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Smart Bike Rack

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ENTITLED

SMART BIKE RACK

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

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Abstract

With more and more people turning to bicycles as their main method of transportation every year, bike theft has become a pressing problem all around the world. Every year, millions of bicycles are stolen due to how ineffective current locking mechanisms are at protecting all the main components of a bike. Furthermore, the inefficiency of these locking mechanisms and the fear of bike theft continues to discourage potential users from buying a bike and using it to commute on a daily basis. Our team constructed a proof of concept for an automatic Smart Bike Rack which employs a three-point locking mechanism, ensuring that a user wastes the least amount of time and energy securing the bike as well as protecting it from theft entirely.

Acknowledgements

We would like to thank Santa Clara University and the School of Engineering for providing all the resources and funding necessary for the successful completion of this project. We would also like to express our deepest gratitude to our advisor, Dr. Godfrey Mungal, for his guidance and continued support throughout the past year. Finally, we would like to thank Rod Broome for the countless hours he spent helping us in the machine shop, as well as Professor Tony Restivo for ensuring our team stayed on track throughout the academic year.

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Chapter 1: Introduction

When our team first got together to begin exploring what we wanted to build for our Senior Design Project, we all had different visions and ideas of what it would mean for the project to be a success. Nevertheless, it was of the utmost importance to all of us that our project would help solve a problem in the world today. Furthermore, we recognized that beyond building something innovative, it was important to make sure that our project could be marketable, and therefore potentially scalable. Instead of simply brainstorming ideas between the members of the team, this encouraged us to pay closer attention to the world around us, and first find an issue that we could solve.

As more and more people look for environmentally friendly ways of transport every year, and given that during the COVID-19 pandemic many people started to look for ways of transport in which they could socially distance, we saw a lot of potential in the bicycle industry. We began to think that we could build something related to bikes that would encourage more people to use them as their main form of transportation, especially around a college campus. For weeks we struggled to decide what exactly we wanted to build, until one day we were walking around the Santa Clara Campus and saw a bike rack with one single bike wheel attached to it, as we can see in Figure 1.1 below.

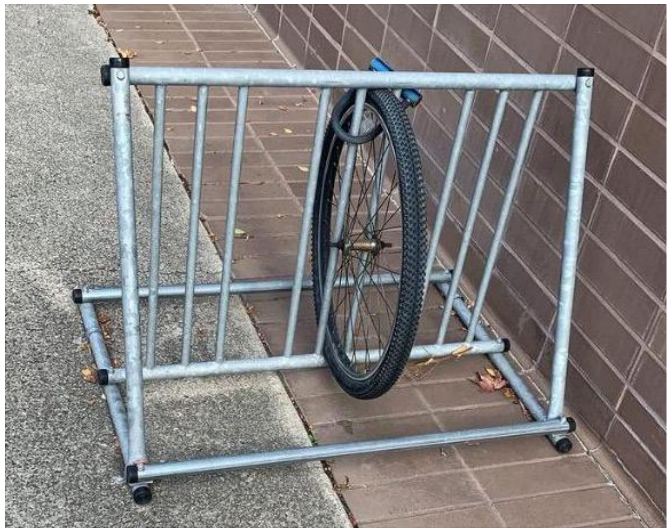


Figure 1.1: Bicycle theft at Santa Clara University

Our team then switched gears and began conducting research on the issue of bicycle security and theft. We came across the shocking statistic that every single year throughout North America, two million bikes are stolen [1]. This, along with further research which will be discussed more in detail, convinced our team that bicycle theft was a big issue around the world, one which our team became increasingly interested in solving. We concluded that our Senior Design project should be focused on constructing an innovative Smart Bike Rack, which is user-friendly and protects the entirety of your bicycle.

Chapter 2: Background Research

2.1 Why don't bike locks work?

The first step of our research process was to try and understand what exactly are the problems with common bike locking mechanisms available today, as they clearly do not protect enough bikes from theft. We came to the conclusion that there are three main issues:

1. Security
2. Efficiency
3. Space Optimization

The first and perhaps most important problem to highlight about bike locking mechanisms available today is that they are very insecure, and leave the entire bike or some of its components vulnerable to theft. Let us take some of the most commonly used bike locks, for example, such as a U-Lock or a Cable Lock. These are illustrated in Figure 2.1 below. A user can attach these to one or at most two components of the bike only, such as one of the wheels or the frame. This then means that almost all the time, two out of the three main components of the bicycle are vulnerable to theft. Bike theft is not just a problem because people steal bikes entirely, but also because they can easily steal a wheel or the frame if it is not secured with a separate lock.

Figure 2.1: Both a U-Lock and a Cable Lock in use

Secondly, the locks which people use on a day-to-day basis are extremely inefficient. What we mean by this is that not only does it take a user a long time to lock and unlock their bike, but it is also very hard to carry a large and heavy lock everywhere you go. Some of these locks also require keys, for example, which can also be easily lost or stolen. To use the U-Lock example once again, bike users would need to carry this big and heavy lock everywhere they go, lock and unlock their bike manually, and still hope that someone does not steal one of their wheels and the frame.

Last but not least, we believe that all of the bike locking mechanisms which people rely on today do not optimize space. It only takes a quick look around our college campus to realize that people park their bikes in all sorts of random locations, and even when there is a bike rack available people do not park their bike in a way which optimizes space. We believe that bike locking mechanisms and bike racks in particular should have a clear and consistent manner in which bike users can drop their bike off and get on with their day.

2.2 Scholarly Sources

If our team was to build a functional Smart Bike Rack, we wanted to make sure that it was as innovative as possible and incorporated the most useful features for bike riders. Through a lot of lengthy research, our team narrowed down five scholarly articles which discussed some of the challenges of Smart Bike systems today as well as detailed information about which problems could arise with our model or its subsystems. We were surprised to find that there is not much information about Smart Bike Racks since it is a very young market. Nevertheless, there is a lot of information about Smart Bike Systems, such as Citi Bikes or Lyft bikes, which encounter many of the same issues that we could potentially come across. A picture of a Citi Bike rack can be found below in Figure 2.2.

Figure 2.2: Citi Bike Rack

Two of the articles confirmed that the number of people using bikes as one of their main means of transportation is increasing exponentially, given that they are eco-friendly and also offer a way to stay socially distanced. Using bicycles in densely populated cities such as San Francisco, for example, also offers an easy way to stay active and avoid traffic congestions [2]. Having said this, Smart Bike systems are facing some challenges. The main one is that throughout big cities, there is an uneven distribution of bikes across stations, and it is hard to predict whether bikes will be available in a certain station at a certain time. In our case, it is reasonable to assume that if Smart Bike Racks were to be implemented throughout big cities or a college campus, for example, bike riders would find it useful to know which rack has spots available and which do not at any given moment. An app could be particularly useful in solving this problem. One of the two articles provides research and information on how one could forecast the demand for specific Bike Racks using data from bike sharing systems in Europe. This could be useful since we want our system to be as efficient as possible and have a quick turnaround time between users [3].

The rest of the articles were focused primarily on two topics which are vital for the success of the project: Efficiency and Security. In order for our bike rack to compete with current locking mechanisms and be marketable, our team had to ensure that it would be easier for people to use and also offer a lot more security than your regular bike lock. For this reason, our team began exploring a bike rack which could be opened with an app or the simple tap of a card. One article in particular discussed the security vulnerabilities of NFC (Near Field Communication) Technology [4]. If our bike rack was to ever incorporate an app in your phone as a way to lock and unlock your bike, we had to ensure that it would be as secure as possible. We then also conducted a lot more research into RFID technology, which is the technology used to open and unlock things with the tap of a card. We identified that this would be particularly useful on college campuses given that every student has an access card that they use daily. We also collected information on what a potential theft-control system would look like, as we understand that nothing is one hundred percent invulnerable to theft [5].

2.3 Interviews

One of the main reasons why our team decided to develop a product in the bicycle industry is because living around a college campus, we have seen how many people rely on bikes as their main source of transportation. This provided a particular opportunity to sit down with fellow students and conduct a series of interviews to understand whether or not there is a market for our product around college campuses. Each member of the team sat down with four students to conduct an interview, half of these students are current bike riders and half are not. This was important because we wanted to know if more people would start using a bike if there were Smart Bike Racks around campus.

Not surprisingly, all of the people we interviewed who currently ride bicycles confessed that at some point in time, they have been concerned that their bike would be stolen, even within the Santa Clara campus. Each shared their current locking mechanism of choice, and what they believe a newer and more modern solution should look like. When asked whether or not they would be willing to replace their current locks with an automated Smart Bike Racks, we got very positive feedback. Almost all of the students answered that they would prefer to use a Smart Bike Rack instead of being responsible for their own locks, which do not necessarily protect their bike.

Perhaps even more important than the bike rider's responses were those of the non-bike riders. One of the main objectives of this Smart Bike Rack would be to encourage more people to ride bikes without the fear that it will get stolen. Similarly to the bike users, the majority of this group told us that the main reasons they do not use a bike every day is because it can get stolen, but also because it is a problem to find somewhere to leave it and secure it. These are, of course, the problems which our project is attempting to solve. Furthermore, most of the non-bike users shared that if there was a more modern product which would guarantee less bike theft and more convenience for the user, they would strongly consider using a bike to move around.

After conducting all the interviews, our team came to the conclusion that a Smart Bike Rack would indeed solve a problem and could be marketable, especially around college campuses. Most importantly, these interviews helped to direct our team in our design efforts. While discussing all the results from the interviews, it was clear that the three key points which had to be fulfilled for our product to be successful were that it was effortless, fast, and reliable.

2.4 Competition

As with any successful endeavor, it is vital to understand the competition and what types of products may already be available in the market. The team was surprised but also excited to find that the Smart Bike Rack market is very young. Through all our preliminary research, we could only find one direct competitor to our product, an Estonian startup called Bikeep.

Figure 2.3: Bikeep Bike Rack

Throughout our analysis of Bikeep, we learned about some things which could be useful in a Smart Bike Rack but also many others which have much room for improvement. The first thing that drew our attention was that the Bikeep rack, once again, does not protect all of the components of the Smart Bike Rack. Figure 2.3 shows a picture of one of the latest Bikeep racks implemented in a BART station in San Francisco. As we can see, a bike user felt the need to secure their back tire and their bike's frame with a U-Lock and a cable lock even after using the Bikeep rack. This means that their product still leaves a part of the bike vulnerable to theft and is not much more useful than your typical bike lock.

Figure 2.4: Bikeep diagram

Furthermore, although it may be easier to use than other products available today, this bike rack still operates manually and requires the user to take time and energy to secure their bike. In order to secure their bike, one must pull down on the rack's green arm and find a spot which fits the bike properly, as seen above in Figure 2.4. Our team believes that there should be a more effortless and time efficient way to leave your bike and get on with your day. Last but not least, Bikeep requires a paid subscription to be able to use it. Most people are not willing to spend a lot of money on a subscription, and that is if they even want to take the time to create an account.

Bikeep does have a few features which are innovative and we would need to compete with. Because their model is operated manually, it ensures that any type of bike fits in the rack, no matter their shape or size. The Bikeep rack also acts as a charging station for people with e-bikes, which are being used more and more every year. They also incorporated an RFID scanner to be able to activate the rack, which is somewhat similar to our idea of students using their access card, for example. Our team wanted to ensure that our design was an upgrade from this product and is more secure and effortless for the user.

2.5 Target Demographic

As we moved forward with the project and began diving deeper into the design of our Smart Bike Rack, it was crucial to remember the target demographic for our product, so that it could be best suited for the people who are most likely to use it. It was evident for our team that the biggest market for our product would be college campuses all around the country, in which thousands of students rely on bikes to commute and move through campus every single day. This is especially true in schools with a large population, where classrooms are often very spread out.

A survey distributed among more than two thousand students in the University of California at Santa Barbara found that roughly 42% of students ride a bike regularly [6]. Not only are college students among those who use bikes the most, but they also provide the unique opportunity to build a bike rack which can be operated through their access card. Every student at a University around the country has a unique access card which allows them to pay for food, access their dorms, etc. This inspired our team to create a bike rack which may be locked and unlocked with an access card, making it desirable for colleges but also convenient for students.

It is also important for our team's target demographic to include the population of large urban areas or cities, such as San Francisco. Every year, more and more people decide to use a bike to get to work, for example. The COVID-19 pandemic also encouraged people in densely populated cities to ride a bike instead of taking buses or metros, which often get crowded. A study in New

York found that bike usage after the pandemic began in 2020 increased by 50% [7]. This also encouraged government officials to modify traffic patterns and open more miles of road to accommodate bikers. Furthermore, many cities in Europe currently beat the US when it comes to the percentage of people riding bikes. A study conducted in Amsterdam, also known as the bike capital of the world, found that its population of 811,000 owns approximately 881,000 bikes. Our product could be particularly useful in such places [8].

Chapter 3: Design Process

3.1 Design Criteria

With the design problem identified and the motivation to fill a gap in the market, our team switched gears into brainstorming potential solutions. The first step was to identify the most important features that we believed had the potential to make or break our product. We listed every criteria that we could think of, and ranked them in a list based on importance. See the table below.

Table 3.1: Bike Criteria

Metric #	Metric	Imp. (1 least - 5 most)	Units	Marginal Value	Ideal Value
1	Total mass (per dock)	2	lbs.	<50	~30
2	Unit manufacturing cost	3	USD	<50	~20 per dock
3	Time to lock	5	seconds	<60	~20
4	Time to unlock	4	seconds	<45	~15
5	Corrosion resistant	5	subj.		
6	Water resistant	5	subj.		
7	Lock cycles until failure	4	cycles	>100,000	>1,000,000
8	Lock bar hardness	5	N/mm^2	>700	>1000
9	Durability of internal electronics	5	subj.		
10	Lock pull resistance	5	tons	>2	>6
11	Bike rack is visually appealing	3	subj.		
12	Space efficiency of rack	3	bikes/ 5ft^2	1.5	2
13	Bike rack is capable of storing many different models and frame sizes	5	Y/N	Y	Y
1	Maintenance cost	5	USD	$50/year	0$/year
15	Time to construct	3	Hours	10 hours	5 hours
16	Backup unlocking mechanism	3	Y/N	N	Y
17	Time to Learn to use	3	Seconds	120 seconds	60 seconds

We boiled the most important features down into a few main categories. These were: Ease of use, Security, Durability, and Compatibility. Ease of use includes things such as being able to understand how the bike rack functions with little or no instruction and how quickly and easily a user is able to lock and unlock their bike once they understand how to use the bike rack. Security includes locking all components of the bike. As was mentioned before, it is common for one or two parts of the bike to be stolen and the rest left behind. It was very important to us to make sure that we locked all the components of the bike securely, we believed this would give us an edge over what exists already on the market. Durability is important for a few reasons; no one wants to invest money into something that degrades or depreciates quickly. Potential customers would be organizations looking to make a large investment in improving the quality of transportation for their employees/students. Therefore it is critical that they will feel that their investment will last for a long time and be worth the initial cost. Finally, compatibility is crucial to the functionality of this product. If users are unable to use the bike rack with their bike it is useless to them. It is of high priority to ensure that a wide range of bicycles are compatible with our Smart Bike Rack. Each of these categories being important in their own right, we made sure to prioritize them in different ways when generating our concepts. Now that our priorities were made clear we could get to the drawing board and begin to generate potential concepts and solutions.

3.2: Chain Design

The first design that we generated is called the chain design due to the prominent chains that extend from either side of the bike rack. A preliminary sketch is shown below in Figure 3.1. The

Figure 3.1: Chain Design

user process for the chain design would be something like the following: A user walks up to the bike rack, leans their bike against the side of the frame, taps their card on the RFID scanner to register the rack, then finally weaves the chains through the tires as they please and then pulls the locking bar down through the chains to lock the entire system. The chain design has a few crucial weaknesses that disqualified it from being further developed. The ease of use of the chain design is far too cumbersome to be practical for a “Smart Bike Rack”. As ease of use is one of our top priorities we could not justify the extra difficulty of the locking process. The process of locking the bike is virtually the same as a U-lock, if not more tedious. However, the chain design has the best compatibility of any of the designs we generated, able to lock virtually any shape or size of bicycle. Eventually we decided that the aesthetic of the chains and the difficulty of using this design were enough to give grounds for moving on beyond this design.

3.3: Y-Bar Design

The next concept that we generated was dubbed the Y-Bar design due to the Y shaped locking bar and frame. See **Figure 3.2** below for a preliminary sketch of the Y-Bar Design.

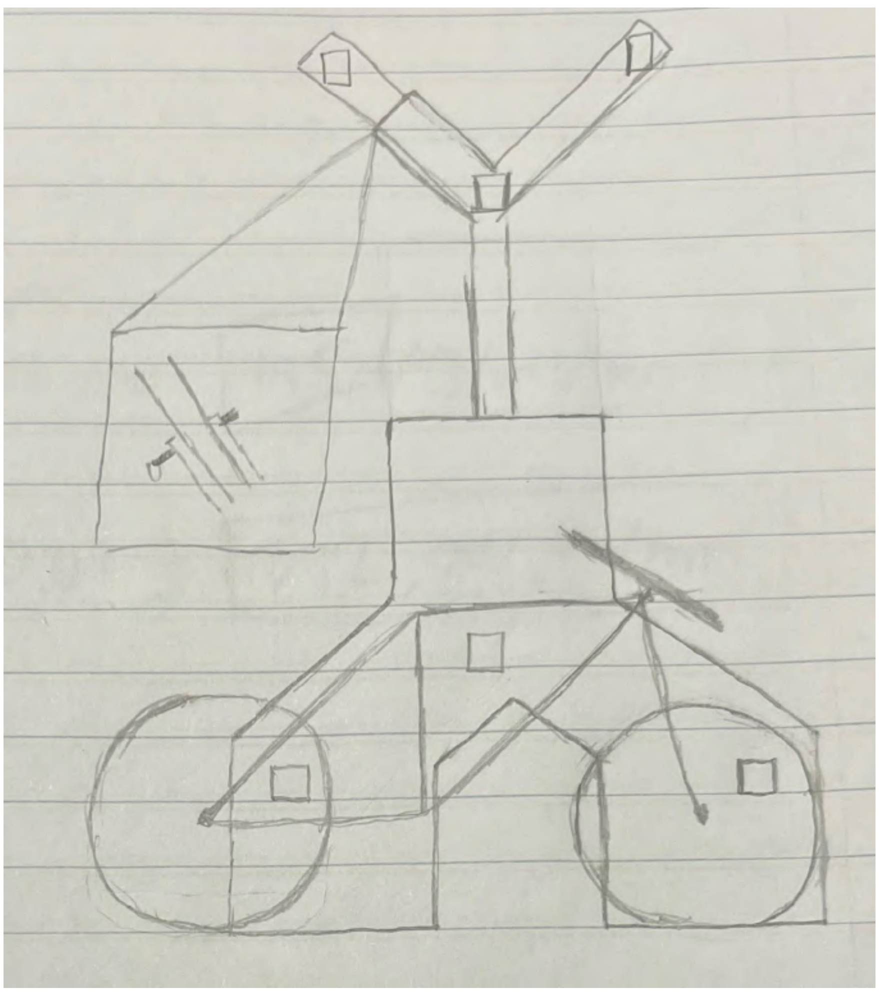


Figure 3.2: Y-Bar Design

The Y-Bar design incorporates the same style of locking bar that was featured in the chain design, except here it is extended in a Y shape to accommodate the rear wheel of the bicycle. The rear portion of the locking bar is a telescoping sliding bar that can be locked into different positions to fit different sizes of bicycles. A user locking their bike with this bike rack would follow a process that looks something like this: the user walks up to the bike rack, aligns their bike with the locking bar and locking points, adjusting the telescoping bar if need be, taps their card and pulls the locking arm down into position. We felt that the ease of use with this design was greatly improved over the Chain Design, but were still able to identify some problems that hindered the feasibility of this design. The process of making sure that everything is aligned and that the path of the locking bar is free of spokes and other small obstructions is still rather annoying from the perspective of a user. Additionally, this design is rather large, occupying a fair bit of space. This could prove to be a potential problem when implementing large scale bike rack systems. We also did not like that this design was very similar to bikeep's smart bike rack, we ideally wanted to create something new and innovative that could disrupt the existing market.

3.4: Track Design

The next design that we generated was the track design, named so because of the track style of rolling a bike in and out of this bike rack. See Figure 3.3 below for a preliminary sketch of the Track Design.

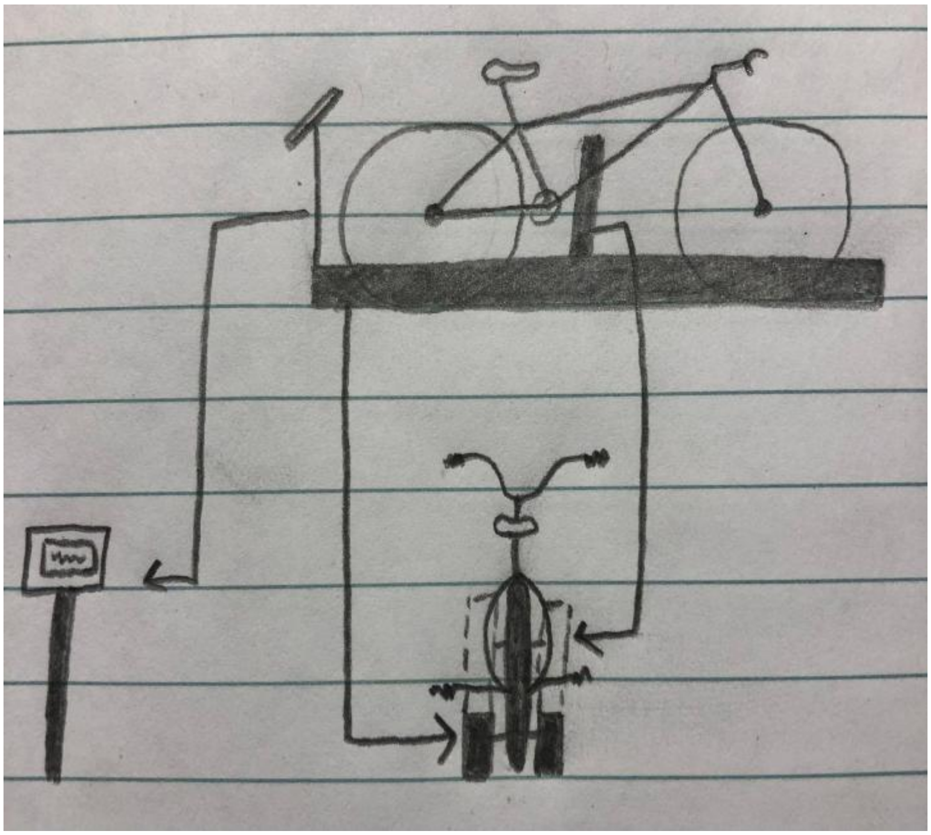


Figure 3.3: Track Design

The track design differs significantly from our previous designs and the other options currently available on the market. It does not feature a locking bar which swings down through the bike. Instead the idea behind this design is that linear actuators can be programmed to extend through each of the three critical sections of the bike, the front and rear wheels and the frame. The actuators would extend from one side of the frame of the rack, through the bike and back into the other side of the rack. The biggest strength of the track design is the ease of use for the end user. In order to use this design, all a user would need to do is, walk up to the bike rack, slide their bike into the design, tap their card, and that's all. After the user taps their card on the RFID scanner, the bike rack would initiate a locking sequence in which all three of the linear actuators would extend to lock the bike.

3.5 Concept Selection

At this stage we felt that we had explored a large range of ideas and concepts that were potentially viable solutions. Now we had to narrow the choices down, refine our ideas, and move forward with testing and prototyping. To do this to the best of our capabilities, we decided to once again create metrics by which we could objectively rank our designs. Some of these metrics are of course more important than others and that was taken into account when making our final decisions. See Table 3.2 below for the metrics that were used to rank the designs.

Table 3.2: Concept Selection Table

Criteria (score 1-5), 5 being optimal	Y-Bar	Chain	Track
Simplicity	4	3	5
Ease of Use	4	2	5
User time	4	2	5
Manufacturability	3	5	4
Durability	3	4	3
Cost	4	5	3
Total Score	22	21	25
Rank (1-3)	2	3	1
Continue?	No	No	Yes

These metrics were chosen based on the most important factors that we identified earlier in our criteria selection process. Simplicity, ease of use, and user time all fall under the broader category of the user experience, which is the most important for us to be able to demonstrate in order to prove the feasibility of our design. Durability includes things such as resistance to weather and how long our product would be able to last under normal operating conditions. This is a very important consideration for a final market ready mass production product, but not as important for concept demonstration and prototyping purposes. Finally manufacturability and cost are important considerations when thinking about a potential business model, as it is very important to be able to manufacture large quantities affordably to operate a viable bike rack business. Additionally, these metrics are also important in the prototyping process as it is much more difficult for us as students to machine large and bulky designs than slimmer and more manageable ones.

With all of these metrics defined, we ranked each of our concepts accordingly. From this we were able to decide that the track design featured the best combination of strengths and weaknesses suited to our goals. It has the best user experience, with the least amount of work required by the end user, and its machining process would also not be excessively cumbersome for students to undertake. For these reasons it was decided that we would be moving forward with the track design, investing all of our future efforts into refining the design and creating different degrees of functional prototypes.

3.6: Concept Refinement and Preliminary Prototypes

After selecting and deciding to move forward with our track design, we began to spend our time further fleshing out the small details and nuances required of transitioning from the conceptual stage to a physical model. Spending more time doing this, we already discovered a few issues which could prove to be problems if left unaddressed. The first things we determined that needed changing were rather simple such as the location of the card scanner, or realizing we would need more space to house the linear actuators and electronics. But then we soon discovered a few issues which would require more creative solutions.

These issues were identified and labeled as such: the pedal problem, the bike obstruction problem, and the spoke problem. The pedal problem is an issue of how the bike's pedals are geared to the wheels. If a bike user rolls a bike forwards the pedals remain stationary, but if they move the bike backwards the pedals will begin to rotate. This worried us as it could prevent users from easily removing their bikes from the bike rack. The bike obstruction problem is a problem involving the frame of the bicycle, including the handlebars and pedals of the bike, being prevented from being properly inserted into the bike rack due to a physical obstruction. This issue has a large scope, and would need to be reevaluated with any changes to the dimensions of the Smart Bike Rack. The first physical obstruction issue that we came across was with the part of the frame of the bike rack that extends upwards to provide a housing for the linear actuator that locks the frame of the bike rack.

See Figure 3.4 for an image of this piece of the frame.

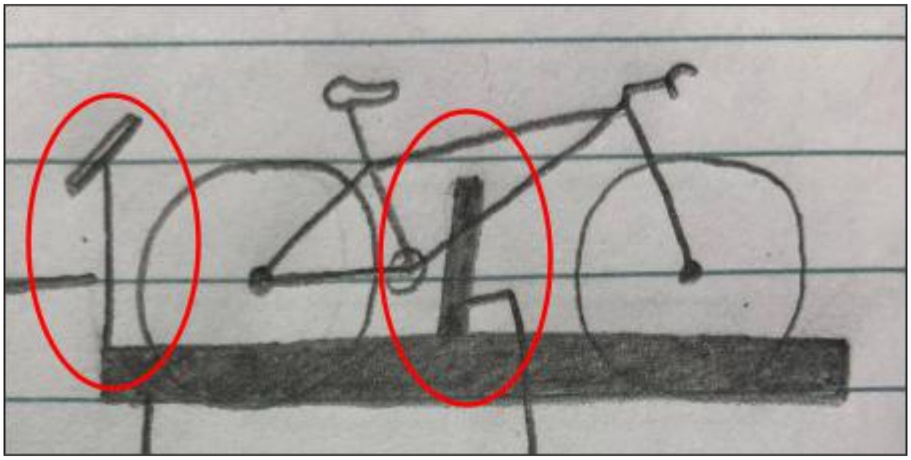


Figure 3.4: Track Design Initial Concept

Our solution to this problem was to tilt this piece of the frame, that way we could provide a much larger amount of clearance for bike pedals to pass through. Figure 3.5 provides an image of the revised design.

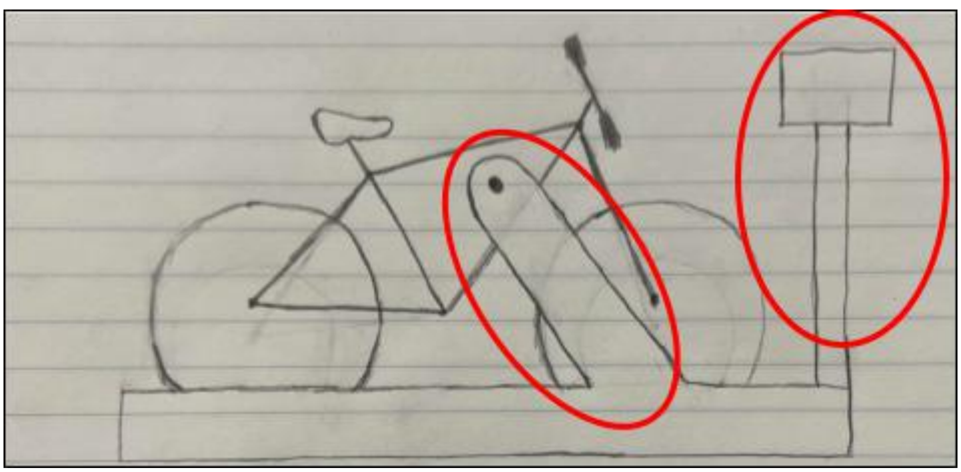


Figure 3.5: Track Design Refined Concept

A similar problem occurred with the location of the RFID scanner, but the solution was much simpler and can also be seen in Figure 3.4 and 3.5.

The spoke problem is the last of the potentially significant issues that we discovered at this stage. It is the problem of the linear actuators contacting a spoke when extending to lock the wheels. We solved this problem with the implementation of two systems that will be further discussed in Chapters 6.2 and 7. Very briefly they are the actuator automatic retraction system to retract the actuators if too much force was detected, and the plastic tips placed on the actuator rods to reduce the likelihood of contact with a spoke.

With these problems identified and preliminary measures taken to reduce the magnitude of them, we moved on to creating our first physical prototype. We discussed a few ideas for what to build our first prototype from, but decided on foam core purely due to the ease of construction. This prototype would not have any functional parts and its purpose would be to merely serve as a real sized physical model that can be used for measurements and obstruction testing. After taking a few measurements on some old bicycles, we very roughly created dimensions and proportions by which to construct this prototype.

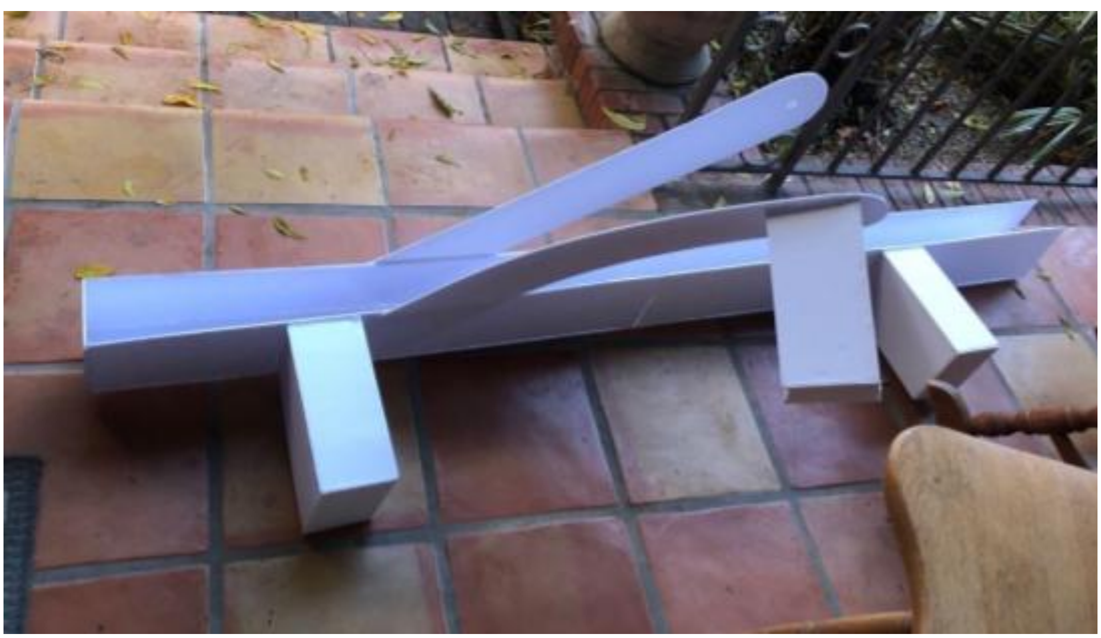


Figure 3.6: FoamCore Prototype

Chapter 4: CAD Models

4.1: Preliminary Design

Drafting the first CAD model started by acquiring dimensions needed for our rack design. Our rack is intended to be used by most bicycles found on the road, though primarily by commuters who typically use a commuter bike, cruiser, or mountain bike design. To achieve the correct functional dimensions to accommodate most bike sizes, our team visited a local bike shop to obtain a multitude of measurements necessary for 6 different bike types and sizes. Figure 4.1 best illustrates the specific measurements we were acquiring and Table 4.1 displays the range of measurements we obtained for each dimension.

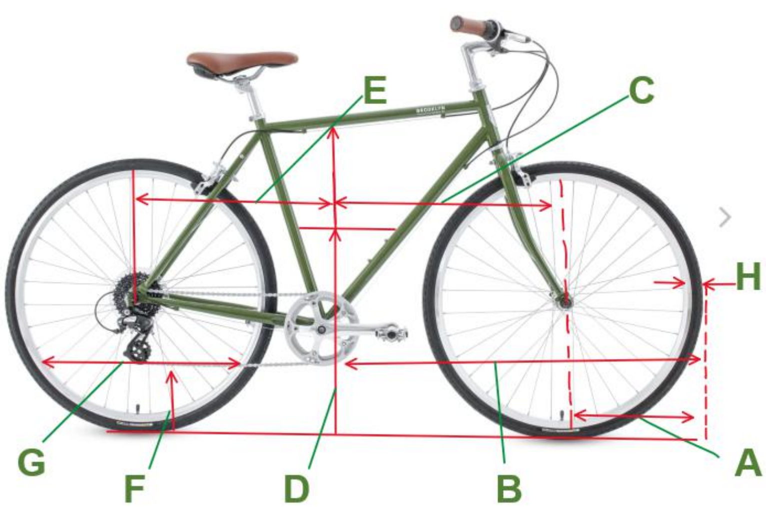


Figure 4.1: Bike Measurements Diagram

Table 4.1: Bike Measurement Data

Measurements	A	B	C	D	E	F	G	H	Total length
Minimum (in)	11.50	31.50	20.00	18.00	18.00	5.50	19.50	2.00	62.99
Maximum (in)	14.50	41.50	27.00	24.63	24.00	9.00	22.50	3.00	75.00
Average (in)	12.96	35.82	22.86	22.01	20.32	7.14	20.77	2.70	69.09

Creating the CAD models on Solidworks was helpful in order to realize any physical issues with our design. The first change that was made from the original sketches was to angle the arms that come up to lock the frame. This was done in order to allow the pedals more room so that they do not interfere with the frame. Another realization that was made was that the user would need to be able to continue to hold their bike as it locks. Since the tracks are unable to be tight on the wheels in order to accommodate different sized bikes. The original design had the RFID scanner area towards the back wheel of the bike which would in practice make it very awkward to use without having the bike tip over as you walk over to lock the bike. With the design shown in Figures 4.2 and 4.3, the RFID scanner has been moved to the front side of the bike in order for the user to hold the handlebars as they walk their bike into the track, and continue holding the handlebars as they tap their card in order to lock the bike in place. After creating the detailed CAD designs, Solidworks drawings were created as well (Figures 4.4 and 4.5) in order to have more technical drawings to base the mockup and first prototype off of.

After much discussion over material choice and the fabrication process, the prototype was determined to be constructed from 80/20 Aluminum . Therefore, an additional CAD model of our prototype design needed to be constructed and implemented for physical assembly. However, due to its sleek nature with curved edges and enclosed spaces, the preliminary design will serve as an idealistic model for a production model. The frame will feature welded joints and be constructed from galvanized steel.

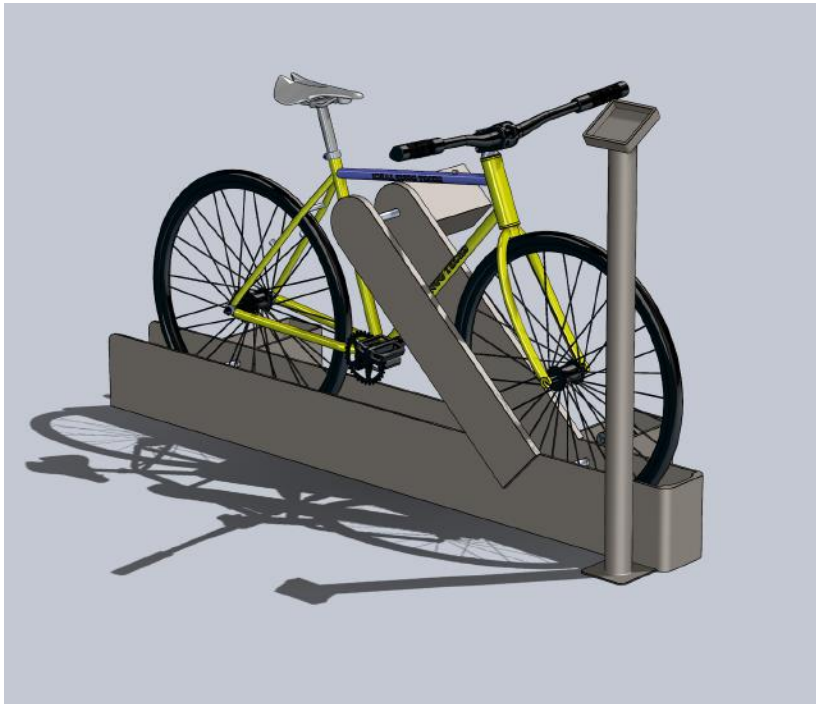


Figure 4.2: CAD Model - Front View

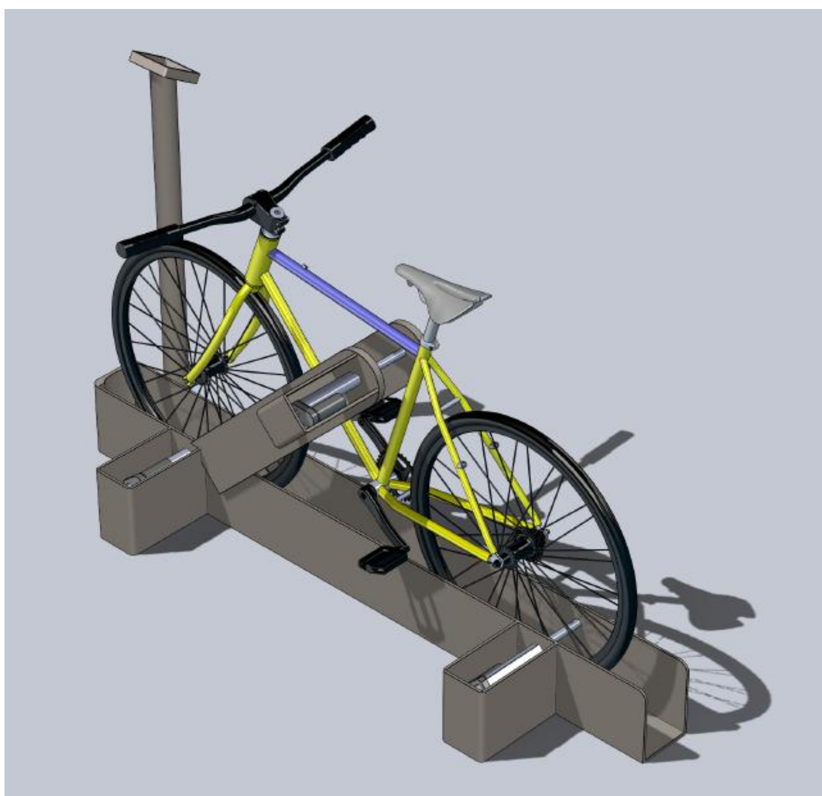


Figure 4.3: CAD Model - Rear View

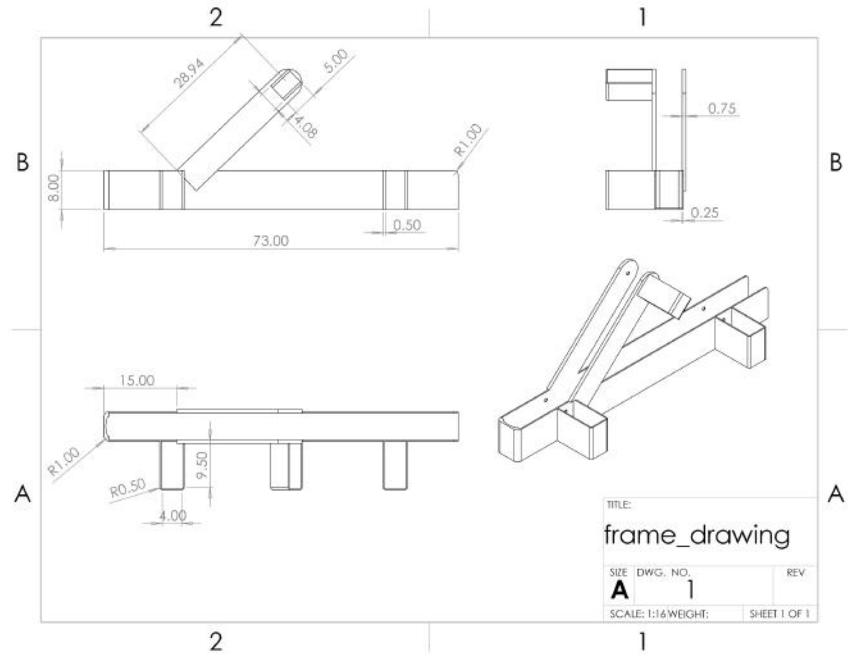


Figure 4.4: CAD Model Drawings - Frame

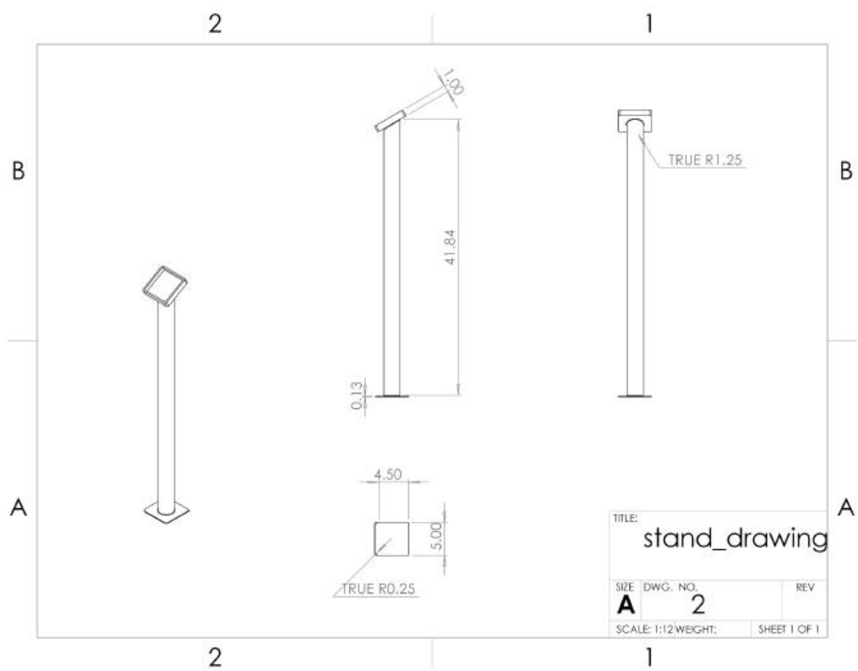


Figure 4.5: CAD Model Drawings - Stand

4.2: Prototype Model

The CAD model for our prototype, completely constructed of 80/20 materials, is depicted in Figure 4.6 below. The prototype version seeks to accomplish the most significant features of our Smart Bike Rack design. Namely, the prototype design will have a 3-point locking mechanism, the same dimensions as the preliminary model, RFID user interface, safety features for mitigating damage to bikes and harm to users. On the other hand, since the material and fabrication process differs immensely from the production model, the prototype will lack in strength characteristics and also is susceptible to tampering due to the modular nature of 80/20 materials. The primary goal of the prototype model is to serve as a proof of concept of the listed features above. These features, especially the 3-point locking mechanism, are the primary objectives of what will make this product unique, convenient, and more effective than any competitors.

Figure 4.6: Prototype Model of Smart Bike Rack

4.3: Material Selection

When designing the preliminary model, our team selected 1020 sheet steel as the material to construct our rack. This material was arbitrarily chosen due to our familiarity with its strength properties. After much deliberation, we realized that machining and welding sheet steel was beyond the scope of our project and capabilities, especially where the limiting factor was our budget. For FEA studies, we used 1020 steel. However, when we began designing our prototype, we deemed 80/20 aluminum (Figure 4.6) to be best suited for our purposes due its great modularity and machinability.

Figure 4.6: 80/20 Aluminum

After completion of our prototype model, we revisited the preliminary design and claimed it as our ideal production model. Upon further research, we have selected galvanized tube steel as the right material for the production model application. Galvanized tube steel is commonly used for public bike racks due to its high corrosion resistance and high strength. The tube-shape is ideal for increasing the moment of inertia for the material making it harder to bend and resists any forceful tampering with our bike rack.

Chapter 5: Finite Element Analysis and Theft Protection

5.1 Bike Theft

In order to defend against bike thieves it is important to understand the modality by which they commit these thefts. Most bike thieves are known as “opportunistic thieves”. They will look for the most poorly secured bike they can find and attempt to steal that bike typically even if it is of lesser value than another bike. This highlights the fact that it is not necessary to defend against all possible types of attacks, but only necessary to ensure that the bike is secure enough to dissuade potential thieves from attempting to steal it.

The choice of tool for any given bike thief varies depending on their experience and preferred victims. Some tools, such as portable grinders are essentially impossible to defend against as they can cut through any feasibly applicable metal relatively quickly. The time to cut through a material can be increased by increasing thickness and strength of the material, but this can typically only add a few minutes to the cutting time. Other tools such as bolt cutters and hacksaws can be defended against simply by using a stronger material like hardened steel. In an environment such as a college campus, which is the main market focus for our product, it would be unlikely for someone to get away with using a portable grinder before being spotted and having the relevant authorities alerted.

5.2 Critical Subsystems for FEA Analysis

Frame Arm

The first critical subsystem we have decided to analyze are the frame arms used for supporting the frame locking mechanism, depicted in Figure 5.1. This subsystem is attached to the overall frame via welds to the base track, and one of the arms includes a housing for the linear actuator that locks the frame. The arms were modeled to have the middle length offset from the bottom welded portion and locking end. This is detailed in Figure 5.2, where several bends in the arm are created to allow for this offset, which is intended to allow bikes with large fork widths to fit through the track. During typical use, these arms are responsible for supporting the weight of a leaning bike, as well as the weight of one linear actuator. Originally, we had decided to make our frame out of some type of steel, so we have selected AISI 1018 steel for use in the bending calculations and FEA.

Due to the length of this particular subsystem, bending is our biggest concern. We need to make sure that someone would not be able to bend the arms enough to the point where the actuator is released and the bike's frame can be taken out. Therefore, our FEA's simulate the force that a person could apply between the arms to try and bend them apart. We have conducted two sets of calculations for observing the bending the arms undergo. The first is applying an arbitrary force we consider an average human being can maximally apply– approximately 200 N– to the arms to force them apart. The second is computing how much force is needed to deflect the arms 0.25 in, which is the displacement needed to dislodge the locking cylinder from its path and potentially unlock the bike. In summary, we are defining failure of this subsystem as deflection of the arm by 0.25 in, where the locking mechanism would then be exposed and compromised.

Figure 5.1: *Smart Bike Rack Arm*

Case 1: Known Applied Force

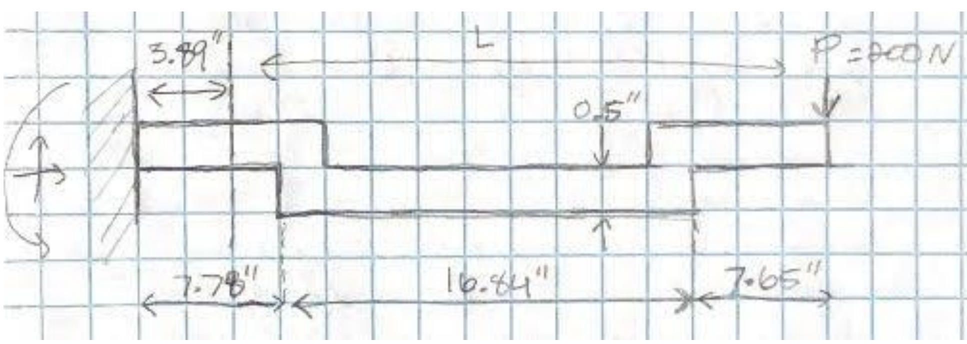


Figure 5.2: *Arm Free Body Diagram*

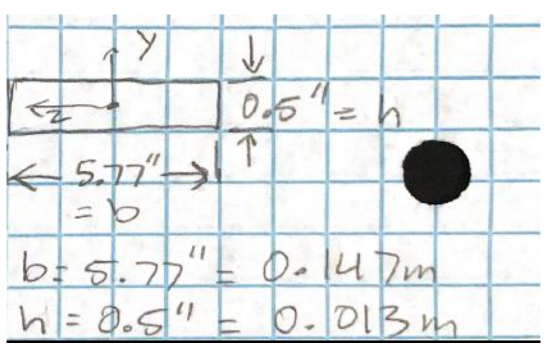


Figure 5.3: *Arm Cross-Section*

Length of Arm L, Moment M, Moment of Inertia I, Distance from Neutral Axis y

Stress σ, Factor of Safety n, Deflection δ, Force $P = 200\ N$

$$L = 7.65" + 16.84" + \frac{1}{2} * 7.78" = 28.38" = 0.721\ m \quad (1)$$

$$M = P * L = 200\ N * 0.721\ m = 144.2\ N \bullet m \quad (2)$$

$$I = \frac{1}{12} * b * h^3 = \frac{1}{12}(0.147\ m) * (0.013\ m)^3 = 2.69 \times 10^{-8}\ m^4 \quad (3)$$

$$y = \frac{h}{2} = \frac{0.013\ m}{2} = 0.0065\ m \quad (4)$$

$$\sigma_{bend} = \frac{M*y}{I} = \frac{(144.2\ Nm)*(0.0065m)}{2.69\times10^{-8}} = 34.83\ \text{MPa} \quad (5)$$

$$\sigma_y = 370\ MPa \quad (6)$$

$$n_{y,fs} = \frac{\sigma_y}{\sigma_{bend}} = \frac{370\ MPa}{34.83\ MPa} = 10.6 \quad (7)$$

For AISI 1018 Steel: E = 29,700 ksi = 205 GPa

$$\delta = \frac{PL^3}{3EI} = 0.0045\ \text{m} = 4.53\ \text{mm} = 0.18\ \text{in} \quad (8)$$

For the known applied force of 200 N, the critical point observed was the point of the arm slightly exposed over the edge of the track of which it is welded to. This exposed edge is seen as a vulnerable point since it is one of the furthest points from the applied force that is not welded to the track. The max bending stress was determined to be 34.83 MPa. Since steel has a yield strength of 370 MPa, the factor of safety was calculated to be 10.6, indicating that the arm is well within the limits of its strength and will have negligible plastic deformation when a human pulls on it.

Case 2: Known Deflection, Unknown Force Calculations

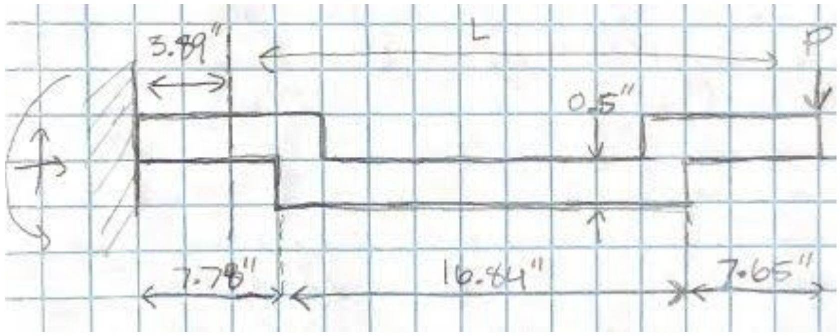


Figure 5.4: Arm Free Body Diagram

Maximum tolerable deflection δ_m= 0.25 in = 6.35 mm

Length of arm L = 0.721 m

For AISI 1018 Steel: E = 29,700 ksi = 205 GPa

$$\delta_m = \frac{PL^3}{3EI} = 6.35\ mm \quad (9)$$

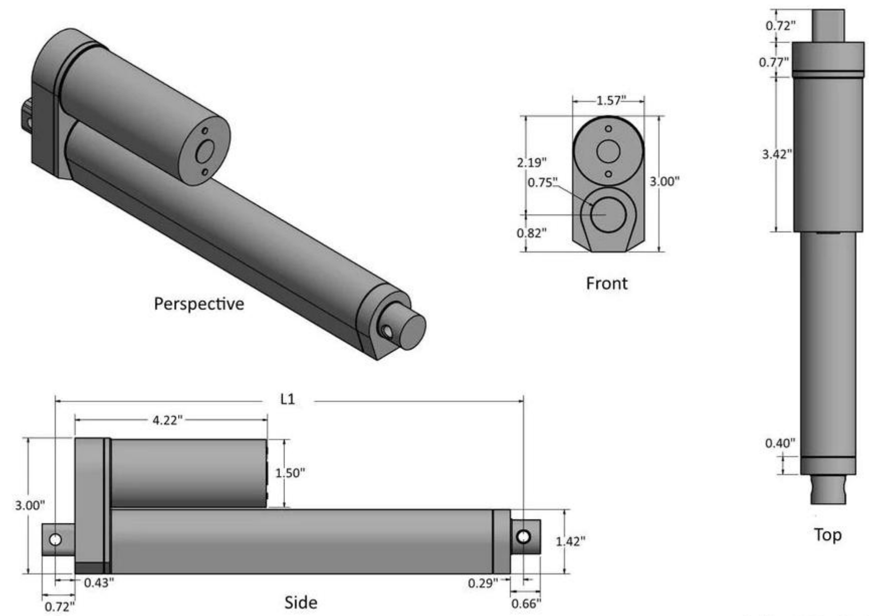
$$I = \frac{bh^3}{12} = 2.69 \times 10^{-8}\ m^4 \quad (10)$$

$$P = \frac{3EI\delta_m}{L^3} = 280.28\ \text{N} \quad (11)$$

To deflect the arm by 0.25 in (6.35 mm), a thief must apply a force of 280 N or 63 lbf. This indicates that a thief with slightly above average levels of strength can pull back the arms to expose the locking mechanism. This raises concern with our current sheet metal design. Although the steel of the arm remains intact and undamaged, theft may be possible. We will explore options to increase bending resistance as well as safely securing the locking mechanism rod in its path so that it cannot be exposed if the arms are bent. One possible solution to this problem is the use of steel tubing for frame construction. Steel tubing is relatively inexpensive and the circular cross section provides a much greater resistance to bending than sheet steel. A frame design composed of steel tubing would be much less susceptible to failure in this manner.

Actuator Rod

Another subsystem which we have deemed necessary to analyze is the linear actuator, particularly the rod which will be pushed through the rack in order to secure both wheels and the frame. As mentioned before, security is of the utmost importance, and for someone to steal any of the bike components they would most likely have to damage these actuators. The actuators we bought are made out of aluminum, and the majority of our tests have been done to check its ability to withstand bending and shearing. Bending could happen when someone tries to pull on the rod to deform it, while shearing would happen in an instance where someone tries to cut a part of the rod, for example. Figure 5.5 below depicts the actuator unit used. Apart from checking for bending and shearing of the aluminum rod, we have also made sure that once it pushes through, the rod is locked securely enough so that it cannot be pulled back horizontally. Our original design was to use the actuator's rod as the mechanism to secure the bike. Having said this, if the calculations reveal that it cannot withstand certain loads we may need to explore additional options, for example using the actuator to push a stronger rod made out of something like steel.



Stroke Length	1"	2"	3"	4"	6"	9"	12"	18"	24"
L1	5.50"	6.50"	7.50"	8.50"	10.50"	13.50"	16.50"	22.50"	28.50"

FA-35-S-12-X
FA-150-S-12-X
FA-240-S-12-X

Figure 5.5: Linear Actuator used (6in)

Calculations

$$\sigma_{bend} = \frac{Mc}{I} \quad (12)$$

$$\tau_{shear} = \frac{F}{A} \quad (13)$$

Length of rod, $l = 6\ in,\ 152.4\ mm$

Diameter of rod, $d = 0.75,\ 19.05\ mm$

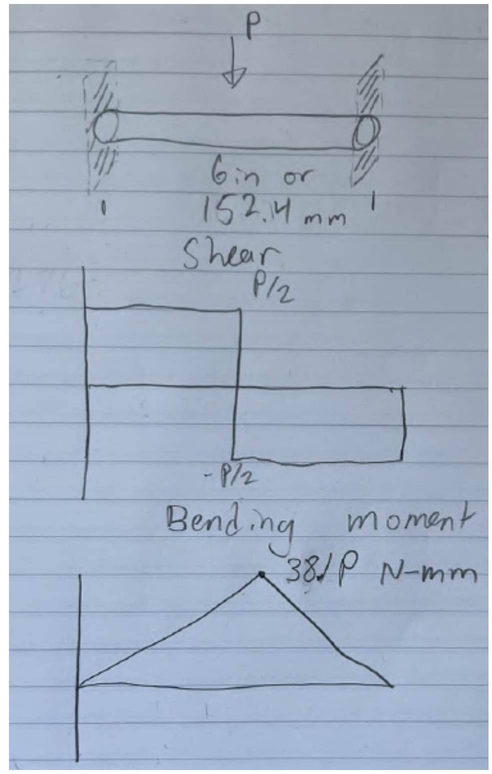


Figure 5.6: Shear and Bending Diagrams

$$A = \frac{\pi d^2}{4} = 285.0\ mm^2 \quad (14)$$

$$\tau_s = \sigma_y = 276\ MPa \quad (15)$$

$$\Rightarrow F = 276\ MPa * 285\ mm^2 = 78.66\ \text{kN} \quad (16)$$

$$M = \frac{F}{2} * \frac{l}{2} = 38.1F\ Nmm \quad (17)$$

$$c = d/2 = 9.525\ mm \quad (18)$$

$$I = \frac{\pi d^4}{64} = 6465\ mm^4 \quad (19)$$

$$\sigma_b = \sigma_y = 276\ MPa = \frac{38.1F*9.525}{6465} \quad (20)$$

$$\Rightarrow F = 4.917\ \text{kN} \quad (21)$$

These calculations indicate that a force of about 80 kilonewtons would be required to shear the actuator rod, and a force of about 5 kilonewtons would be required to break the actuator rod via bending. It is important to note that the rod of the actuator when housed will be supported at both ends by the walls of the track channel.

5.3 Solidworks Finite Element Analysis

For the FEA done on Solidworks, we first wanted to verify that we can match results determined by our hand calculations. The two parts of the rack that are the most vulnerable are the arms that lock the frame of the bike, and the actuator rod itself. When beginning work on the hand calculations, we found that the added bend in the arms made it a bit more complex to analyze the stresses in the steel. Because of this, we wanted to leave it to the Solidworks FEA analysis. To verify that we could produce hand calculations that were similar to what Solidworks would show us, we created simplified versions of the arms in order to analyze the way we've learned in previous classes (Figure 5.7). When running the Solidworks FEA on the simplified subsystems as seen in the figures below, we were able to obtain results that were close enough to our hand calculations that we could be confident when running the more complex FEA with Solidworks.

Once we felt confident with our results after comparing the hand calculations and the Solidworks FEA, we ran the FEA on the full complex model with the added bends. The forces we added were on both arms, pushing them out from the track with 200N on each side. As seen in the Figure 5.8 below, the majority of the stress is on the lowermost bend in the arms and on average is about 23.8 MPa.

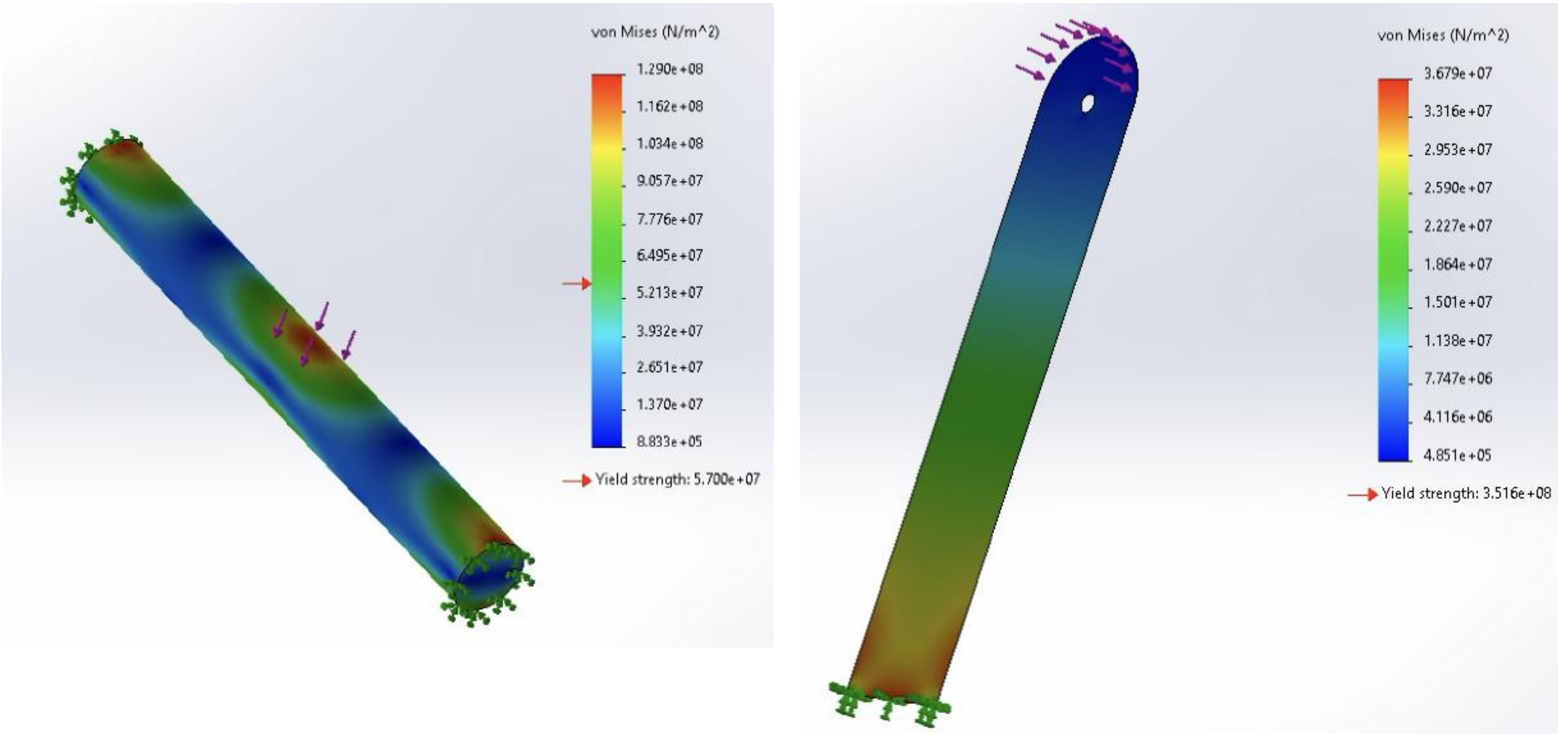


Figure 5.7: *Simplified FEA Models*

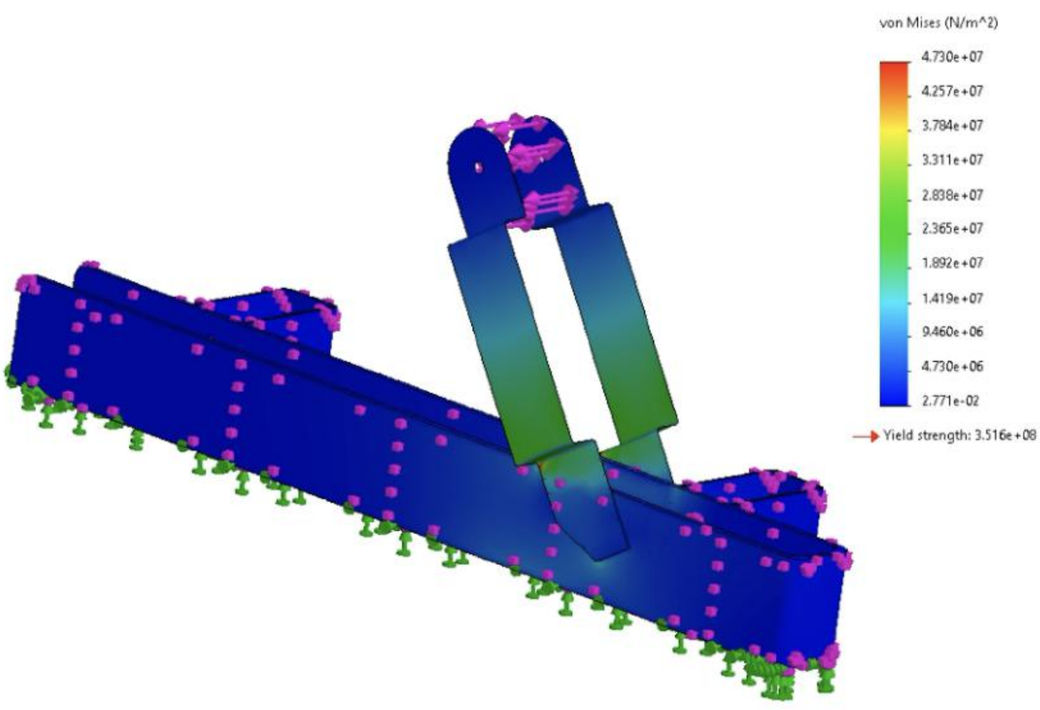


Figure 5.8: *Full Model FEA*

5.4 Analysis

For the locking arms, the FEA and hand calculations complemented each other well. At our determined critical point, the bending stress was 34.83 MPa. For the FEA on the simplified model the maximum stress was found to be 36.7 MPa; the full model FEA had a max stress of 47.3 MPa, but that stress was distributed onto the track walls as well. In general, the stress values from analysis and calculations were in the same ballpark and of the same magnitude, and all were lower than the material's yield strength. However, the deflection is significant enough to allow theft or damage of the locking mechanism.

Based on the results of these calculations, we determined that the actuator rod is more susceptible to breaking from a bending force than a shear force. This is acceptable as the one of the most common thief tools is the bolt cutter, which produces a shear force. Thieves, in general, are much less capable of producing bending forces than they are of producing shear forces. A typical bolt cutter is capable of exerting about 20 kilonewtons of shear force, this would give a factor of safety of about 4.

<u>**Chapter 6: Manufacturing Processes**</u>

6.1 Metal Fabrication

The first part of our metal fabrication started with the completion of our prototype CAD model. The prototype was created using a specific 80/20 Solidworks toolbox that allowed us to obtain the dimensions and components from our model and export them to a shopping cart on 80/20's website. From there, we ordered all of our 80/20 components cut to specifications. When the shipment arrived, our team assembled the entire rack by hand using allen wrenches in a span of 2 hours. The bare rack assembly is depicted in Figure 6.1 below.

Figure 6.1: Complete Bike Rack Assembly Frame

Further machining was conducted on the 80/20 rails to mount our linear actuators for our locking system. On the side of the rack where the linear actuators were mounted, the rails were milled with through-holes at the exact location where the actuator pistons would protrude from. On the other side of the rack, where the pistons would secure at the end of their locking cycle, the rails were milled to have holes of the same diameter but only 0.75” of depth so that the pistons could not be tampered with while they were resting in their locked position.

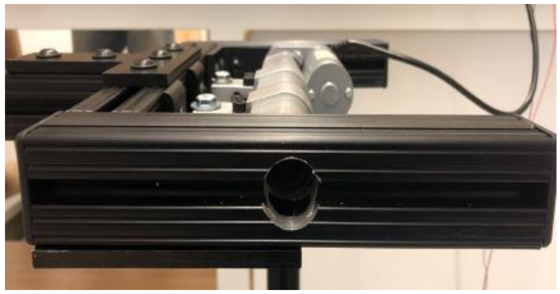


Figure 6.2: Linear Actuator Rails Through-Hole

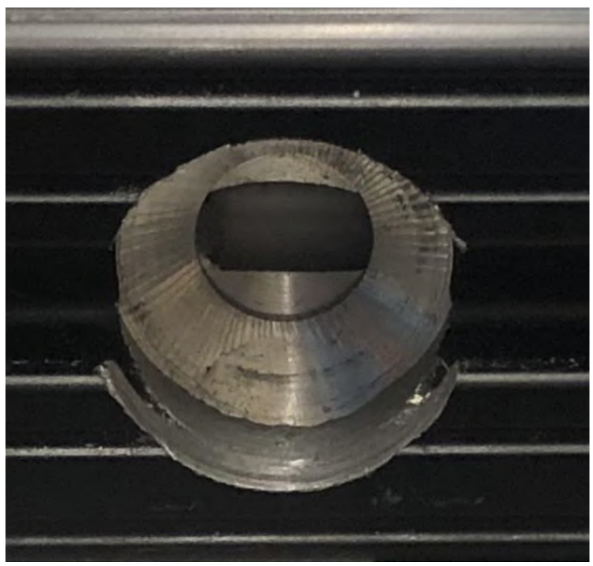


Figure 6.3: Locking Hole for Pistons

6.2 Plastic Components Fabrication

The linear actuators are built with cylindrical pistons that protrude from the actuators using a screw driven mechanism. The head of the pistons have a flat edge of 0.75 inch diameter. These flat surfaces are prone to cause catastrophic damage to bicycle wheels or other foreign objects in their path without any safety features. Moreover, the flat edges are likely to just push the obstructions in front of them along their axis of motion. To mitigate any effects of these normal forces on bicycle wheel spokes and other objects, we iterated on multiple designs for tips that were angled and not flat so that they can push objects to the side when they run into these obstacles, rather than push them forward along their path. The best tip design our team composed was a cone-shaped tip (Figure 6.4) . The cone was designed on Solidworks and it was dimensioned with a 0.75 inch diameter at the base and angled at 60°. After the CAD model was completed, the model was 3-D printed using PETG filament and the tip was further filed down to reduce its point.

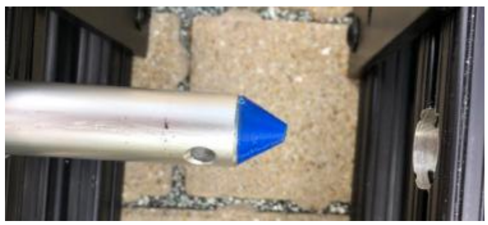


Figure 6.4: 3-D Printed Cone Tip

Additionally, we fabricated a transparent acrylic housing for our electronics components. The purpose of this housing was not nearly as mechanical as it was aesthetic as it served to hold our electronic controllers and display the complexity of the wirings. To construct the box, we designed the 6 panels of the box using a 2-D modeling software and cut the panels from a workpiece using a laser cutter. The panels were then conjoined together through a process utilizing acrylic cement to chemically bound the joints for a sturdy finish. Figure 6.5 depicts the acrylic housing during its operation.

Figure 6.5: Electronics Housing

6.3: Overall Assembly

With the main rack structure assembled and the additional plastic components fabricated, the remaining task was to construct all these parts into a final prototype product. The linear actuators we ordered were the ‘Classic Rod Linear Actuators’ (Model # FA-35-S-12-6) manufactured by Firgelli Automations. These actuators were then bolted at their designated locations seen in Figure 6.6.This process required trial and error by placing spacers between where the actuators were mounted so that their pistons can protrude cleanly through their holes without any additional friction. Moreover, the electronics were transferred to the acrylic housing, which required delicate maneuvers in order to not unplug any of the wires from the controllers or breadboard. The electronics housing was then mounted adjacent to the top actuator, which was the central most location of the bike rack and allowed for easy access to the RFID scanner (Figure 6.7). Plastic slats from 80/20 were cut to length and placed in any exposed locations of the 80/20 rails to create a clean look for the prototype. The finished prototype product is detailed in Figure 6.8.

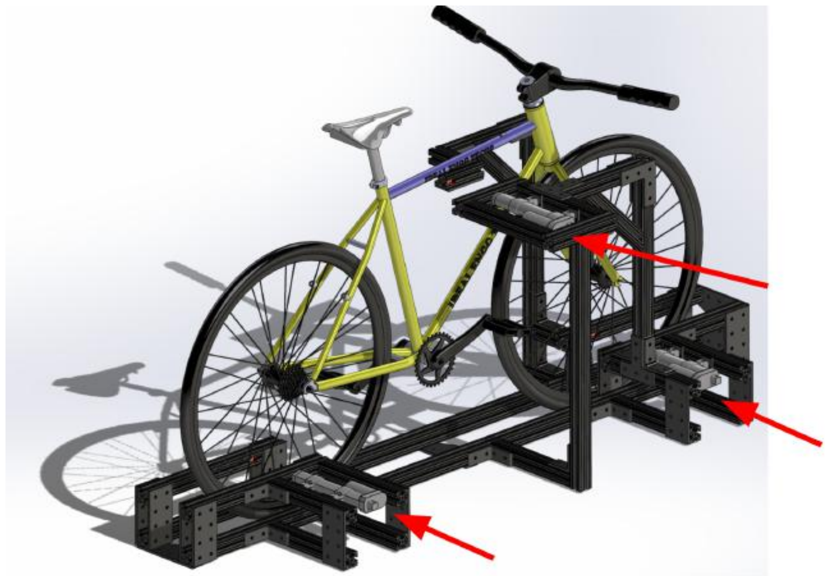


Figure 6.6: Linear Actuator Locations

Figure 6.7: Mounted Electronics Housing

Figure 6.8: Finalized Prototype Assembly

Chapter 7: Electronics & Software

Moving to the electronics, there were certain requirements that we knew had to be met, such as:

1. Controlling and powering the actuators
2. RFID usability
3. Upper actuator kill switch for non-ideal bikes
4. Safe retractability features

For the prototype, we were comfortable moving forward with using an Arduino RedBoard to act as the main computer behind all of the needed features. Firstly, we wanted a simple proof of concept for the electronics where we'd be able to press a button and have 1 actuator extend and retract. These actuators (Firgelli Model #FA-35-S-12-1) each require 12-24V, and can draw up to 5A. An arduino is not capable of directly powering a device of that power, so motor drivers were required. A motor driver is a simple concept: it takes in a lower power signal from the Arduino, and is able to then direct the full power source to the motor drivers (Part # BTS7960). This allows for the 12V power supply to power the actuators without having the current move through the Arduino board (which would destroy the Arduino). Once there was a successful test of controlling one actuator with a button and the Aruduino, the next step was to replace the button with the RFID interface (SparkFun KIT-15209). Using the RFID scanner ended up being rather straightforward and the button was easily replaced with the scanner.

The next focus was deciding on how we wanted to control and power the two remaining actuators. When we first started working on this project we assumed that each motor would be independently controlled, allowing for the most flexibility, what we soon realized is that it would be unnecessary and overly complicated to control each actuator on its own. There are two main parts of the locking mechanism for the bike rack: the frame, and the wheels. At first, our easiest option was to just increase the current from the power supply, and connect all 3 actuators in parallel with a manual kill switch for the frame locking actuator. The problem that arose here was that this would cause changes on the overall current flow depending on if the frame actuator was turned on or off. This left us with the option we decided to move forward with: having the lower two actuators controlled together in parallel, and having the frame actuator controlled on its own with a manual kill switch. The manual kill switch becomes important in the scenario that the user has a bike that has a large battery in the frame or any other object where the actuator would not be able to pass through. In this situation, the user would flip the switch allowing only their two wheels to be locked instead of all three points.

User safety has been the top priority for the bike rack. We know that whenever there are motor driven actuators involved, it is important to assume that the user could end up with their hand in the path. When we first started looking into this issue, we thought the best option would be to either have a button on the end of the actuator rod, or have an infrared sensor on either end of the path similar to a garage door. While these ideas seemed feasible, we quickly realized that there were small issues that would make it much more difficult. For the idea of having the button on the end of the rod, we were not able to devise a way to manage the wires from the button due to the fact that the rod would need to be able to move in and out of the actuator body with little to no clearance. For the infrared sensor approach, we realized that due to the fact that the light would not be coming directly out of the end of the actuator rod, it would be difficult to have the rod not be triggered by nearby bike spokes which may not have been directly in the path of the rod.

After experimenting with watching the current draw from the actuators, we realized that the current significantly increases when a force is acting on the rod. This gave us the idea that we could use a current sensor to detect when the actuators are hitting an obstacle. After ordering two current sensors (SparkFun SEN-14544) (one for the wheel actuators and one for the frame actuator), we successfully were able to automatically retract the actuators if any obstacle was hit. We also adjusted the sensitivity of the current sensors to allow for small impacts with the wheels in case they just needed to be rotated by the actuator rod before locking. When adding in the current sensors, we came into an issue where the Arduino seemed to have trouble with monitoring the RFID reader and the current sensors in parallel. Due to the fact that we were getting to the deadline for this project and were unable to get this figured out, we decided to add a second Arduino (an Arduino Mega), that would be entirely for watching the current sensors. When the Arduino Mega saw that the current sensors hit the limit to trigger retraction, it would send a simple signal to the Arduino RedBoard which would retract the actuators. All of this can be seen in the circuit diagram in Figure 7.1. As for the Arduino code itself, there are two scripts that were written. One for the Arduino RedBoard, and the other for the Arduino Mega. Both scripts can be seen in Appendix D.

The Arduino software that was coded allows for a user to tap one of the two RFID cards (SparkFun KIT-15209) against the device to lock the bike rack. The bike rack then will lock the bike with the three actuators and will retract if any obstacles are hit. When the user would like to unlock their bike, they must tap with the same card that they used to lock the bike. Showing that our rack will only unlock with the same card that locked the bike in the first place.

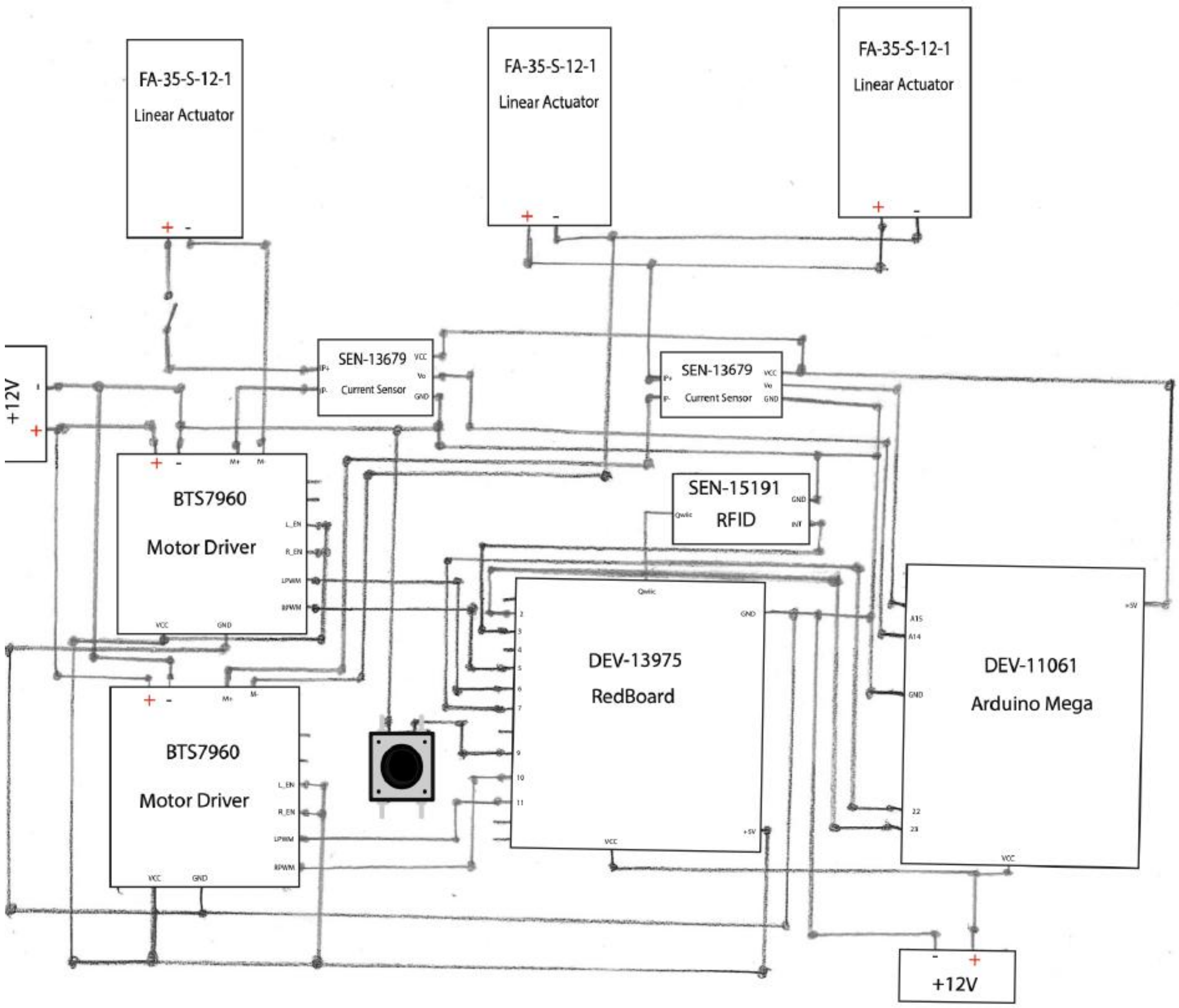


Figure 7.1: Circuit Diagram

Chapter 8: Business Plan

8.1: Production Model

Although our team was constrained by time and resources through the process of Senior Design, we believe that there would be a strong market need for our product worldwide. After the success of our prototype model, we are confident that moving forward with a production model on a larger scale would reduce bike theft significantly and therefore encourage more people to ride bicycles. Our production model also has significant room for improvement and may be adjusted in many ways to make it better fitted for a specific location or environment.

A more advanced production model could see two bike racks sharing one actuator housing in order to optimize space and be able to install as many racks one wishes. It is of the utmost importance that our product remains environmentally friendly, which is why we could also explore the idea of installing solar panels to power a few of the racks, and potentially even incorporate additional features such as e-bike charging. If these racks were to be installed in a city rather than a college campus, it would also be worthwhile to develop an app from which you can lock and unlock the bike, since people do not carry around access cards. This app could also allow the team to install tamper proof sensors on the bike rack, so that a user would get a notification or an alarm would sound if there is any attempt to forcibly steal a bike.

Perhaps the most important point to consider when looking at large scale production is to identify the cost of assembling many racks simultaneously, especially now that the prototype paved a clear path forward. We were happy to discover that some of the most expensive components, such as the linear actuators and electronics, become relatively inexpensive when ordered in bulk. Our team anticipates that when items are bought in bulk, the total cost for putting together each rack would be below $250. The cost to benefit ratio is extremely high given that this product has the potential to prevent people from losing thousands of dollars due to bike theft, and if implemented by companies or universities, they could get a quick return on investment. A detailed breakdown of the production model's cost when items are purchased in bulk is provided in Table 8.1 below.

Table 8.1: Cost breakdown per bike rack

Item	**Cost ($/unit)**
Galvanized Tube Steel	30
Linear Actuators (x3)	60
Electronics	40
Application Services	20
Welding	100
Total	$250

8.2: User Management

The production model is intended to coexist with a Customer-Relation Management (CRM) software to manage customers' use of each bike rack. The first marketspace we intended our product to enter was the Santa Clara University campus. Here, and like many other universities, students scan an "ACCESS" card to enter buildings, rent books from the library, pay for food with meal points, etc. Students who wish to commute by bicycle can pay for points specifically used to access the bike racks. Using the ACCESS card, an SCU student can walk their bike into any vacant bike rack, scan their card on the rack's RFID scanner and automatically lock their bike with their pre-paid points. When the student wishes to retrieve their bike, they can scan their card again and the bike is automatically unlocked.

An issue lots of universities have is that many students leave their bikes locked and unattended at the end of the year and never return to retrieve them. To combat this problem, the bike rack CRM can send an automated email to the student prompting them to retrieve their bike or use additional points to keep their bike locked for extended periods of time (such as after a 48 hour period of the bike being locked). If students neglect their bikes and never intend to retrieve them, the bike rack can be unlocked with permission from campus security. This mitigates the issue where campus facilities workers have to cut and remove any bike locks from neglected bikes.

Chapter 9: Experimentation

Most of our time after building the 80/20 frame was spent on testing. We brought in numerous bikes belonging to our team and friends. One of the first changes we made was adjusting the high of the actuator that locks the frame. We found that with one of the bikes we were testing it had a frame where the rod of the actuator would directly hit the frame and not be able to close. We figured the best option was to raise the actuator by 1.5 inches in order to allow for above-frame locking. The idea with above-frame locking was to have the actuator close above the frame (for bikes with a low upper frame bar) which still didn't allow for the frame to be removed. We also decided to move the rear wheel actuator slightly closer to the middle of the frame in order to shorten the size of the rack.

Once we were happy with the physical layout of the bike rack, the remainder of the experimentation was relating to the actuators, electronics, and software. Lots of time was focused on ensuring that the actuator rods lined up properly with the holes in the 80/20 on the other side of the track. Because of the safety retracting system, we knew that if the rods were slightly off center, it could cause the bike rack to always retract. With the rods lined up, the remainder of the testing was mainly spent on the safety retraction system. We knew it had to be sensitive enough to retract before potentially causing harm, but also had to be strong enough to bump a spoke out of the way if need be. This was a challenging problem because we found the current to not always be the most predictable. We found that the instant that the actuators turn on, there is a current spike. This current spike would appear as if the actuator hit an obstacle which would then cause the actuators to retract. The way we ended up fixing this issue was not turning on the safety retraction system until one second after the actuator started moving. This allowed for the current spike to pass, and also is during a part of the path where there is no risk of harm. Once we passed the initial current spike, we just had to adjust the sensitivity in order to allow the rod to brush past a spoke without retracting. Experimentation was a crucial part of this project for us. We spent countless hours in the shop working on seemingly minor problems that required tedious testing and revising.

Chapter 10: Environmental Impact

10.1 Ethical Engineering

To embody the standards of ethical engineering, our team believes that it is our responsibility to ensure that our product cannot be used or implemented in a way that causes undue or unnecessary harm to the environment. With this in mind we have reviewed the proposed design choices that we have made thus far to see if anything could be improved in this regard. We analyzed a few metrics to try to determine what scale of impact our product could have on the environment.

10.2 Frame Material

The first thing that we looked at was our material choice for the construction of the frame. The frame is the largest subsystem of our Smart Bike Rack, and therefore would have the largest impact of any of the building materials chosen. Our production model would be made of primarily galvanized steel, which is the standard material for bike rack construction and is among the most green construction materials available. This is due to the fact that it does not deteriorate or degrade in the weather, and it is also infinitely recyclable. With this in mind, it was an easy choice to commit to for our final design.

10.3 Power Consumption

Another important consideration for the environmental impact of any product is power consumption. Power consumption directly contributes to the emissions of greenhouse gasses and therefore should be reduced and eliminated where possible. From analysis of our demonstration prototype, the power consumption of our Smart Bike would be expected to be in the range of 1-5 watts when idle and around 30 watts when actively locking or unlocking a bike. Since the power consumption is relatively low, entire Smart Bike Rack locking stations could be powered by a relatively modest solar panel and battery system. This has the added benefit of being completely separate from the grid. Allowing operation during black out times and no added carbon emissions due to power consumption.

10.4 Green Transportation

Bicycles are also a zero emission transportation method. For this reason if bikes are made more accessible and easier to own and operate, it follows that more people would take up bike riding instead of driving their car or taking public transportation. This has the potential to actually reduce carbon emissions from other sources. For this reason our team can stand proudly behind the design and ethics of the Smart Bike Rack.

Chapter 11: Conclusion

11.1 Summary

Our goal at the beginning of this project was to successfully construct and develop an advanced prototype for our Smart Bike Rack, and most notably for it to serve as a proof of concept for our automatic 3-point locking mechanism. As expected, our team encountered many design challenges throughout the year and we had to pivot several times, but we are proud to say that we accomplished what we set out to do and more. By the end of the year, our prototype was completely functional and we were able to prove that it may accommodate and secure a wide range of bicycles of all shapes and sizes. Furthermore, our team had enough time to thoroughly investigate exactly what a production model would look like and develop advanced CAD models.

11.2 Future Plans

Completing this project was definitely a bittersweet feeling. Our team felt very happy to successfully complete the project, however we feel that there is a ton of potential to develop the production model further and see our Smart Bike Rack operational in the real world. This tells us that we created something innovative and special. As with any endeavor, there are always many lessons learned and things which could have been improved. The team feels that throughout the course of the academic year, and especially during our Senior Design Conference presentation, we received very useful feedback that could be used to improve the production model in the future. A few of these things could be to build an app for the bike rack to be controlled remotely, linking the rack to a solar panel so that it can be more environmentally friendly, modify the arm design so that it can fit any type of bicycle no matter the shape and size, and even incorporate smaller lockers to the racks so that a user could safeguard other items.

11.3 Personal Reflection

On a personal level, our team saw immense growth in what was a very hectic year. Completing this project has made each of us stronger Engineers, but perhaps most importantly better leaders and teammates. It is not always easy to find a group of people with whom you feel comfortable sharing any ideas, no matter how crazy they may sound, but we strongly believe everyone's voice was heard and taken into consideration every step of the way. We understand that everyone has different strengths and abilities to offer, and when it comes to a big project like this the work has to be split up and we need to hold each other accountable. Having said that, we think that part of the reason why the design was successful is because we each took the time to understand exactly how every component worked and the role it played in the final product. One thing we can all agree on is that the Smart Bike Rack will be a teacher we will remember for the rest of our lives.

References

1. Coulon, J. (2020). *Bike Thefts Are on the Rise. But We Can Fight Back*. Bicycling. https://www.bicycling.com/news/a28846575/project-529-bike-theft-data/.
2. *E. Collini, P. Nesi and G. Pantaleo, "Deep Learning for Short-Term Prediction of Available Bikes on Bike-Sharing Stations," in IEEE Access, vol. 9, pp. 124337-124347, 2021, doi: 10.1109/ACCESS.2021.3110794.*
3. *Ramon Alvarez-Valdes, Jose M. Belenguer, Enrique Benavent, Jose D. Bermudez, Facundo Muñoz, Enriqueta Vercher, Francisco Verdejo, Optimizing the level of service quality of a bike-sharing system, Omega, Volume 62, 2016, Pages 163-175, ISSN 0305-0483*
4. A. ALBATTAH, Y. ALGHOFAILI and S. ELKHEDIRI, "NFC Technology: Assessment Effective of Security towards Protecting NFC Devices & Services," 2020 International Conference on Computing and Information Technology (ICCIT-1441), 2020, pp. 1-5, doi: 10.1109/ICCIT-144147971.2020.9213758.
5. P. S. R. Teja, V. Kushal, A. S. Srikar and K. Srinivasan, "Photosensitive security system for theft detection and control using GSM technology," 2015 International Conference on Signal Processing and Communication Engineering Systems, 2015, pp. 122-125, doi: 10.1109/SPACES.2015.7058229.
6. *How Many College Students Ride Bikes - BikeHike*. BikeHike. (2022). Retrieved 2 June 2022, from https://cyclinghikes.com/how-many-college-students-ride-bikes/#How_many_bikes_are_at_UCSB.

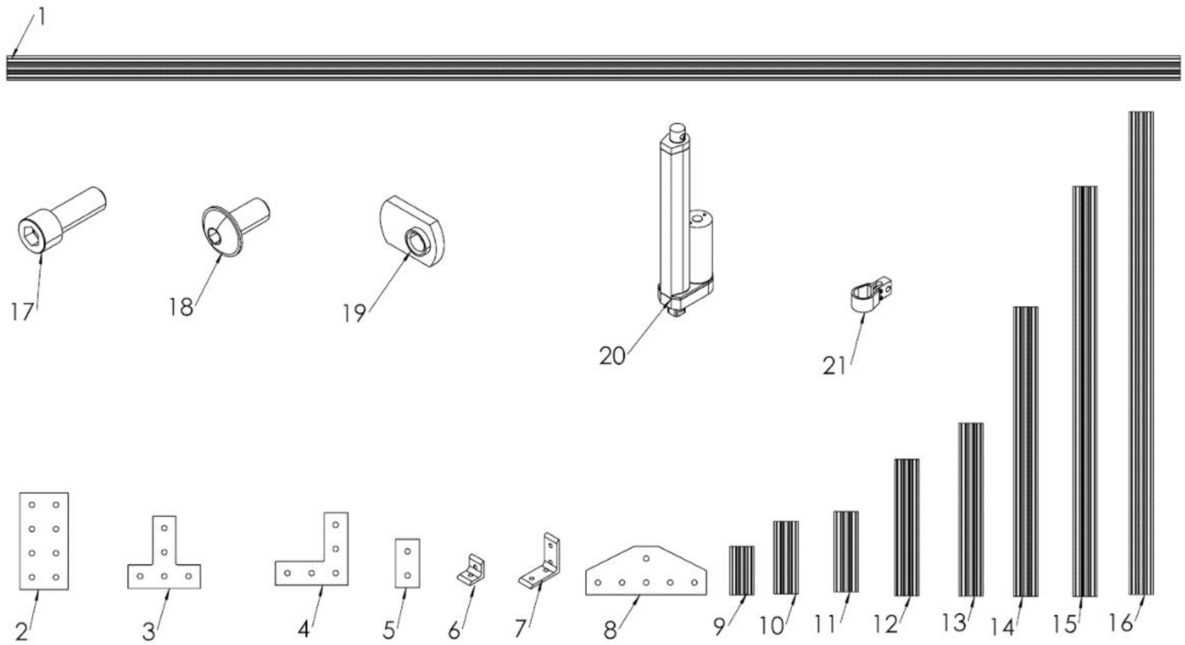
7. Powell, E., & Hait, A. (2021). *Surge in Demand Prompts Bicycle Shortages, Higher Prices*. United States Census Bureau. Retrieved 2 June 2022, from https://www.census.gov/library/stories/2021/06/consumers-turn-to-biking-for-safe-fun-exercise-during-pandemic.html#:~:text=It%20also%20reported%20that%20cycling,to%20accommodate%20bikers%20and%20pedestrians.
8. *Amsterdam: City of Bikes*. Amsterdam Tourist Information. (2022). Retrieved 2 June 2022, from https://www.dutchamsterdam.nl/68-amsterdam-city-of-bikes#:~:text=As%20of%202017%2C%2068%25%20of,are%20more%20bikes%20than%20residents.

Appendix A: Smart Bike Rack List of Parts and Diagrams

Table A1: List of Parts

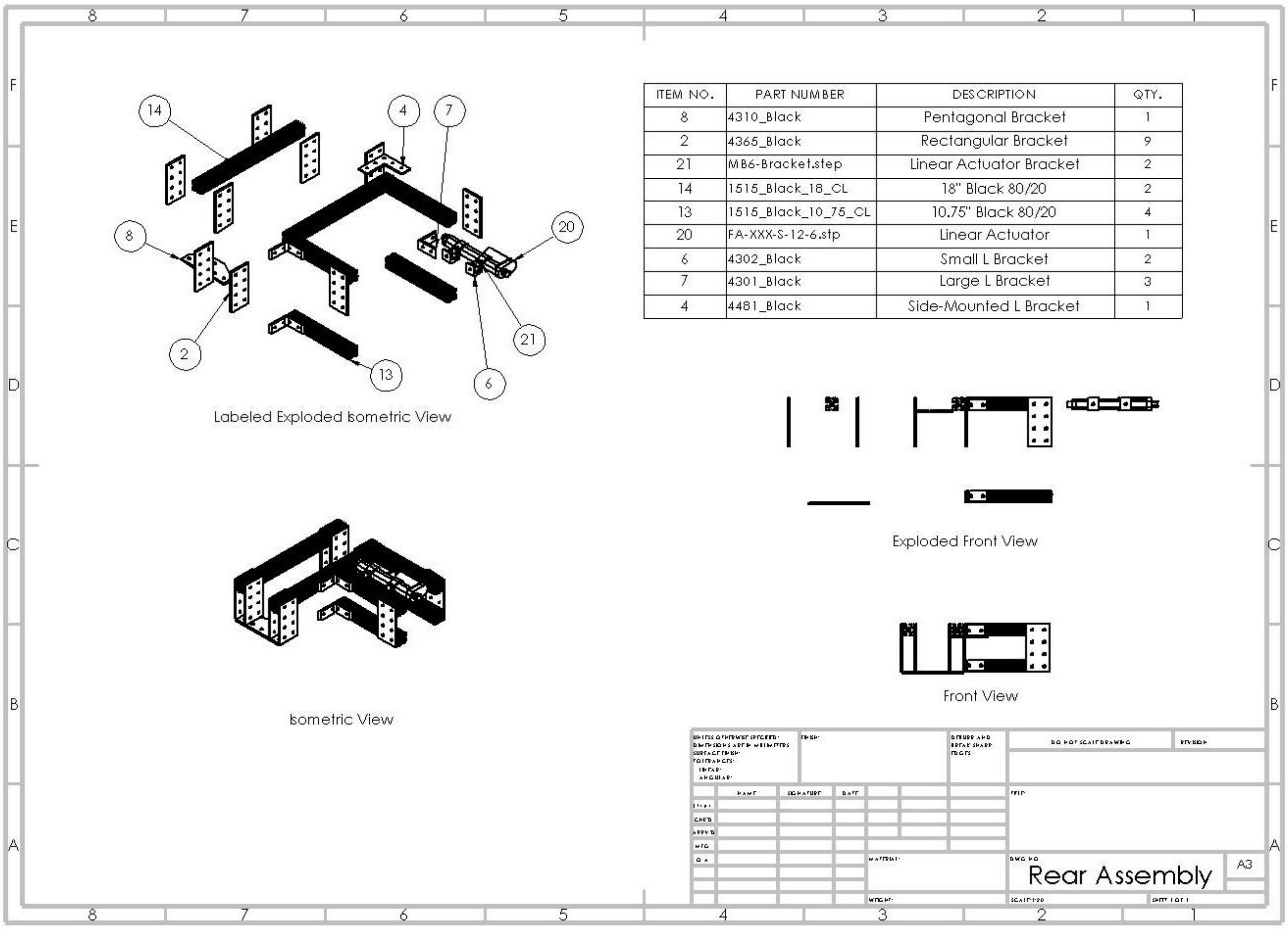
Item No.	Part	Description	Quantity
1	1515 Track Bar	73in long	2
2	4365 Fastener	8-hole flat	15
3	4480 Fastener	5-hole flat T-shaped	2
4	4481 Fastener	5-hole flat L-shaped	8
5	4307 Fastener	2-hole flat	1
6	4302 Fastener	2-hole L-shaped	6
7	4301 Fastener	4-hole L-shaped	16
8	4310 Fastener	6-hole flat	5
9	1515 Track Bar	3in long	1
10	1515 Track Bar	4.5in long	2
11	1515 Track Bar	5in long	1
12	1515 Track Bar	8.5in long	2
13	1515 Track Bar	10.75in long	15
14	1515 Track Bar	18in long	4
15	1515 Track Bar	25.5 in long	1
16	1515 Track Bar	30in long	2
17	3119 Cap Screw	N/A	5
18	3330 Cap Screw	N/A	208
19	3278 T-nut Thread	N/A	205
20	Linear Actuator	N/A	3
21	MB6 Bracket	N/A	6

Figure A1: Individual Part Drawings



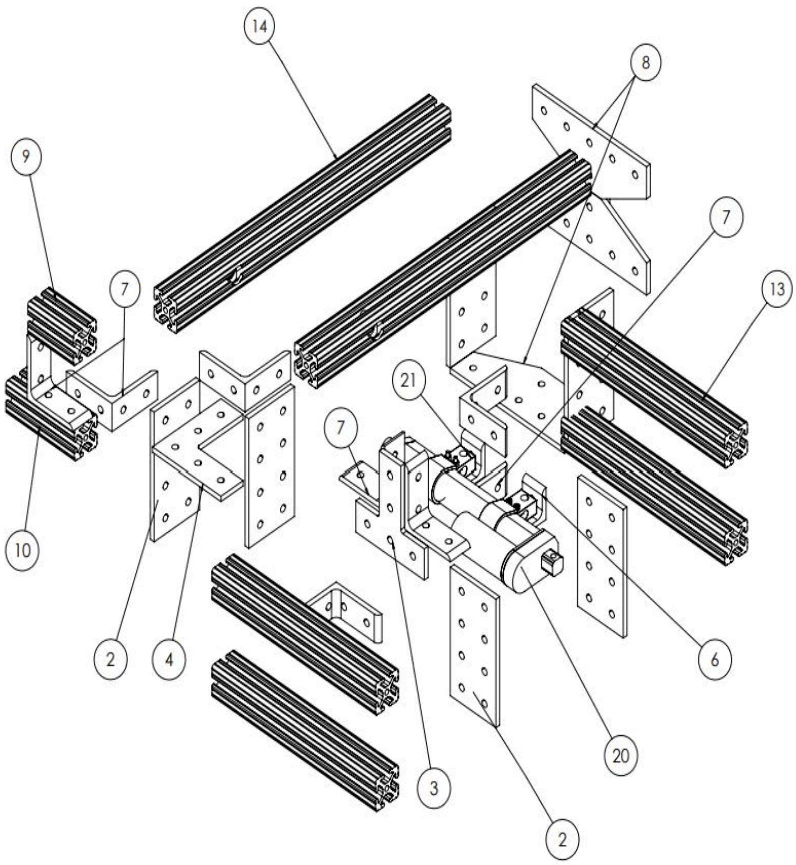
Appendix B: Assembly Drawings

Figure B1: Rear Actuator Housing Assembly



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
8	4310_Black	Pentagonal Bracket	1
2	4365_Black	Rectangular Bracket	9
21	MB6-Bracket.step	Linear Actuator Bracket	2
14	1515_Black_18_CL	18" Black 80/20	2
13	1515_Black_10_75_CL	10.75" Black 80/20	4
20	FA-XXX-S-12-6.stp	Linear Actuator	1
6	4302_Black	Small L Bracket	2
7	4301_Black	Large L Bracket	3
4	4481_Black	Side-Mounted L Bracket	1

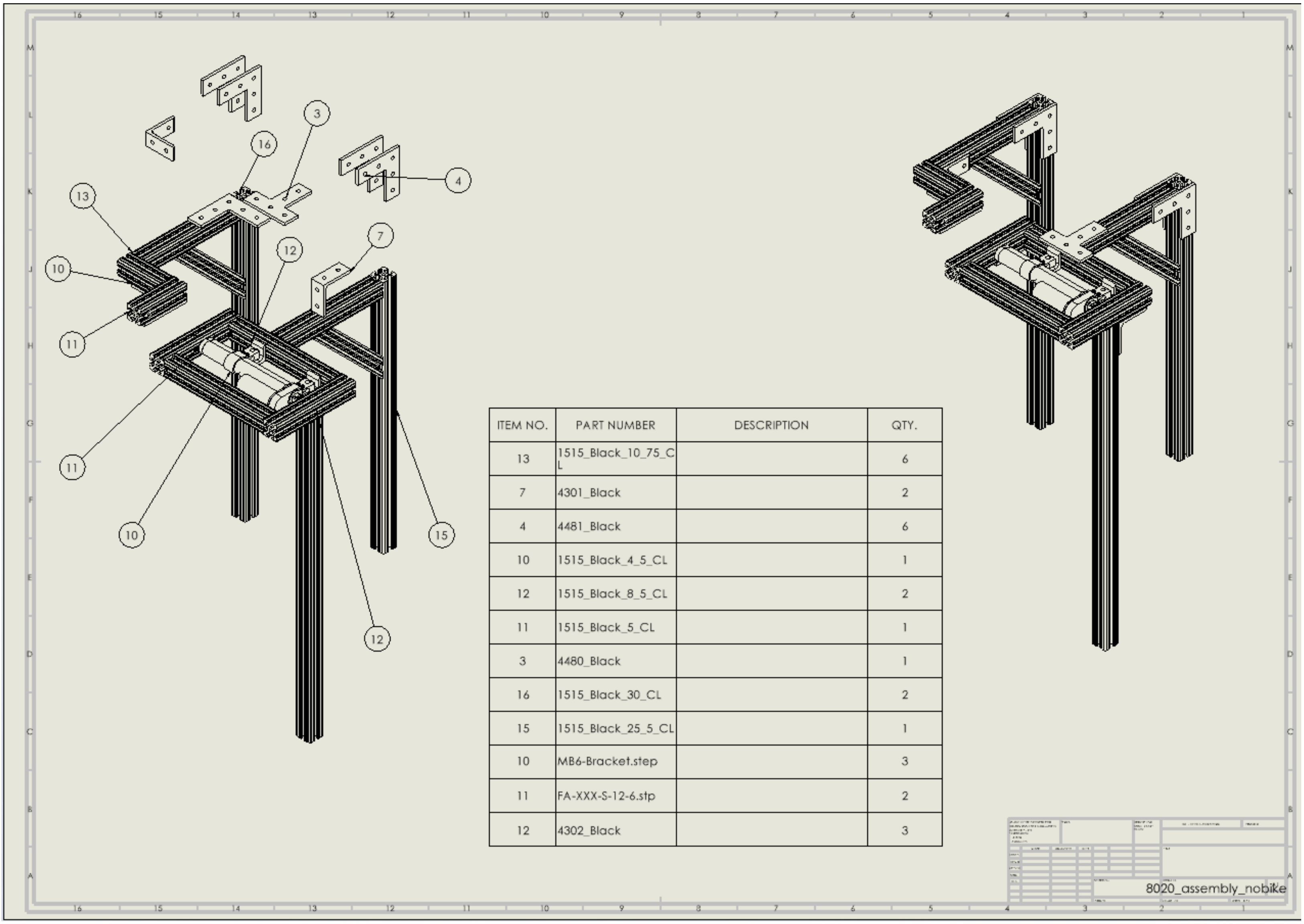
Figure B2: Front Actuator Housing Assembly



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
8	4310_Black	6-hole flat	3
2	4365_Black	8-hole flat	6
5	4307_Black	2-hole flat	1
21	MB6-Bracket.step	N/A	2
14	1515_Black_18_CL	18in long	2
13	1515_Black_10_75_CL	10.75in long	4
20	FA-XXX-S-12-6.stp	Linear Actuator	1
6	4302_Black	2-hole L-shaped fastener	2
7	4301_Black	4-hole L-shaped fastener	8
4	4481_Black	5-hole flat L-shaped fastener	1
10	1515_Black_4_5_CL	4.5in long	1
3	4480_Black	5-hole flat T-shaped fastener	1
9	1515_Black_3_CL	3in long	1

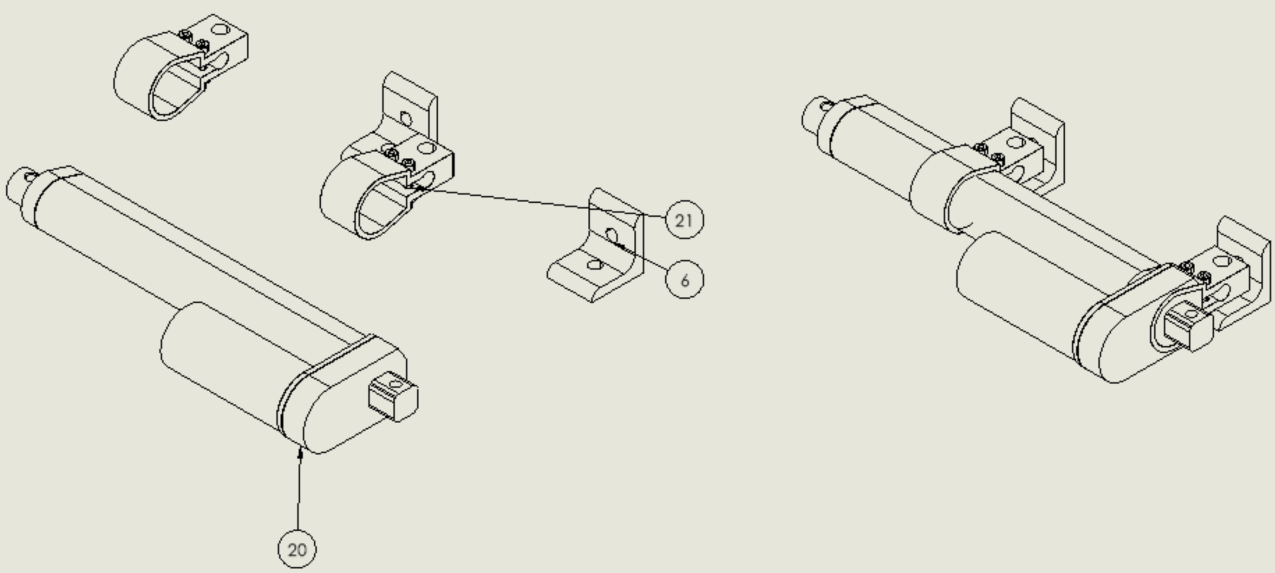
8020_front_system

Figure B3: Top Actuator Housing Assembly



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
13	1515_Black_10_75_CL		6
7	4301_Black		2
4	4481_Black		6
10	1515_Black_4_5_CL		1
12	1515_Black_8_5_CL		2
11	1515_Black_5_CL		1
3	4480_Black		1
16	1515_Black_30_CL		2
15	1515_Black_25_5_CL		1
10	MB6-Bracket.step		3
11	FA-XXX-S-12-6.stp		2
12	4302_Black		3

Figure B4: Linear Actuator Assembly



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
21	MB6-Bracket.step		2
20	FA-XXX-S-12-6.stp		1
6	4302_Black		2

DWG. NO. 8020_assembly_nobike A3

Figure B5: Views of Completed Assembly

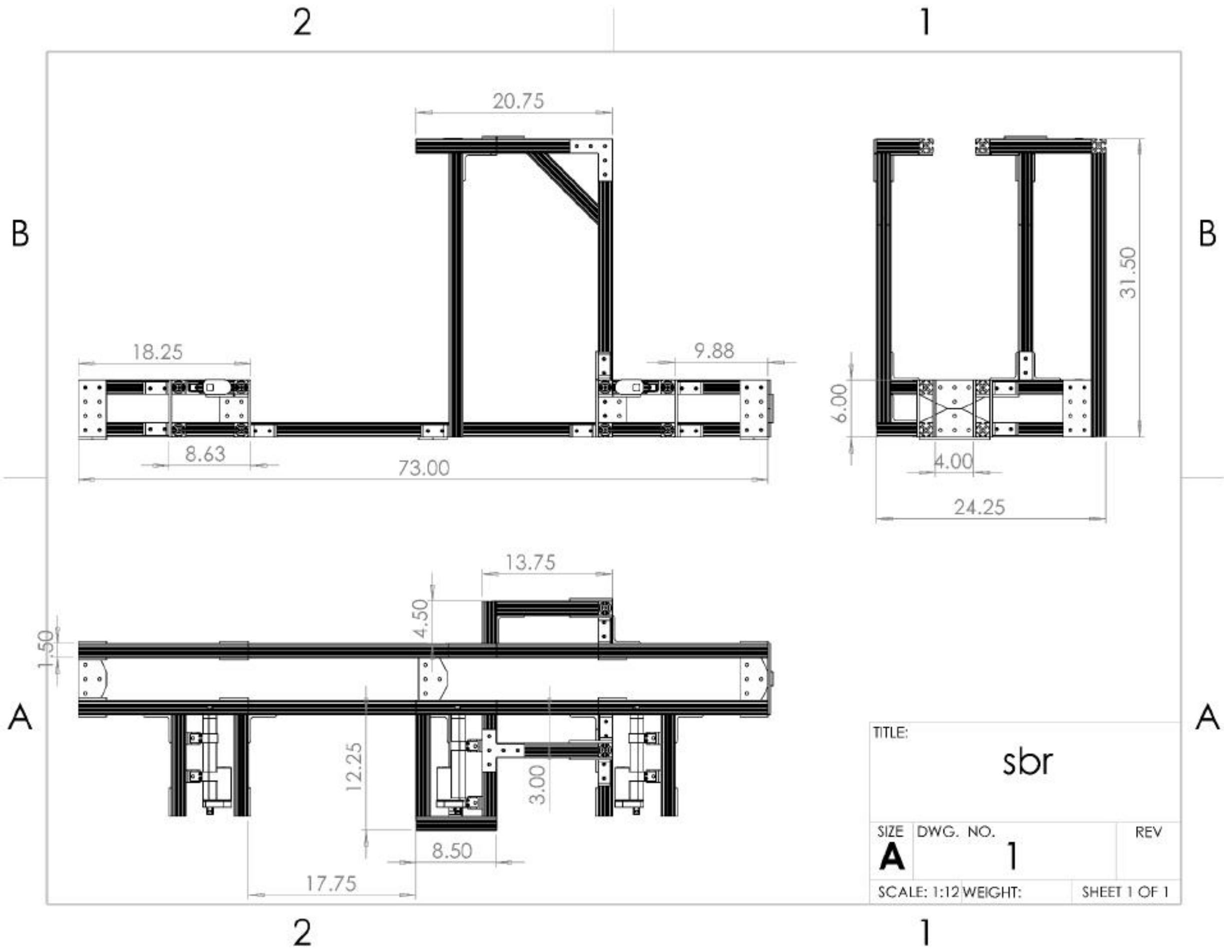
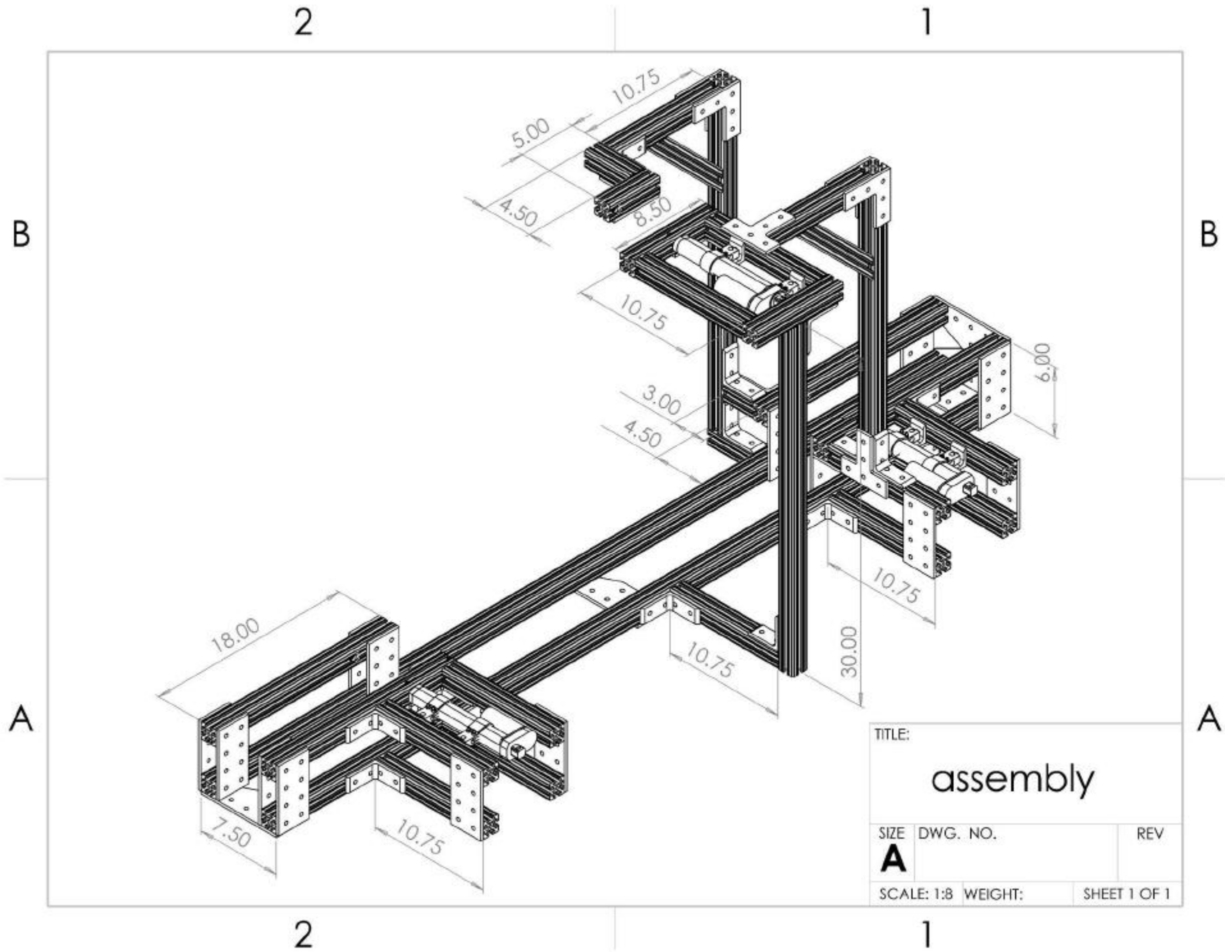


Figure B6: Isometric View of Completed Assembly



Appendix C: Arduino Code

Main code:

```
#include <Wire.h>
#include "SparkFun_Qwiic_Rfid.h"

#define RFID_ADDR 0x7D // Default I2C address

// Interrupt Pin on pin 3.
const int intPin = 3;
String tag;
bool locked;

Qwiic_Rfid myRfid(RFID_ADDR);


int RPWM1 = 10;  //connect Arduino pin 10 to IBT-2 pin RPWM
int LPWM1 = 11;  //connect Arduino pin 11 to IBT-2 pin LPWM
int RPWM2 = 5;
int LPWM2 = 6;
int Speed1 = 255;
int Speed2 = 195;
int buttonPin_in = 9;

int lockedID;

void setup()
{
    Wire.begin();
    Serial.begin(9600);

  if(myRfid.begin())
    Serial.println("Ready to scan some tags!");
  else
    Serial.println("Could not communicate with the Qwiic RFID Reader!!!");

//  tag = myRfid.getTag(); // this block would be used to keep track of if 
the device was locked after a power cycle.
//  String testTag = String(tag); // would need a backup battery for the 
RFID scanner so it doesn't lose the scanned card during a power cycle
//  if (testTag != "000000"){
```

```
//    Serial.println("locked");
//    locked = true;
//   }

  pinMode(intPin, INPUT_PULLUP); // for RFID

  pinMode(RPWM1, OUTPUT); //lower motors
  pinMode(LPWM1, OUTPUT);
  pinMode(RPWM2, OUTPUT); //frame motor
  pinMode(LPWM2, OUTPUT);
  pinMode(buttonPin_in, INPUT_PULLUP); // for emergency retract button
  pinMode(13, OUTPUT);
  pinMode(7, INPUT); //for current sensor for lower motors
  pinMode(2, INPUT); //for current sensor for frame
}


int retractAll() {
  locked = false;
  lockedID = 0;
  myRfid.clearTags(); // reset RFID scanner once system is unlocked
  analogWrite(RPWM1, Speed1);
  analogWrite(LPWM1, 0);
  analogWrite(RPWM2, Speed2);
  analogWrite(LPWM2, 0);
}

int retractFrame() {
  analogWrite(RPWM2, Speed1);
  analogWrite(LPWM2, 0);
}

int retractLower() {
  analogWrite(RPWM1, Speed1);
  analogWrite(LPWM1, 0);
}

int extend(int id) {
  locked = true;
  lockedID = id;
  analogWrite(RPWM1, 0);
```

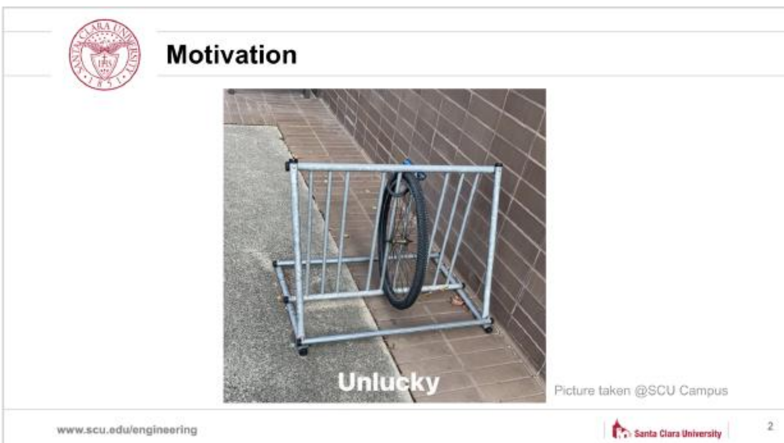
```
  analogWrite(LPWM1, Speed1);
  analogWrite(RPWM2, 0);
  analogWrite(LPWM2, Speed2);
  delay(1500);
}


void loop() {
Serial.println(locked);

  if(digitalRead(7) == HIGH) {
    retractLower();
  }

  if (digitalRead(2) == HIGH) {
    retractFrame();
  }

  // If the pin goes low, then a card has been scanned.
  if(digitalRead(intPin) == LOW){
    tag = myRfid.getTag();
    int userID = tag.toInt();
    Serial.println(tag);
    if (locked == false) {
      extend(userID);
    } else if (locked == true && userID == lockedID){
      retractAll();
    }
    else {
      Serial.println("Not authorized");
    }
  }
  if (digitalRead(buttonPin_in) == LOW) {
    retractAll();
  }

  delay(100);

}
```

Current sensor code:

```
const int analogInPin1 = A15; // lower motors
const int analogInPin2 = A14; // frame motor

const int avgSamples = 50;

int sensorValue1 = 0;
int sensorValue2 = 0;



float sensitivity = 100.0 / 500.0; //100mA per 500mV = 0.2
float Vref = 2500; // Output voltage with no current: ~ 2500mV or 2.5V

void setup() {
  // initialize serial communications at 9600 bps:
  Serial.begin(9600);
  pinMode(22, OUTPUT);
  pinMode(23, OUTPUT);
}

void loop() {
  // read the analog in value:
  for (int i = 0; i < avgSamples; i++)
  {
    sensorValue1 += analogRead(analogInPin1);
    sensorValue2 += analogRead(analogInPin2);
    delay(2);

  }

  sensorValue1 = sensorValue1 / avgSamples;
  sensorValue2 = sensorValue2 / avgSamples;

  // The on-board ADC is 10-bits -> 2^10 = 1024 -> 5V / 1024 ~= 4.88mV
  // The voltage is in millivolts
```

```
  float voltage1 = 4.88 * sensorValue1 / 1000;
  float voltage2 = 4.88 * sensorValue2 / 1000;

  if (voltage1 < 2 && voltage1 > -3) { //lower motors
    Serial.println("Lower Impact" + String(voltage1));
    digitalWrite(22, HIGH);
    delay(250);
    digitalWrite(22, LOW);
  }
  if (voltage2 > 2.9) { //frame motor
    Serial.println("Frame Impact" + String(voltage2));
    digitalWrite(23, HIGH);
    delay(250);
    digitalWrite(23, LOW);
  }


  Serial.print(voltage1);

  // -- DO NOT UNCOMMENT BELOW THIS LINE --
  Serial.print("\n");

  // Reset the sensor value for the next reading
  sensorValue1 = 0;
  sensorValue2 = 0;
}
```

Appendix D: Senior Design Conference Slides



Research

Current bike locking mechanisms are:

- Insecure
  - Do not protect all bike components (Frame, Wheels)
- Inefficient
  - Takes long to lock bike
  - Hard to carry
- Do not optimize space

Interviews

Bike users want a better alternative, and non-bike users would consider using one if there was a secure, easy-to-use locking mechanism

- Effortless
- Fast
- Reliable

Smart Bike Rack

Target Demographic

- College Campuses
- Large urban areas (Ex. San Francisco)

Competition

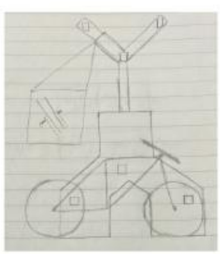
- Bikeep
  - What is wrong with this picture?
    - Bikeep rack does not secure frame and wheels
    - Requires user to manually lock bike
    - Requires a paid subscription
- There is a better solution to the bike theft problem

Design Goals

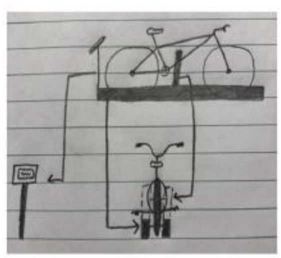
- 3-Point Locking System
- Automatic Locks
- Secure Access via RFID Scanner
- Capability to fit as many bikes as possible

Concept Generation: The Drawing Board

Design 1: Chain

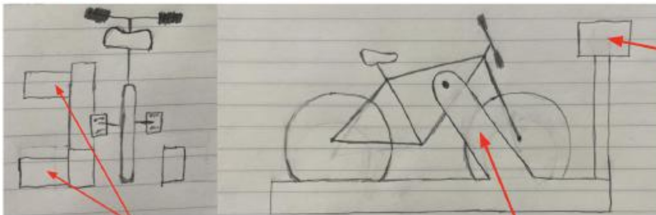


Design 2: 'Y-bar'



Design 3: Track

Finalized Conceptual Design



Move the Scanner to avoid the handlebars

Added housings for actuators and electronics

Tilted arms, avoid pedals

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CAD Model: Production Assembly

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CAD Model: Prototype Assembly

- Material: 80/20 aluminum
- Exposed frame
- Production dimensions

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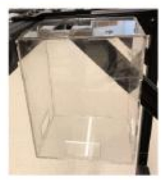
Mechanical Design: Key Elements

- Actuators placed at strategic locations
  - Based on real metrics
- Cone-shaped tips on locking rods
- Closed anchoring point to reduce tampering with rods
- Transparent housing for electronics

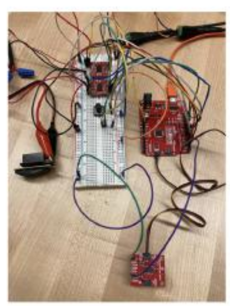
Mechanical Design: Fabrication Process

- 80/20 Aluminum pre-cut to length
- 80/20 rails milled
- 3D-printed tips fixed to actuator rods
- Electronics housing fabricated with laser cutter



Electronics: Requirements

- Extend, retract, and power the actuators
- Allow RFID card scanning
- Frame disconnect switch
- Safety retracting



Hardware: Specifications

- Linear actuator - x3
  - 12-24v
  - Up to 5 amps
  - 35lb force
- Motor driver - x2
  - 2 actuators in parallel
  - 1 actuator on its own
- Current sensor - x2
  - Added safety
- Arduino



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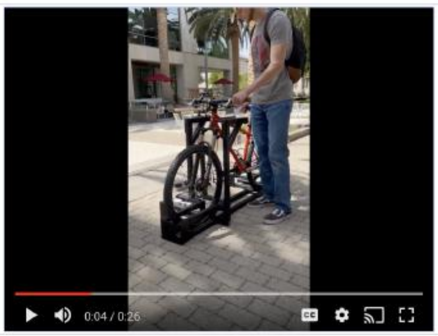

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Production Model & Additional Features

- Productional Model:
  - Frame and rods constructed from galvanized tube steel
  - Protective housing for electronic components
- Additional Features:
  - Alarm/tampering sensors
  - Adjustable top arm
  - Power source for e-Bike charging
  - Tamper-proof screws

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Environmental Impact

- Environmental Impact is a concern
- Our Production Model is made primarily from Steel
- Power consumption is very low
- Increase in bike riders

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Conclusion

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