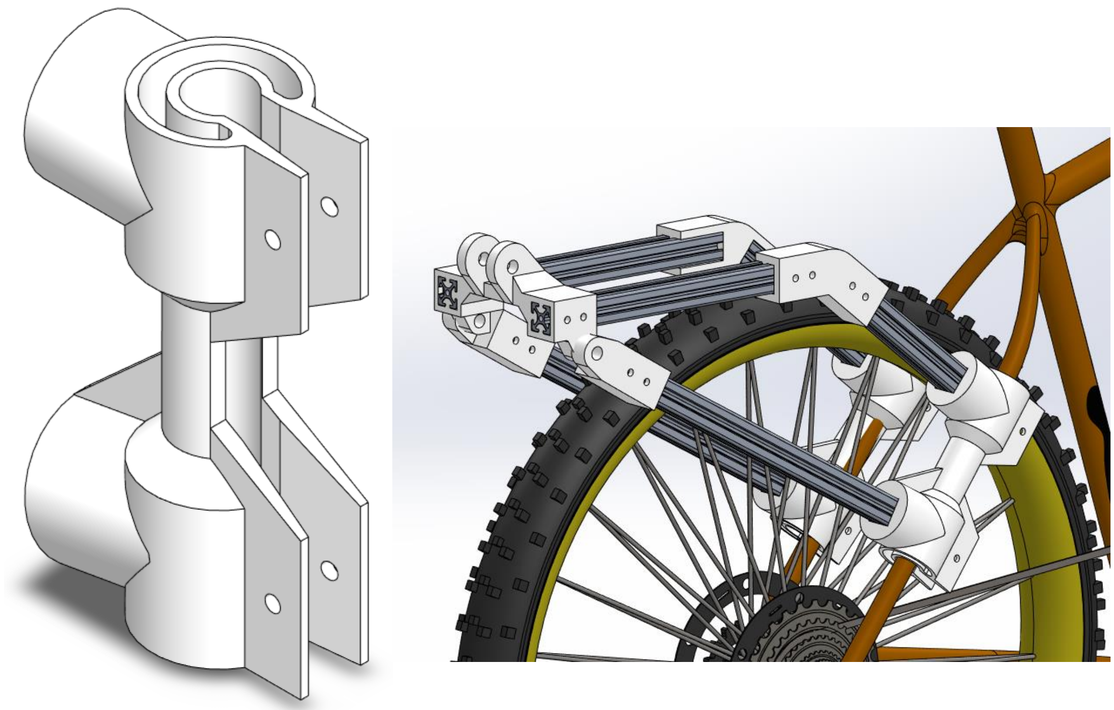

Figure 61: Mounting Part (left) and Mounting Bracket (right)

The left image shows the part itself with the open slot that allows it to be pushed onto the strut of the bike. The right image shows how the part is positioned on the bike strut and holds up the rest of the mounting bracket.

With the mounting piece, the team primarily wanted to test if it could be pushed onto the bike strut without breaking and clamp onto it strongly. To that end, test prints were made out of PLA to try and push the part onto the strut. The first print, shown in Figure 62, could not be pushed onto the strut, so the opening was widened and more material was removed from the part's interior to make it more flexible. A second test print was made and it was possible to push the part onto the strut with the wider gap and less interior material. This is shown in Figure 63.

Figure 62: First Mounting Part Test Print

Figure 63: Second Mounting Part Test Print

While the second test print was a success, the full mounting parts have not been printed yet as the team is concerned about differences in the angle, length, and diameter of bike struts over a range of different bicycles, which would make the design not universal. The team will be considering a new mounting design in phase 4 that will be more universal and will still make use of the push-on design of the current mounting part.

Prototype Construction

As each subsystem was tested, and the subsequent parts that they relied on printed, cut, or purchased, the full prototype was assembled. The completed prototype is featured in Figure 64.

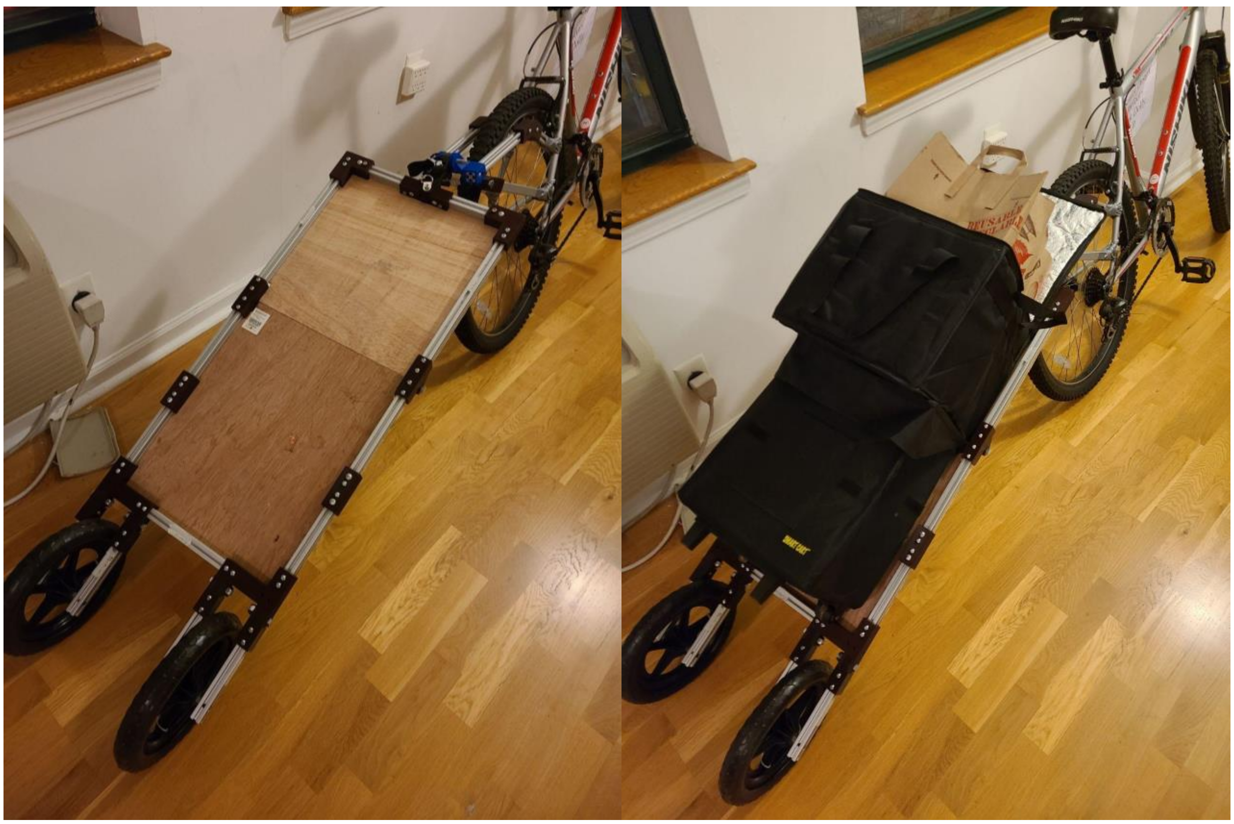

Figure 64: Completed Prototype Without Bags (left) and with Bags (right)

The custom parts, which consist of the hinges and joints between the frame bars, were all 3D printed out of ABS plastic, for its strength and durability in the face of the heat, cold, and other weather the dolly will be subjected to while outside. The 20 mm square aluminum frame bars and the plywood used for the container platforms were salvaged from previous design projects and cut to the necessary dimensions for the dolly. The container bag seen on the lower frame is a

Smartcart that was also salvaged from the previous Duck Dolly team. The flexible connector, 12 in wheels, and 14in cube container bag seen on the upper frame were purchased and added to the prototype after their delivery.

To secure the printed parts and the plywood to the frame bars, M5 by 10 mm long button head bolts were fitted through holes printed in the plastic parts or drilled in the wood and secured to T-nuts sitting in the slots of the frame bars. The bolts and the T-nuts are pictured in Figure 65.

Figure 65: M5 by 10 mm Long Bolts (left) and T-nuts (right)

Each of the hinges on the prototype were pinned using a 3/8 in-16 by 1.5 in long hex bolt and lock nuts, like those in Figure 66.

Figure 66: 3/8 in-16 by 1.5 in Long Hex Bolt (left) and Lock Nut (right)

Without the mounting parts to fix the mounting bracket onto the bike, the frame bars of the mounting bracket are currently only attached to the bike with duct tape, as seen in Figure 67.

This is to get an idea of size and fit, and once the mounting parts are redesigned, they will be printed and used to provide the mounting bracket with a sturdier and more permanent solution during performance tests conducted with the prototype

Figure 67: Temporary Duct Tape Mount

Prototype Testing and Evaluation Plan

Once the redesign of the mounting components are complete and the parts printed, the first step in testing the prototype will be to finish hooking it up to the bike and then riding around on the bike with the dolly attached. The dolly will be unloaded at first, and the team will simply test the rider’s ability to ride with the dolly by making turns, going over obstacles, traversing over different terrains, and riding at different speeds. If the dolly's components do not fail while undergoing these initial tests, then it will be loaded with 50 pounds of cargo, which is the minimum weight capacity for the dolly outlined in the target specifications, and the same riding tests will be conducted with the cargo. Once again, if no problems are encountered, the dolly will be further loaded with cargo with the goal of testing it with 100 pounds of cargo to see if it can hold twice the desired minimum. Any problem encountered, such as a component or subsystem failing or not functioning as designed, will be studied to determine the cause of failure and the best way to correct the issue before testing resumes.

Project Plan

Project Overview

For the Fall 2021 semester, the team will have completed phases 1-3 on the project. Along the way, we will have progress reports and phase reports to demonstrate our progress. This will include having an alpha prototype to show. By the end of the Spring 2022 semester, the team will have finished all phases of the project and will have a working beta prototype to be presented at the 2022 Innovation Expo. The beta prototype will display the extra storage capacities of the product as well as demonstrate its collapsibility.

Phase 1 Task Breakdown

For this project, the team has been utilizing ClickUp for planning and organizing all of the tasks that need to be done for the project. As shown in Figure 68, the first two weeks of the project were spent researching current solutions for the state of the art review, creating the customer survey to be sent out to gather more information, as well as creating the progress report. Once we received the input from the customer surveys, the team then compiled a customer needs and target specifications sheet, as well as began our concept generation. From there, we spent the remaining weeks in phase 1 screening the concepts and choosing which ones we will continue developing. This led into finalizing the phase 1 report and presentation, as well as beginning preparations for phase 2.

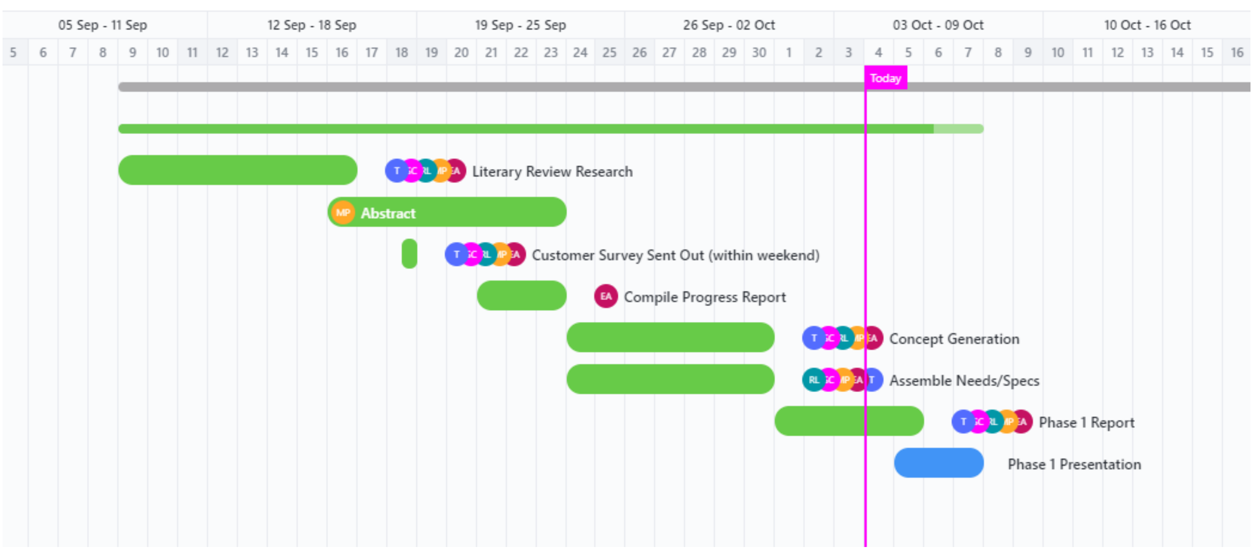

Figure 68: Phase 1 Gantt Chart

Phase 2 Task Breakdown

For phase 2, the first few weeks were spent starting technical analysis, creating CAD models for the remaining concepts, and beginning to build our website. Once CAD models were finished, a final concept was decided upon and a more detailed technical analysis could be done. Throughout the later half of phase 2, the team was adding pages to the website with Phase 1 information, as well as occasional blog updates. This led into publishing the project website, finalizing the phase 2 presentation, as well as beginning preparations for phase 3. The phase 2 Gantt chart can be seen in Figure 69 below.

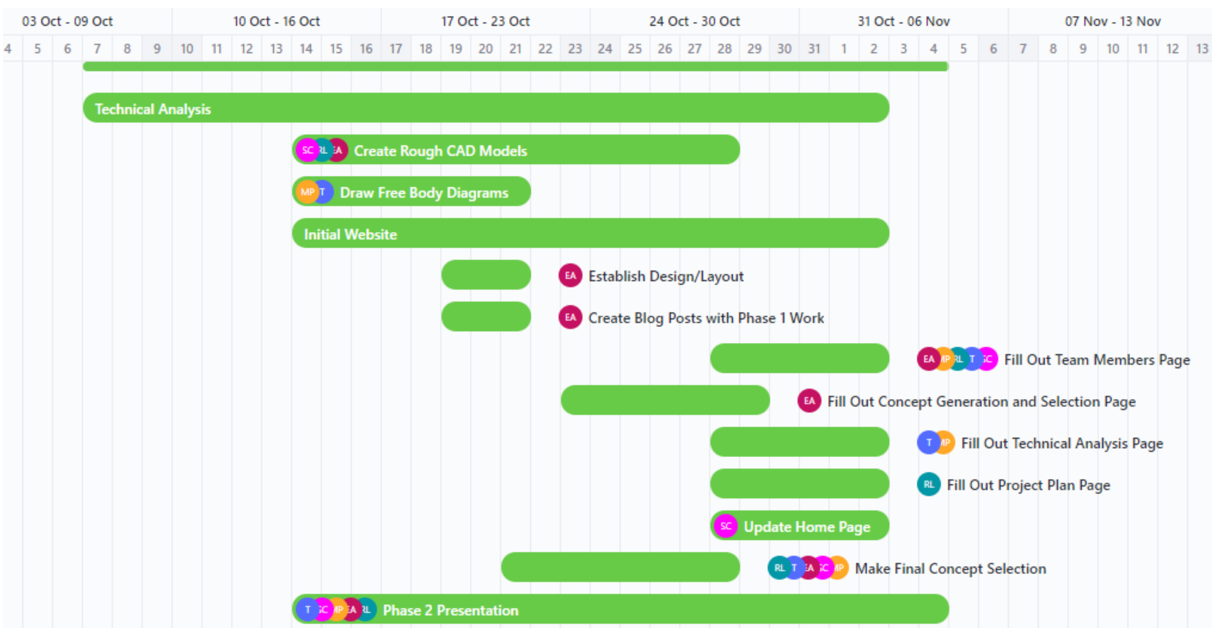

Figure 69: Phase 2 Gantt Chart

Phase 3 Task Breakdown

For Phase 3, the team started with finalizing any more technical analysis as well as preparing for what will become our alpha prototype. This involved taking an inventory of what parts we already had from the previous year’s design, as well as creating a list of what we needed to order and what we needed to print. From this, the team did revisions to the CAD models in order to begin printing parts as well as put in shipping order to have any other parts delivered. Once everything was compiled, the team assembled a full scale alpha prototype. This led into finalizing the alpha prototype, compiling the phase 3 presentation, as well as beginning preparations for phase 4. The phase 3 Gantt chart can be seen in Figure 70 below.

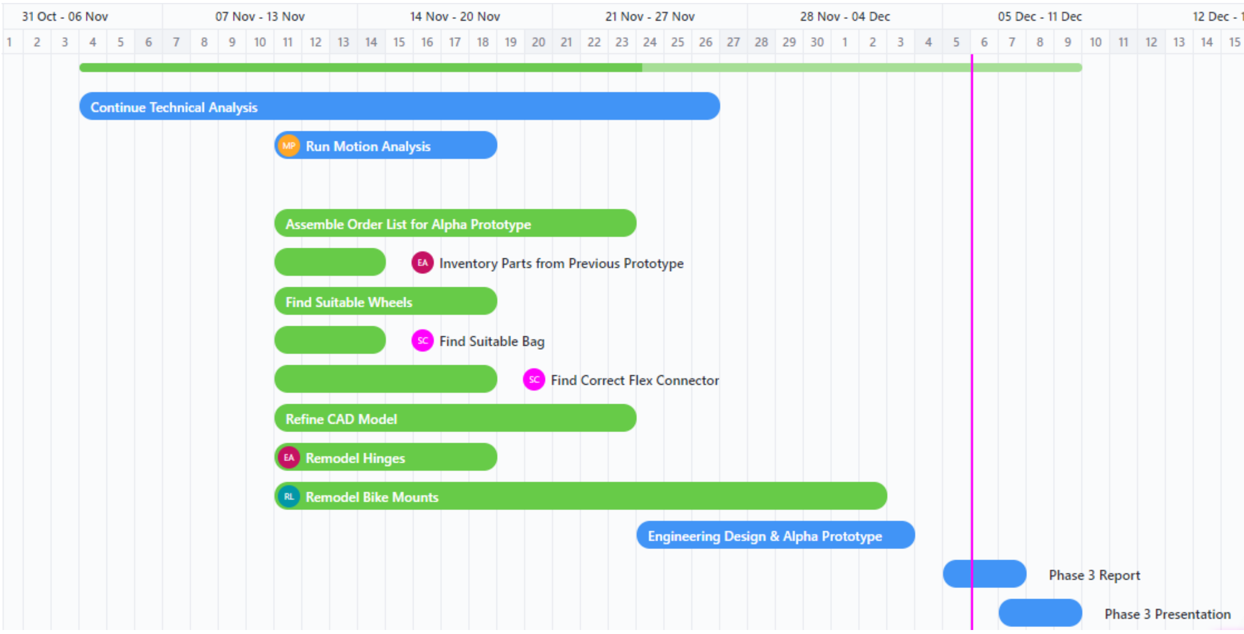

Figure 70: Phase 3 Gantt Chart

Budget Estimation

Based on our most promising concept for the project so far, concept 1, the team did a rough estimation on what it would cost to create a prototype during phase 1. Utilizing the cost of the collapsible boxes in which this design is based on, two of them will cost $40. The wheels will cost around $30 - $50. Apart from that, we plan on using aluminum for the structural elements of the design, as well as the hardware needed to combine everything. We estimate this to cost around $80-110. Overall, a prototype will cost between $150-$200. This is a slight overestimate as well and may change based on our design changes. For concepts 3 and 5, the team estimates it to cost around the same, apart from the addition of the two bags for concept 3 that will cost an additional $50-$100.

In phase 3, the team assembled a full scale alpha prototype. Based on the ordered parts for prototyping, the team spent around $106. This does not include T-slot bars which we recovered from last year's project as well as from the machine shop. We estimate those additional materials to cost another $100-$150. This would put our new estimate for the product to cost around $200-$250. We plan on reducing some of these costs by making some of the ordered parts ourselves, such as the Burley Flex Connector. This would remove the need for the ordered part and reduce overall cost.

Conclusion

The main objective for this project is to continue the research and developments from last year's project, and design and create an attachable cargo storage device for bikes that are used in city environments. The main goals of this design are to satisfy the customer needs and improve on current solutions for this problem. Some of the main customer needs include storage size, attachability, collapsibility, affordability, durability, and safety. Using the customer needs and specifications, the group came up with multiple design concepts in order to determine the best solution to the problem. There were six different design concepts that were developed. Using the customer needs, the concepts were compared against the project's main competitor, the Trenux Trailer. The folding boxes design of concept 1, the saddle bags design of concept 3, and the linkages design of concept 5 were selected for further analysis. As the team moved into phase 2, concept 1 was ultimately chosen after comparing the three concepts. Then the group went more in depth for the technical analysis. The in depth technical analysis led to building a full scale alpha prototype in phase 3. Then, a motion study was created to test the design. For the continuing phases in the next semester, the group will continue to test and develop the alpha prototype in order to refine our product.

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6. "Why Canadians Can't Bike in the Winter (but Finnish people can)", YouTube video https://www.youtube.com/watch?app=desktop&v=Uhx-26GfCBU

Appendix

Survey Questions

Bike Cargo Storage Survey

Thank you for agreeing to participate in our bike cargo storage survey. We are collecting customer input on the issues with current cargo storage options while riding a bike. We plan to use this information to develop an improved compactable storage device that can be attached to a bike.

* Required

1. What type of bike to you have?

   Mark only one oval.

   - Standard
   - Mountain bike
   - Cruiser
   - Sport bike
   - Electric bike
   - Collapsible bike
   - I don't have a bike
   - Other: ____________

2. Is your bike your primary mode of transportation? *

   Mark only one oval.

   - Yes
   - No
   - Other: ____________

3. How often to you use your bike?

   Mark only one oval.

   - Every day
   - multiple times a week
   - 1-2 times a week
   - less Than once a week
   - Other: ____________

4. On average, how long is a single bike ride for you? *

   Mark only one oval.

   - 0-15 minutes
   - 15-30 minutes
   - 30-45 minutes
   - 45-60 minutes
   - More than 1 hour

5. On average, how many distinct bike rides do you go on per day?

   Mark only one oval.

   - 0-1 rides
   - 2-3
   - 3-4
   - 5+

6. What terrain do you often encounter on your bike rides?

Check all that apply.

- [ ] Flat pavement
- [ ] Some potholes or Speed bumps
- [ ] Steep hills
- [ ] Cobblestone/uneven pavement
- [ ] Grass/dirt paths

7. For what purpose(s) do you ride your bike? *

Check all that apply.

- [ ] Leisure
- [ ] Commuting/transportation
- [ ] Delivery Service (food, other)
- [ ] Errands
- [ ] Exercise/sport

Other: [ ] ______________________

8. For what purpose do you require storage while riding your bike?

Check all that apply.

- [ ] Grocery shopping
- [ ] Food delivery
- [ ] Personal items (water bottle, wallet, etc.)
- [ ] Work/school items (briefcase, laptop)
- [ ] Equipment(technology, musical instruments, sports gear)

Other: [ ] ______________________

9. Approximately what size storage would be ideal for you?

Mark only one oval.

- ( ) Fits a backpack/briefcase
- ( ) Fits 1-2 grocery bags
- ( ) Fits 3-4 grocery bags
- ( ) Fits an average storage bin or more
- ( ) Fits large, bulky, odd shaped items
- ( ) Other: ______________________

10. Approximately what storage weight capacity would be ideal for you?

Mark only one oval.

- ( ) 0-25 lbs
- ( ) 25-50 lbs
- ( ) 50-75 lbs
- ( ) 75+ lbs
- ( ) Other: ______________________

11. What solution do you currently use for storage while riding your bike?

Check all that apply.

- [ ] Cargo bike
- [ ] Pannier/saddlebag
- [ ] Built-in trunk
- [ ] Backpack
- [ ] Attachable cart
- [ ] Front basket
- [ ] Hang from handelbars
- [ ] Hold with hand/arm

Other: [ ] ______________________

12. On a scale of 1 to 5, how satisfying is your current bike cargo storage solution?

Mark only one oval.

	1	2	3	4	5	
Not at all satisfied	( )	( )	( )	( )	( )	Completely satisfied

13. On a scale of 1 to 5, how important is storage capacity?

Mark only one oval.

	1	2	3	4	5	
Not important	( )	( )	( )	( )	( )	Extremely important

14. On a scale of 1 to 5, how important is the size of the storage solution attachment (i.e. wideness, bulkiness)?

Mark only one oval.

	1	2	3	4	5	
Not Important	( )	( )	( )	( )	( )	Extremely important

15. On a scale of 1 to 5, how important is bike maneuverability?

Mark only one oval.

	1	2	3	4	5	
Not important	( )	( )	( )	( )	( )	Extremely important

16. On a scale of 1 to 5, how important is it for the storage system to be removable?

Mark only one oval.

	1	2	3	4	5	
Not important	( )	( )	( )	( )	( )	Extremely important

Previous Cargo Storage Design: Primary targets are people using bikes for commuting and errands in a city environment.

17. Our previous design team came up with the above design for bike cargo storage. Is this design something you would like? Please add any comments you have.

____
____
____
____

18. Would an ideal storage solution encourage you to use your bike more often/ for more purposes?

Mark only one oval.

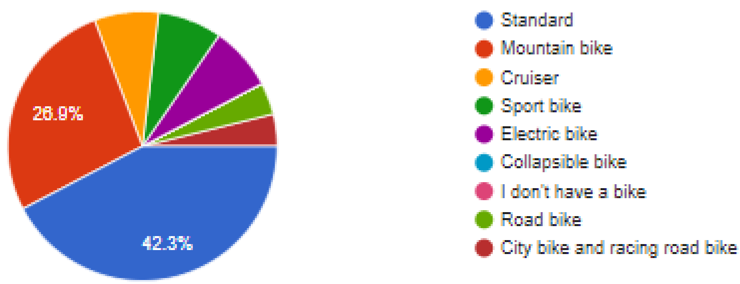
- Yes
- No
- Unsure

19. Do you have any additional comments or suggestions about bike storage solutions?

Survey Results

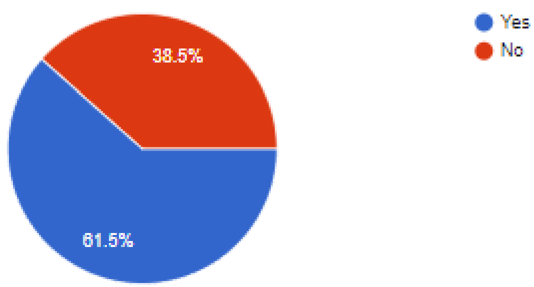
What type of bike to you have?

26 responses



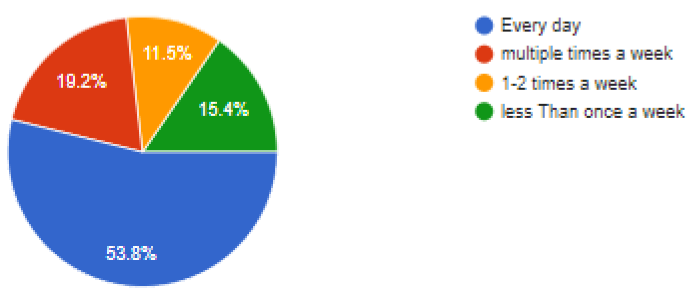
Is your bike your primary mode of transportation?

26 responses



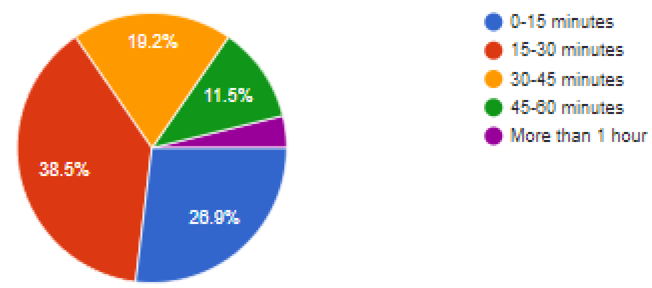
How often to you use your bike?

26 responses



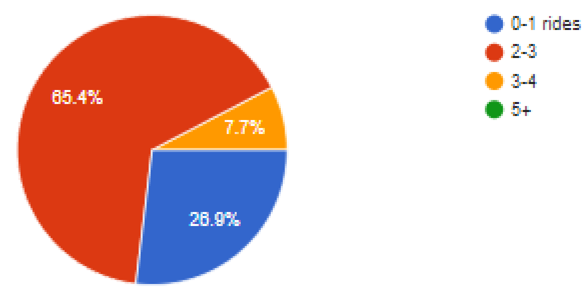
On average, how long is a single bike ride for you?

26 responses



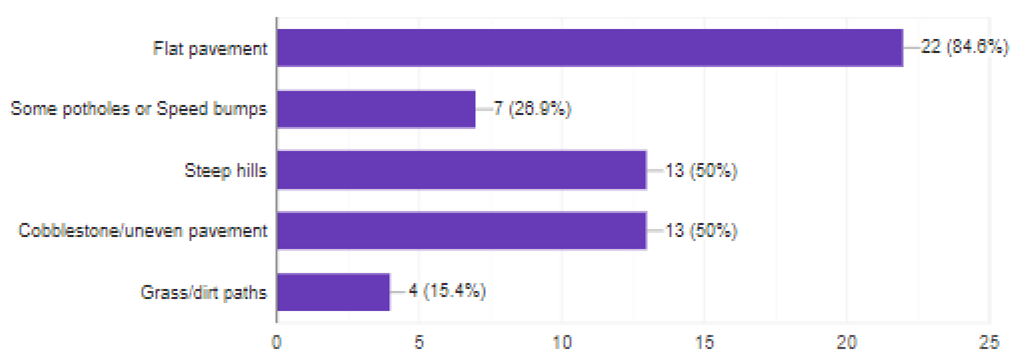
On average, how many distinct bike rides do you go on per day?

26 responses



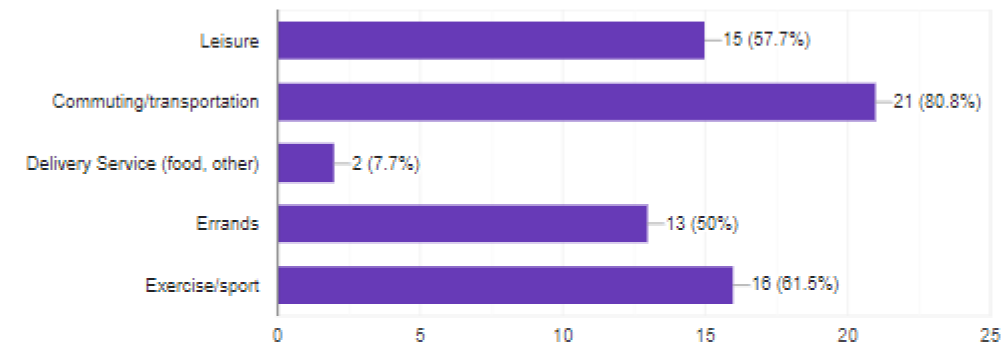
What terrain do you often encounter on your bike rides?

26 responses



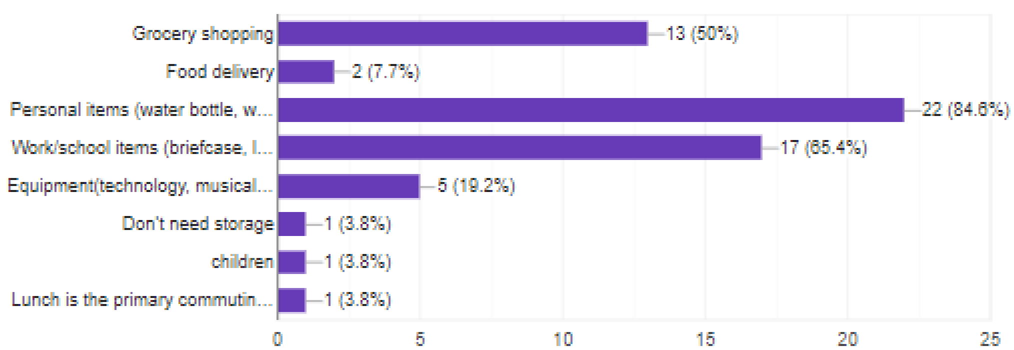
For what purpose(s) do you ride your bike?

26 responses



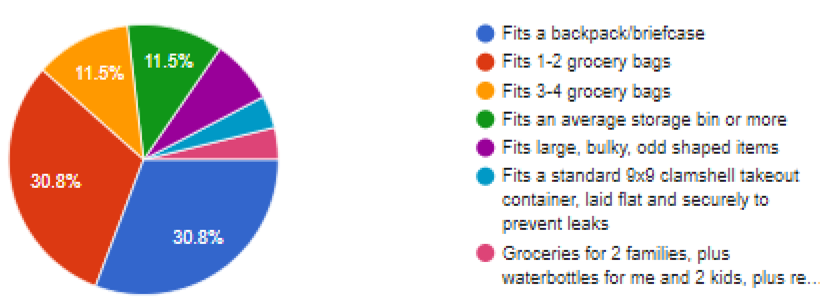
For what purpose do you require storage while riding your bike?

26 responses



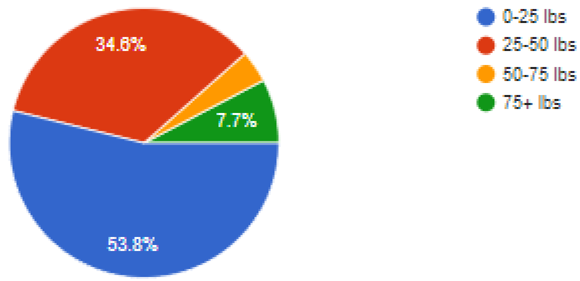
Approximately what size storage would be ideal for you?

26 responses



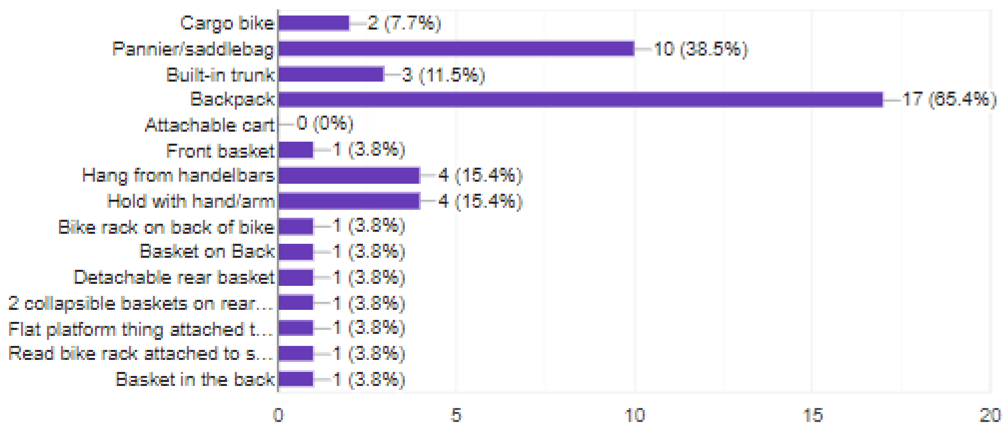
Approximately what storage weight capacity would be ideal for you?

26 responses



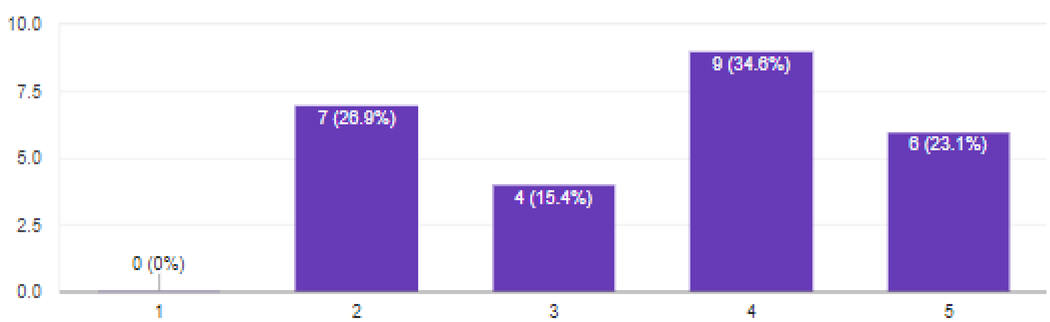
What solution do you currently use for storage while riding your bike?

26 responses



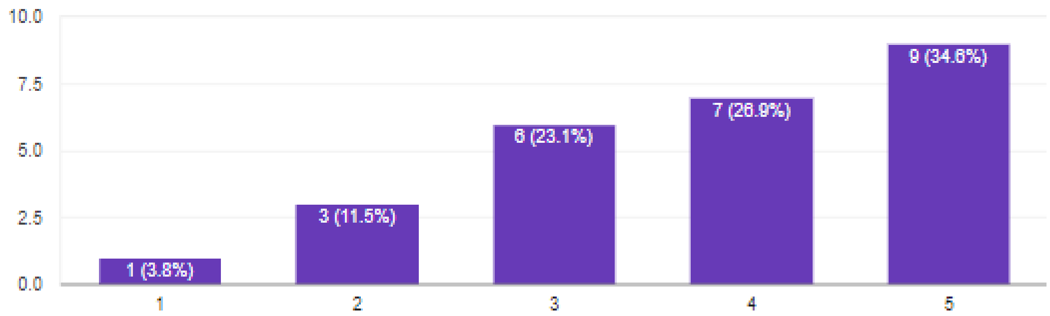
On a scale of 1 to 5, how satisfying is your current bike cargo storage solution?

26 responses



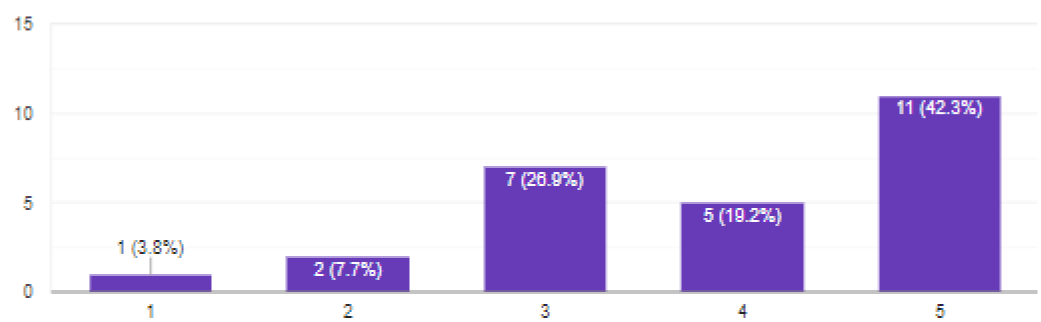
On a scale of 1 to 5, how important is storage capacity?

26 responses



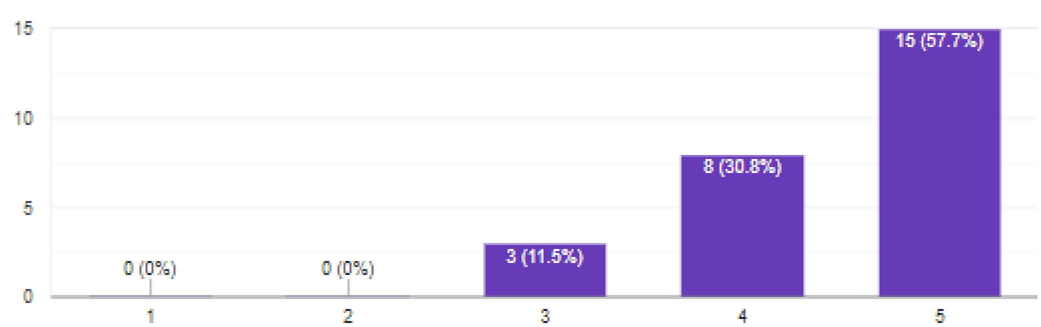
On a scale of 1 to 5, how important is the size of the storage solution attachment (i.e. wideness, bulkiness)?

26 responses



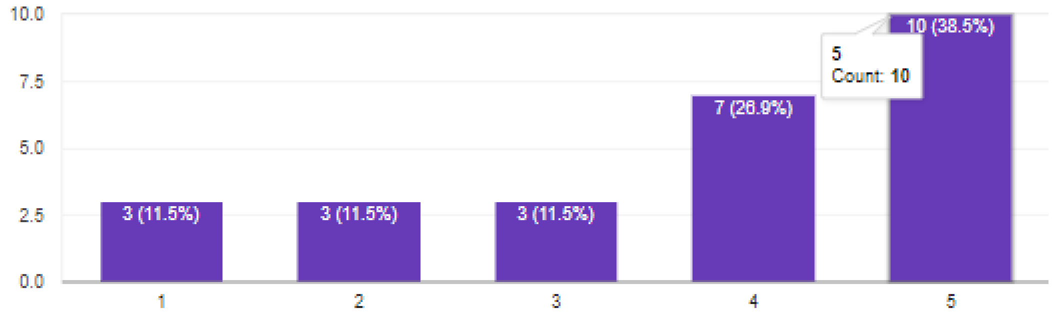
On a scale of 1 to 5, how important is bike maneuverability?

26 responses



On a scale of 1 to 5, how important is it for the storage system to be removable?

26 responses



Our previous design team came up with the above design for bike cargo storage. Is this design something you would like? Please add any comments you have.

5 responses

No

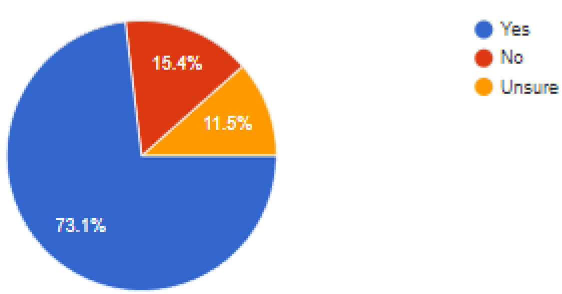
Seems like it would be hard to maneuver especially due to the small wheels. I would not say go crazy with the wheel size but something bigger.

this looks like something that could easily be stolen, also wouldn't work on bikes without a carrier above the rear wheel

Going over pot holes looks scary

Would an ideal storage solution encourage you to use your bike more often/ for more purposes?

26 responses



Do you have any additional comments or suggestions about bike storage solutions?

9 responses

A lock to secure items if I have multiple stops, protection from weather and wet roads

I have multiple cargo solutions since they are all affordable: large panniers for commuting, frame bags for small personal and bike maintenance gear, detachable basket for my cruiser bike, backpack for my mountain bike. Also, know that bicycle subreddits may be skewed in their opinions since there are a lot of enthusiasts here.

I have multiple bikes... Only one with panniers though

I REALLY want a storage system that can hold my takeout without leaking or making a mess

No mention of electric assist. That makes a ton of difference in choice of storage solution and cargo capacity.

The solution should also be weather-proof

I love the idea of a bike trailer that is designed to be detached and easily transported like a piece of carry on luggage or something

Do you have any additional comments or suggestions about bike storage solutions?

9 responses

No mention of electric assist. That makes a ton of difference in choice of storage solution and cargo capacity.

The solution should also be weather-proof

I love the idea of a bike trailer that is designed to be detached and easily transported like a piece of carry on luggage or something

Looking at the CAD model it looks like the bike caddy is mounted to an existing bike rack. I think it would be better if it attached directly to the bike frame where the seat post is (not on the seat post if possible because some people ride with their seat all the way down). For the wheels I would suggest using wheels size similar to the wheels on children bike trailers so better stability and handling. Depending on what the weight capacity is going to be I suggest adding a brake to the trailer if possible (50lb+) as not all bikes have good breaking and the additional weight will put more strain on the existing brakes (least important thing I would add). It would also be cool to have an optional wire basket attachment so that smaller items do not get lost while biking.

something like the big bags doordashers use would be cool