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The BorrowBike

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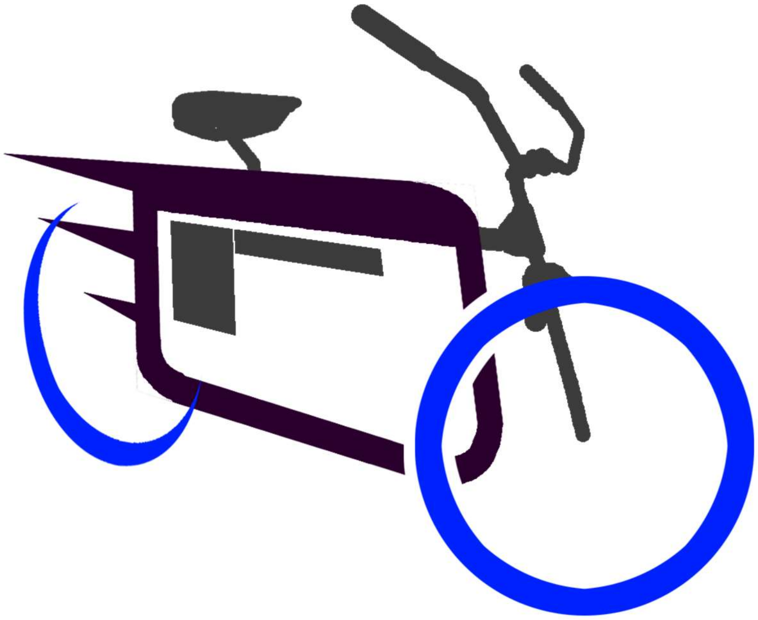
Team BorrowBike



**Grayson Taylor, Jesse Rubenstien, Aaron Leung,
Martin Woodby, Ryan Dehart, Jack Padon**

ABSTRACT

The bike rental system on UP's campus is underutilized by students. The resource consistently has available bikes, yet few students choose to use the resource due to rental process limitations. *BorrowBike* is turning UP's bike rental system from an inconvenient process to a hassle-free swipe of a card. *BorrowBike's* smart lock and online web application streamlines the check-out process and allows bikes to be rented at any time of the day.

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I. INTRODUCTION

The *BorrowBike* is an interactive locking system that allows students to rent bikes with the use of their student I.D. or cell phone. The product itself is comprised of a physical bike lock and a paired renting system application. All University of Portland Students possess a student I.D. that allows them access to certain buildings, allows them to buy food on campus, and so on. By extrapolating upon magnetic strip technology existing in these I.D. cards, the *BorrowBike* lock can be actuated as a rental checkout. This lock will be fitted to attach to a variety of bikes, relieving checkout constraints. The website system will be paired with the locks allowing students to check bike availability and permit the Outdoor Pursuits office to easily monitor the system for regulation purposes and maintenance.

The design of a lock will be both light and strong while the website system will facilitate the streamlined rental process. As the deliverable, a fully functional prototype will be fabricated including the lock paired with the fully functioning website that connects the bikes, students, and administrators all together.

The goal of this project is to design a bike share system for UP students scoped with two major systems: a website and a physical lock, see Table 1. The team will need to design a bike lock that is built into a bike and unlockable with a UP student ID. The system will be paired with an App or website that can track and show availability of bikes. University students will be able to check out bikes for use anywhere on or off campus and have the availability to lock and unlock anywhere. For our purposes, users of this system must return bikes to a designated area (most likely OPP office) in order to be considered returned.

Table 1. Project Scope

User/Admin Website:	A web application that will track available bikes in real time with basic bike information.
Physical Lock:	A bike lock with UP ID scanning functionality in order to unlock a *BorrowBike* including a wireless receiver that checks when the bike has been returned to its storage location.

In summary, our team goal is proof of concept of a bike share system for UP ID holders. The proof of concept will include a fully functioning prototype of the bike lock and a fully operational app paired with the lock. Our team consists of three computer science majors and three mechanical engineering majors whose roles are delegated as shown below; see Table 2.

Table 2. Team Roles and Responsibilities

	Software Team
Grayson Taylor	*The Project Lead* organizes the team, set up meetings, ensure work is distributed appropriately, and keep the team on track so that set milestones are reached. *The Application Developer* must ensure that the physical and networking systems are in place and must test finished application to meet required functionality.
Ryan Dehart	*The Webmaster and Marketing Officer* oversees the team's website to properly update the status of the team and promotes the project's visibility through the website and other promotional events. *The User Interface Developer* creates UI that fits customer needs and optimizes an intuitive user experience.
Aaron Leung	*The Financial Officer* ensures budget clearance and oversees purchasing, ordering, and overall expense management. *The Full Stack Developer* creates the web application functionality and links it with the database and backend program.
	Mechanical Engineering Team
Jesse Rubenstein	*The Mechanical Lead* updates the Project Lead on mechanical engineering components of the project and maintains that all mechanical milestones are met. *The Design Engineer* oversees completion of all CAD, design work, and component organization needed for the project.
Jack Padon	*The Project Outreach Director* maintains contact with outside resources associated with the project, identifies potential stakeholders, and contacts new assets that may arise. *The Spatial Arrangement Engineer* oversees the configuration and alignment of the physical components of the project, documents component dimensions, and ensures all aspects of the project meet specifications as planned.
Martin Woodby	*The Documentation Officer* maintains all meeting minutes and ensures all necessary documents are shared between required project personnel within the shared folder. *The Prototype Engineer* ensures that the final product has been sufficiently created and developed as envisioned in the original design.
	Advisors
Andrew Borel	*The Industry Advisor* will share knowledge, advice, and skills with the team as viewed from an engineer in a real-world setting.
Dr. Doughty	*The Faculty Advisor* provides guidance and direction for defining the problem and finding an effective solution.
Dr. VanDeGrift	*The Secondary Faculty Advisor* provides guidance and direction for defining the problem and finding an effective solution with matters related to the software aspects of the project.

II. BACKGROUND

a. Observations

The existing bike rental system on UP's campus is underleveraged, underutilized, and undervalued. In a survey the team conducted of 121 students, only 29 reported using the rental system. Of the students who had used the system, only 2 used it on a weekly basis. The survey inquired why users and non-users do not use the program more frequently, and the top limiting responses were: 1) Hours to rent are limited (44 students), 2) Checkout process is too time-consuming (44 students), 3) Lack of locations to return bikes(22 students), and 4) Never heard of it (21 students). Nearly 90% of students responded that an autonomous checkout would in some capacity compel more bike usage.

b. Literature Search

The concept of a bike share program dates back to 1965, when a group of activists in Amsterdam created the Witte Fietsen, or White Bikes. These were regular bikes, painted white, and left unlocked for anyone to use and leave behind for the next person. After many of the bikes were stolen or damaged, the program was quickly shut down and considered a massive failure.[1] This approach to bike share was tried again in 1994 with similar results. A nonprofit group in Portland, OR launched a city-wide bike sharing program known as the Yellow Bike Project. Around 1000 bikes were saved from the junkyard, quickly repaired, painted bright yellow, and placed around Portland.[2] With no system for tracing bikes, and a limited budget for repairs, the program lasted for only two years before the streets were devoid of functional yellow bikes.[3] 1995 saw clear improvements over Amsterdam's White Bikes. Copenhagen's Bycyklen, or City Bikes, allowed users to access sturdy, shared bicycles at specific locations throughout the city via a coin-operated system; however, thefts and vandalism still plagued the program. In 1996, Bikeabout, a small bike-share system limited to students at Portsmouth University in the U.K., was the first to come up with a solution to the theft problem. Users had to swipe an individualized magnetic-stripe card to borrow a bike, which allowed them to be tracked when they weren't returned. In 1998, Vélo à la Carte in Rennes, France, became the first city-scale, free of charge, bike share program to use magnetic swipe cards and RFID technology. By 2015, similar programs had launched dozens of major cities around the globe including: Paris, London, Buenos Aires, Hangzhou, New York and many others. Today, approximately 1 million bikeshare bikes function globally, 75% of which are in China.[1]

c. Intellectual Property

Intellectual Property around bikeshares is becoming a hot-topic issue especially in the China bikeshare market. Ofo, has applied for over 500 trademarks in China, and it has one established as an artificially intelligent lock[4]. Its biggest competitor, Mobike has applied for over 140 patents for its vehicle equipped with a Beidou-GPS-Glonass positioning chip[5]. Mobike is competing with overseas markets such as Citi Bike in the US. No information has been found on US companies with patents, and the concept of a standalone lock system such as the *BorrowBike* lock has not been found as patented.

d. Existing Solutions

In July 2016, Nike launched its own bike share program for the Portland area--Biketown[6]. Compared to the failed Yellow Bike Program, this system is the model of efficiency. One thousand sturdy, bright orange bikes are distributed through 100 hubs around Portland. The system is operated by Motivate, a global leader in bike share, which also operates bike shares in metros including New York City, Chicago, and Washington, D.C.[6] The system is ideal for one-way commuting trips parking to any hub or public bike rack (for an additional fee). Various pricing and membership options are available depending on the duration and frequency of use. Additionally, Biketown allows for real-time GPS tracking of its bikes through the official Biketown app and website. However, the current system is not convenient for University of Portland students as it only serves downtown and East Portland from Hawthorne to Piedmont. No bikeshare system currently serves North Portland or University Park[6].

College campuses have found to be popular bikeshare environments funded by both private and public sectors. One startup from Cambridge, Massachusetts named Zagster already hosts 20 campus bikeshares around the country[7], while LimeBike out of San Francisco has partnered with 22 campuses including University of Washington, and Arizona State University[8]. Since 2018, the University of Oregon has been funded by the City of Eugene with $1.2 M to launch a campus wide bikeshare program[9].

Of all the bikeshares mentioned, all of which require a specialized bike to operate. This has the strength of brand recognition and larger opportunity for technology integration to the entire bike. The downside is the minimal viable product requires a higher start-up cost and manufacture cost. The *BorrowBike* differs in the fact that any bike with a given tube size is able to be mounted with the lock and integrated into a bikeshare system. This gives rise to the potential for grassroots bikeshares to flourish with individual contribution and bike leasing such as Uber does with automobiles. The opportunity to scale this widely comes at the cost of limitations technologically that can be integrated into the system given the opportunity to scale.

e. Impact

The need that the *BorrowBike* seeks to address is that of accessible and reliable bike transportation for University of Portland Students. The current bike rental system, although fully functional, has several critical limitations that potentially limit student use. These limitations include limited check-out hours, a time-consuming check-out process, and the absence of an online system to check the availability of bikes. These limitations hold back the potential utility of a bike share system on campus. Being a future service for students, faculty, and staff of the University of Portland, user interface and user experience are two of the most prominent non-calculative design factors. Since a major pain point in the existing system is the hassle to checkout, our design must streamline processes to check availability, check-in, and check-out. Regarding user interface, the web application must be intuitive, clean, and straightforward. Bikes should be readily apparent with a visual and description simple enough to be selectable without much user effort. The user experience with the rental bike must follow an intuitive, simpler process than is currently offered. Scanning in, unretracting the lock cable, riding with the bike lock attached, and locking into the receiver are each crucial considerations for the adoption of rental bike usage on campus.

Providing a bike share service has several positive impacts on both global and local scales. The current rate of greenhouse gas emissions, approximately 50 billion metric tons per year globally, is a source of great concern for our species. The transportation sector is responsible for percent 28% of national greenhouse gas emissions[10]. This figure is of course mostly due to transportation of goods and raw materials; however, personal motor vehicles are a significant part of the problem. Quantitatively, the average passenger vehicle emits about 411 grams of carbon dioxide (CO2) per mile [10]. For a typical passenger vehicle, this figure equates to an annual emission of about 4.7 metric tons of CO2. In addition to CO2, automobiles produce methane and nitrous oxide from the tailpipe and hydrofluorocarbon emissions from leaking air conditioners. The emissions of these gases are small in comparison to CO2; however, the impact of these emissions can be important because they have a higher global warming potential (GWP) than CO2[11]. Additionally, the emissions and material consumption from vehicle manufacturing would decrease, further reducing our environmental impact. The *BorrowBike* has the ability to mitigate emissions in favor of an accessible, more healthy form of transportation near campus. If 20 *BorrowBikes* were utilized for an average of 5 miles per day, the *BorrowBike* system would mitigate over 16 metric tons of carbon emission per year from the atmosphere. This volume of these saved emissions is greater than the size of Beauchamp Athletic Facility.

On a local level, students who live too far from campus to walk would have the incentive to bike to class rather than drive, as they would not have to pay for gas or find parking. If every student on campus had access to free bike transportation, a greater percentage of students would be inclined to make this choice. These students would help alleviate the problem of limited parking on campus and experience the obvious health benefits of human-powered transportation.

III. PROBLEM STATEMENT

a. Problem

The bike rental system at UP is slow, cumbersome, and inconvenient. It requires users to go to the bike shop in Beauchamp during the bike shop's limited hours, human and paper interaction, and taking down student ID. Additionally, first time users must be instructed on how to properly use the system and sign waiver. We believe we can streamline this process via a bike lock activated by the swipe of a UP student ID, and a website for all other functions.

b. User Benefits

The primary benefitting user is UP students living on campus who need to go off campus to buy groceries and other various reasons but do have a car on campus. Particularly, freshmen are required to live on campus but are not allowed to have a car on campus. The secondary benefitting user is the bike shop, which needs to track and maintain bikes, in addition to checking them out to users.

c. Downstream Effects

BorrowBike offers a convenient means of transportation between campus and nearby areas. The cumbersome sign up and check out process is streamlined to on online waiver and the swipe of an ID. Users will also be able to see which bikes are available prior to walking to the bike rental station via the website. Additionally, the bike shop will be able to more easily track and maintain bikes via the website. The primary downstream effects are bikes having lower impact on the environment than motorized vehicles and an opportunity to exercise.

IV. DESIGN CRITERIA

a. Constraints

The main design considerations we are focusing on are performance, economic, and manufacturability. Performance is at the core of our design; we want users to reliably and quickly be able to unlock and lock a bike. As constraints given to us by the Outdoor Pursuits Office the lock must lock up both wheels of the bike and the frame. We also are not allowed to alter the bikes themselves. We must make a modular device that can be moved and fit to a variety of bikes. On the web app side, we want users to be able to accurately look up bike availability in real time with a simple user interface. Because these functions are involved in majority of the use cases, we need to make sure those functions are done well.

Our next important design consideration is how economic the lock is. There are many inexpensive materials that satisfy our performance and security needs, so there is no reason to spend extra money. The advantage of using inexpensive materials is that in case there is an issue and the lock needs to be serviced, or if the bike and lock go missing, it would be economical and easy to replace.

Manufacturability is another major consideration because it allows for expansion and increased effectiveness when the bike sharing system is done at larger scale. When there are more *BorrowBikes* available, more users can take advantage of the system, which has an environmental impact because users are less inclined to use an automobile.

b. Functional requirements

The basic and most fundamental functions are locking the bike, unlocking the bike, allowing users to be able to check the bike availability, and allowing admins to be able to check a bike's checkout history and data. The sub-functions making up the core functions include validating a valid I.D. card has been used, validating the bike has been successfully checked out, and validating the bike has been successfully checked back in. As mentioned above the lock must lock up both wheels on the bike as well as the frame. The lock must be able to be moved from bike to bike with ease.

Reliability and security is the highest priority for the design considerations because the main action that users will be doing is unlocking and locking the bike. Those fundamental functions must be reliable because they happen so often and if a bike isn't locked securely, a lot of money would be wasted to replace the bikes and the bike sharing program would not be used. A user should be confident every time he/she locks the bike so there aren't any worries about the bike being stolen and having to be liable for it. Also, on the software side, the main use of the web app is to allow the user to check how many bikes are available for checkout, so that information must be reliable. If the information wasn't reliable, there wouldn't be any reason to use the website. The rank criteria can be seen in Table 3.

Table 3. Design Criteria

#	*Criteria*	*Priority*	*Description*
1	Reliable	Essential	Lock must reliably stay locked and secure, not break during use; Accurate representation of bikes available
2	Security	Essential	Lock can't be broken easily; Must only be unlocked using a valid UP I.D. Must have redundant systems in the event of lock failure
3	Easy to Operate	High	Lock must be easy to find/use; Unlockable within 20 seconds; Web app must be simple and intuitive
4	Economical	High	Inexpensive enough to implement for most/all of the current bikes offered at Beauchamp, price to be determined
5	Lightweight	High	Shouldn't be large/heavy to the point where it drastically increases the difficulty to ride the bike (less than 5lbs)
6	Aesthetically Pleasing	Medium/Low	Lock itself has low aesthetic priority; Website has medium aesthetic priority
7	Easily Serviced	Low	If cheap enough to replace, not a big deal to try and fix it rather than buy a new one; Maximum of 1-hour fix time

V. SELECTION METHODS

a. Generation

Ideas for the *BorrowBike* were conceived through a timed, unstructured ideation session. Group members split off and individually brainstormed any idea that came to mind, regardless of feasibility. For fifteen minutes, members sprinted to list as many ideas or details as possible in their respective whiteboard space. Creative ideas generated spanned from a lockable bike helmet to a basket that doubled as a cage lock. System details such as an electrically charged "hot" locking cable and disturbing alarm noises arose from the brainstorm. More conventional ideas were also generated. More feasible systems included U-lock mechanisms, rear lock, ratcheted cable locks as shown in Table 6.

Table 4. Physical Lock Decision Matrix

Concept	***Basic Description***	***Foreseeable Pros***	***Foreseeable Cons***
U-Lock	U-lock attaches to a port of the housing of the computer and student I.D. scanner, wraps around parking location. Housing rests directly above the rear wheel of the bike. U-lock separates and is stored outside the housing.	Secure technology Ample space on bike rear	Separated components easy to lose Possibly bulky and heavy Limits parking locations
Rear Tire Bike Lock	Rear tire lock is fixed underneath the seat post of the bike and wraps through the rear wheel. The computer and student I.D. scanning components lie on the opposing side of the bike frame.	Light weight Compact Few materials	Doesn't lock to structures Less secure Separated components difficult for communication
Retractable Cable Lock	Retractable cable attaches to a port of the housing containing the computer and student I.D. scanner. Cable wraps around parking location, both wheels, and bike frame. A small electric current will be run through the cable to alert theft attempts to the user and administration.	Versatile locking locations Single housing unit Lightweight Lock cutting notification	Larger housing unit Moving parts Less secure than thicker U-lock

b. Selection

The team selected the retractable cable lock for our final *BorrowBike* lock design. The selection process stemmed from surveying, meetings, and research. The group initially created design criteria, and the criteria was tested via a human-centered design survey to unveil student requests and needs for the program on campus. It was well-predicted that an 'easy-to-operate', autonomous checkout was a high priority to students. Almost 90% of 120 student surveys listed that an autonomous checkout would compel them more to use a bike rental system. The ability for 24hr checkout was not fully predicted as a high priority for the system before the survey results were posted. Charging ports were then incorporated into the hub for consistent system checks and charging capabilities to enable more rental time.

For selection of the locking mechanism type, the group decided to consult Outdoor Pursuits Program Director and key stakeholder, Nathan Hingley. The group inquired about the locking requirements for the current bike rental system. After the meeting, the team concluded a cable locking system of 3/8 -in would be most effective to appease Nathan's request to secure both wheels and frame by the locking mechanism. The selection of the Arduino operating system similarly was selected after consulting Dr. Timothy Doughty, the team's faculty advisor. The simplicity and functionality for proof of concept made Arduino a safe, inexpensive decision.

Subsystem design was mostly researched by individual group members and selected by group majority. For instance, the electromagnet locking mechanism was researched online for feasibility and cost by an individual. The member presented their findings and inputted details to fit the cable key using a spring-loaded pin. The group convened with an alternative solenoid piston configuration. The pros and cons of each design were discussed, and chose the electromagnetic lock based off feasibility to lock and unlock smoothly for the user. The system of the electromagnetic lock also interfaces well with Arduino and a circuit.

VI. SUBSYSTEMS AND KEY FEATURES

a. Spool and Ratchet

Team *BorrowBike* decided to go with a spring-loaded spool and ratchet system, with the cable that locks up the bike wrapped around the spool. This allows the user to pull the cable out of the lock and lock it at the desired length. Then when the user wants to put the cable away, they simply have to release the ratchet and let the cable spool system reel the cable back to the unlocked position. The design is more user friendly compared to our alternative design of reeling in the cable via a hand crank and has fewer moving parts than the hand crank. Although the design in general will still have many moving parts that will require tight tolerances, and consistent maintenance will be necessary to sustain optimal function. An existing patent on a retractable reel with a ratchet mechanism serves as the basis for our design. This patent details a self-retracting electrical extension cord, but the concept is similar.

b. Electromagnet Locking Mechanism

The electromagnetic locking mechanism serves as a vital component behind the automated checkout system of the *BorrowBike*. When users swipe their student ID through the card reader, this will send a signal to the circuit connecting the electromagnet to switch the current from charging a capacitor to allowing the capacitor to discharge giving current to the electromagnet. The electromagnet will pull up the locking pin and release the cable, allowing the user to stow the cable and ride off with their selected bike. The simple circuity for the design allows optimal power output. The basics for the design were found from patents concerning electromagnetic locks, where they detailed devices with a movable bolt being held electromagnetically. The main concern with this design, since the lock is located on the front of the *BorrowBike* housing, is that grit and water will find their way into the locking mechanism and cause rapid wear due to abrasion. The locking component is small, difficult to access, and therefore may prove time consuming to service during regular maintenance.

c. Cable

The cable design serves as a lightweight locking system that can lock the frame and both wheels up to a variety of bike lock hubs. Since the cable can be cut or broken with greater ease than a solid metal U-lock, the lock runs a current through the cable that if cut will sound a loud alarm. Sending a signal back to the campus administrators for the bike rental system may not be a reliable option due to the device's inability to link into a cell phone network, but this could be a future endeavor.

d. Placement of lock

The lock system is located in the middle triangle of the bike, much like the extra storage bags on a touring bike. This placement creates the most space while remaining out of the way to the user's knees/legs while riding the bike. The placement also allows the lock to sit symmetrically on the bike to remain balanced. With this placement the wheels have high potential to throw dirt and water on the lock housing, which will require more maintenance to ensure that the lock remains functional.

e. Attachment System

With two friction clamps that have varying sizes of rubber spacers underneath the friction clamps the *BorrowBike* lock can be attached to a variety of bike frames. The friction clamps are bolted together via bolts that need a special tool to release (similar to a penta-bolt). If one had the correct tools the bolts could be undone and the lock unattached from the bike frame. The placement of the lock makes it so even if the lock were to be removed from the frame while locked up the bike would still remain locked up and the person attempting to take the bike would find themselves unsuccessful.

f. Arduino/ID Card Scanner/WiFi Shield

To control the whole system we used an Arduino Uno. This allowed us to have a central control that allowed us to code the hardware functionality for the lock. Attached to this Arduino we had an RFID Scanner and a WiFi Shield. The RFID Scanner functionality is to allow the users to scan their student ID and gather the information from the card and unlock the bike. The WiFi shield is how the bike is connected to the website. The shield allows the Arduino to send HTTP requests to the website thus updating the database and logging the user information. This also will send other statuses such as when the bike is checked back in or when it is stolen.

g. Website

The website allows for users to quickly look up any information about the bike share system. The homepage contains information about general policies and what the program is about. There is another page that displays a table of all the bikes and its availability status. There is an admin login page that shows more detailed table of all the bikes and includes which users checked out which bikes. Lastly, there is an about page that has contact information for Outdoor Pursuits in case there is anything that needs to be relayed directly to them.

h. Database

There is a central database hosted on Amazon Web Service's Relational Database System that the website pulls data from. Data is divided into three tables: bikes, users, and admin. The bikes table contains all the information about the bikes, such as its name/ID, type, availability, and the user ID of the person that checked out that bike. The users table stores all the names of the users in the system and their respective ID number. Lastly, the admin table stores the username and password of all the admin accounts to login the website.

VII. DEVELOPMENT

a. Subsystem Prototypes

The retractable spool system was chosen as a starting point for prototyping due to its mechanical complexity and centrality to the proposed bike lock design. A half-scale spool mockup was constructed to ensure the efficacy and performance of the proposed torsion spring design. To this end, a 5in diameter disk, 2in thick, was cut from scrap wood; for details see Figure 1. A prototype mandrel was cut from 1/4in steel rod stock, to function as a temporary axle for the spring and spool. The center of this test mandrel was turned down on a lathe until the spring no longer clamped down on it at full rotation (3 revolutions). Finally, an extension spring was modified to meet the specifications of the torsion spring shown in Figure 2 in the calculation section of this report. One end of this spring was permanently fixed in a hole drilled into the mandrel, see Figure 1. This step was necessary to fix one end of the spring relative to the spool. As per the calculations section of this report, this spring was designed to achieve 2.5lbs of force at full extension of a 5ft cable wrapped around the spool. This scale spool mockup proved the feasibility of the design; however, doubts were raised about the short-term durability of the torsion spring, which was experiencing significant plastic deformation at full cable extension. As such, the result of this prototyping phase was the design decision to shelve traditional torsion spring designs in favor of spiral clock springs.

Figure 1. The prototype torsion spring and mandrel assembly.

Figure 2. Wooden spool mockup.

The prototype lock device developed from a simple mockup, similar to the mockup spool, to the final working prototype. The initial prototype utilized a 5.5V electromagnet mounted on the top of a wooden block. A prototype steel locking bolt and steel tube receiver were fabricated and installed in the wood block. Details of this device may be found in the construction section of this report. A steel locking pin with a spring spaced between the pin and electromagnet was used to test the effectiveness of the 5.5V device. Through this first iteration a few things were learned; first the electromagnet was not strong enough to pull the pin and the spring up, also a steel pin was not effective, as the steel pin transferred the magnetism through to the entire locking system. The second prototype of the lock replaced the 5.5V magnet with the 12V electromagnet, which remained in the final device. Additionally, a new aluminum locking pin was constructed and press fitting it to a circular block of steel to replace the initial steel pin. These changes resulted in a fully functioning device, which was modified additionally during final construction to improve performance reliability.

b. Modeling

The following figures detail the products of the initial modeling phase of the design process. Figure 3 is a rendering of the final device attached to a bike. Figure 4 details the interior and key components of the final device. See Figure 5 and Figure 6 for assembly drawings of the key components.

Figure 3. Using the inner triangle of the bike for the positioning of the lock the *BorrowBike* lock can utilize the most space.

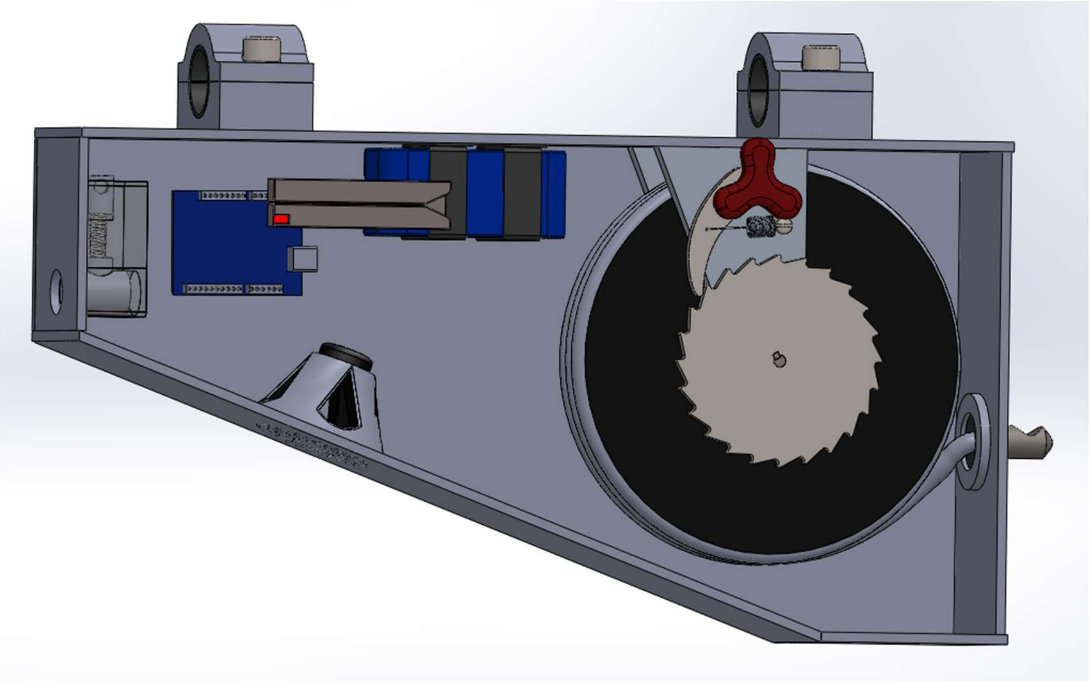
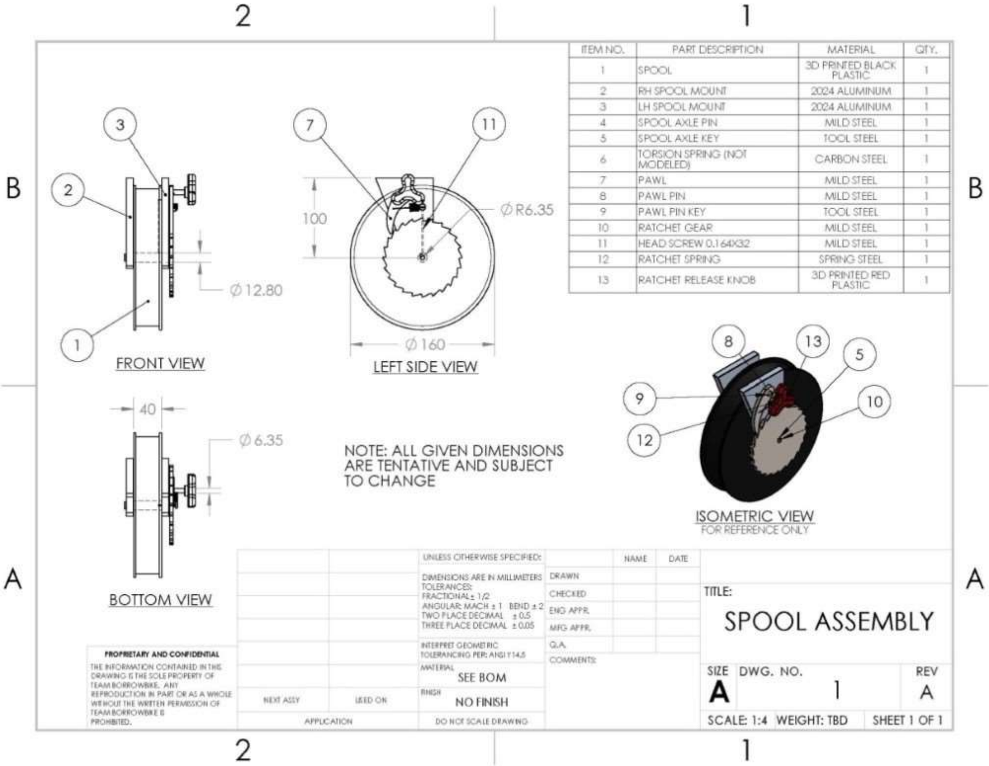
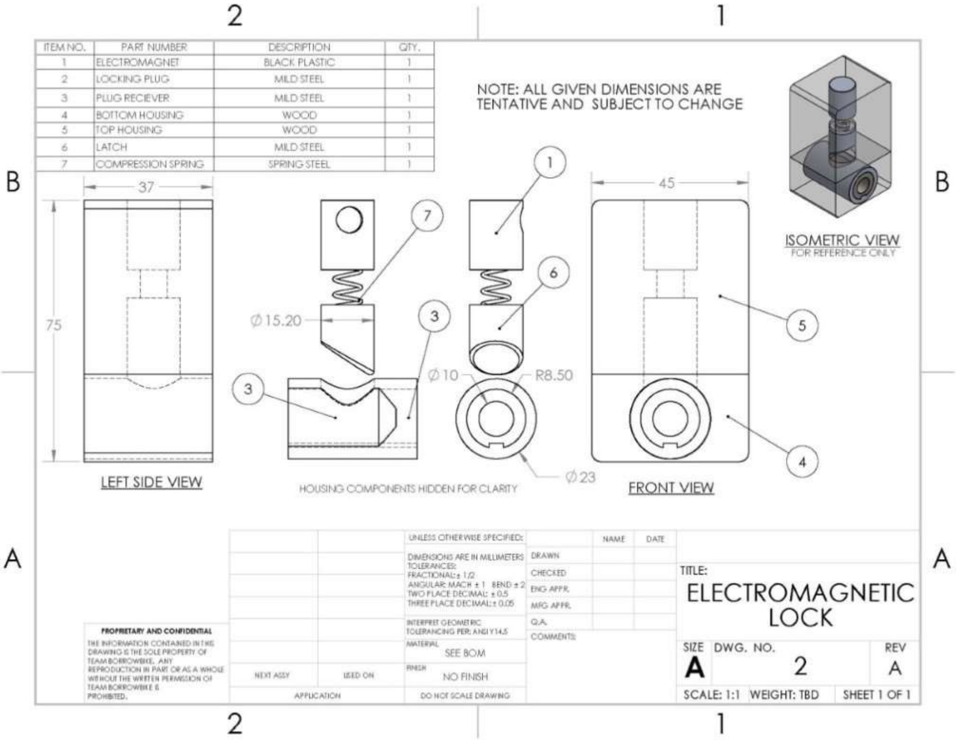


Figure 4. The cutaway of the bike lock shows the positioning of all the interior components.



ITEM NO.	PART DESCRIPTION	MATERIAL	QTY.
1	SPOOL	3D PRINTED BLACK PLASTIC	1
2	RH SPOOL MOUNT	2024 ALUMINUM	1
3	LH SPOOL MOUNT	2024 ALUMINUM	1
4	SPOOL AXLE PIN	MILD STEEL	1
5	SPOOL AXLE KEY	TOOL STEEL	1
6	TORSION SPRING (NOT MODELED)	CARBON STEEL	1
7	PAWL	MILD STEEL	1
8	PAWL PIN	MILD STEEL	1
9	PAWL PIN KEY	TOOL STEEL	1
10	RATCHET GEAR	MILD STEEL	1
11	HEAD SCREW 0.164X32	MILD STEEL	1
12	RATCHET SPRING	SPRING STEEL	1
13	RATCHET RELEASE KNOB	3D PRINTED RED PLASTIC	1

Figure 5. The retractable cable spool and ratchet assembly drawing, displaying the major components and critical dimensions.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	ELECTROMAGNET	BLACK PLASTIC	1
2	LOCKING PLUG	MILD STEEL	1
3	PLUG RECIEVER	MILD STEEL	1
4	BOTTOM HOUSING	WOOD	1
5	TOP HOUSING	WOOD	1
6	LATCH	MILD STEEL	1
7	COMPRESSION SPRING	SPRING STEEL	1

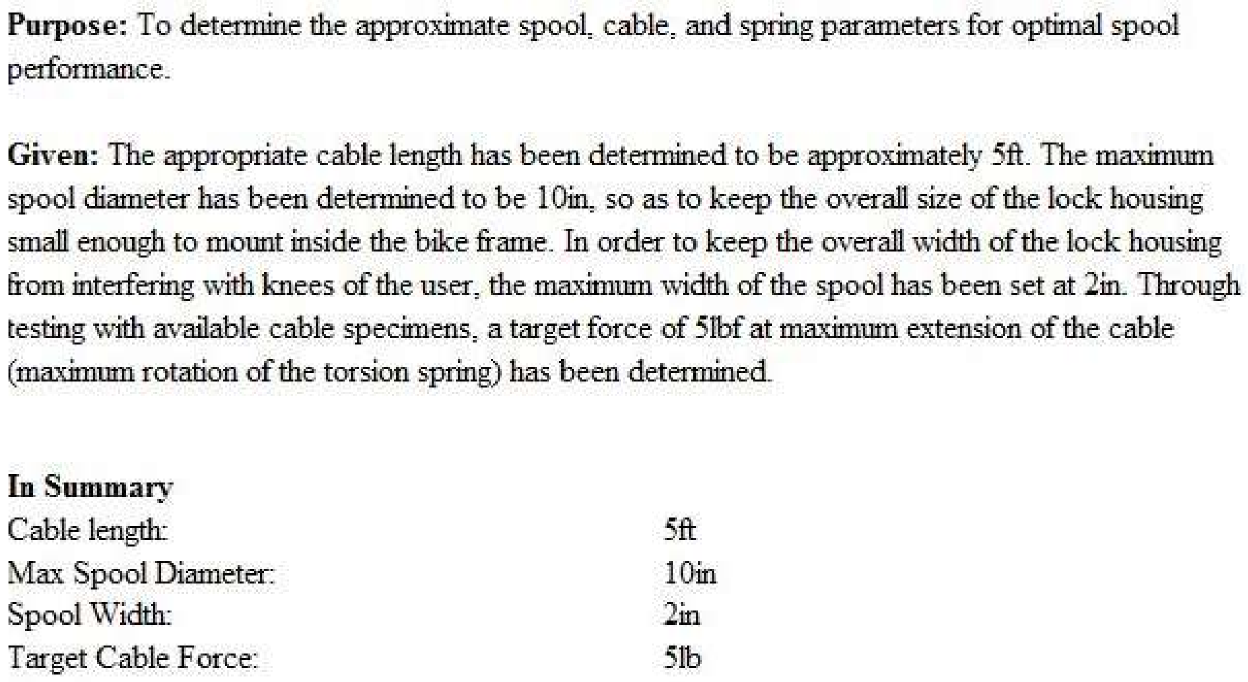
Figure 6. The figure above depicts a detailed drawing of the electromagnetic lock assembly showing major components such as the magnetic lock and locking latch.

c. Analyses

Table 5. Pro/Con Summary for Major Design Components.

Design Component	Pros	Cons
Retractable Cable Spool and Rachet Assembly	-User friendly -Smooth retraction action	-Lots of moving Parts -Not as easy to keep clean
Electromagnetic Locking Mechanism	-Simple circuitry for locking system -Mechanically simple	-Energy inefficient -Difficult to clean -Sensitive to grit and water
Cable	-Versatile for various locking hubs -Light weight -Alarm if cut	-Easier to cut than U-Lock -Cable could become tangled
Placement of Lock	-Balanced -Out of user's way -Efficient use of space	-Potential to catch water or dirt from the wheels
Attachment System	-Versatile -Durable	-Lack of security; can be removed with common tools

d. Calculations



Purpose: To determine the approximate spool, cable, and spring parameters for optimal spool performance.

Given: The appropriate cable length has been determined to be approximately 5ft. The maximum spool diameter has been determined to be 10in, so as to keep the overall size of the lock housing small enough to mount inside the bike frame. In order to keep the overall width of the lock housing from interfering with knees of the user, the maximum width of the spool has been set at 2in. Through testing with available cable specimens, a target force of 5lbf at maximum extension of the cable (maximum rotation of the torsion spring) has been determined.

In Summary

Cable length:	5ft
Max Spool Diameter:	10in
Spool Width:	2in
Target Cable Force:	5lb

Table 6. The effect on number of spool revolutions as a function of spool diameter.

Spool Diameter [in]	Cable length [ft]	Number of Spool Revolutions, N
10.0	5.0	1.9
9.0	5.0	2.1
8.0	5.0	2.4
7.0	5.0	2.7
6.0	5.0	3.2
5.0	5.0	3.8

A spool diameter between 6in and 9in is optimal to reduce the number of revolutions that the torsion spring will be required to make. Torsion springs that are capable of more than 1080 degrees of revolution are difficult to source. Additionally, in order to maximize the storage capacity of the spool at a given width (2in), an integer number of spool revolutions is superior to a non-integer number of revolutions. A spool diameter of approximately 6in will allow for the optimal number of spool revolutions for the given length of cable, and a spool width of under 2in with a 5/8in diameter cable.

Design Decision: Use a spool diameter of approximately 6in

A spool width of 2in and number of spool revolutions of 3 will allow for a cable with a maximum diameter of 5/8in (assuming some slack for spool flanges).

Using the Hooke's law linear formula for torsion spring force and torque, Eq. 1 and 2, the force and torque of the spring was calculated for values of N from 0 to 3.0. This process was completed for a variety of stock springs that are available for purchase online. A suitable spring was found given the constraints that the spring must be under 2in in length with a force of approximately 2.5lb applied to the cable at full rotation. This spring is the 72558 from Forney Industries.

Eq. 1. Torque on the Spring: $T = \frac{Ed^4N}{10.8nD}$

Eq. 2. Force on the Spool: $F = \frac{T}{r}$

Where:
T is the torque
F is force
r is the moment arm
E is the Modulus of Elasticity
d is the wire diameter
D is the coil diameter
n is the number of effective coils
N is the number of revolutions

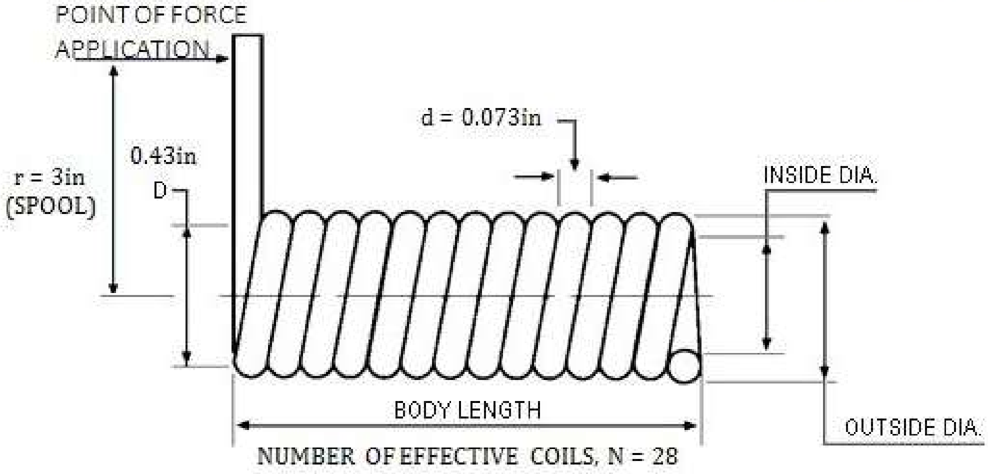


Figure 7. A typical linear torsion spring and relevant dimensions for Forney Industries spring 72558.

Table 7. Torsion Spring Parameters 72558 (Forney Industries)

Coil Diameter, D [in]	Wire Diameter, d [in]	Modulus of Elasticity, E [ksi]	Number of Active Coils, n	Number of Revolutions, N	Moment Arm, r [in]
0.43	0.073	29,000	28	0.5	3
0.43	0.073	29,000	28	1.0	3
0.43	0.073	29,000	28	1.5	3
0.43	0.073	29,000	28	2.0	3
0.43	0.073	29,000	28	2.5	3
0.43	0.073	29,000	28	3.0	3

Table 8. Force on the cable and torque on the spring as a function of revolutions of the spool.

Number of Revolutions, N	Force, F (lbf)	Torque, T [in-lbf]
0.5	1.1	3.17
1.0	2.1	6.33
1.5	3.2	9.50
2.0	4.2	12.67
2.5	5.3	15.83
3.0	6.3	19.00

This spring should be suitable as a little extra force is preferable. This is as close to the 5lbf target as can be achieved with stock springs and the given constraints. The width of the spring with 28 turns is approximately 2in.

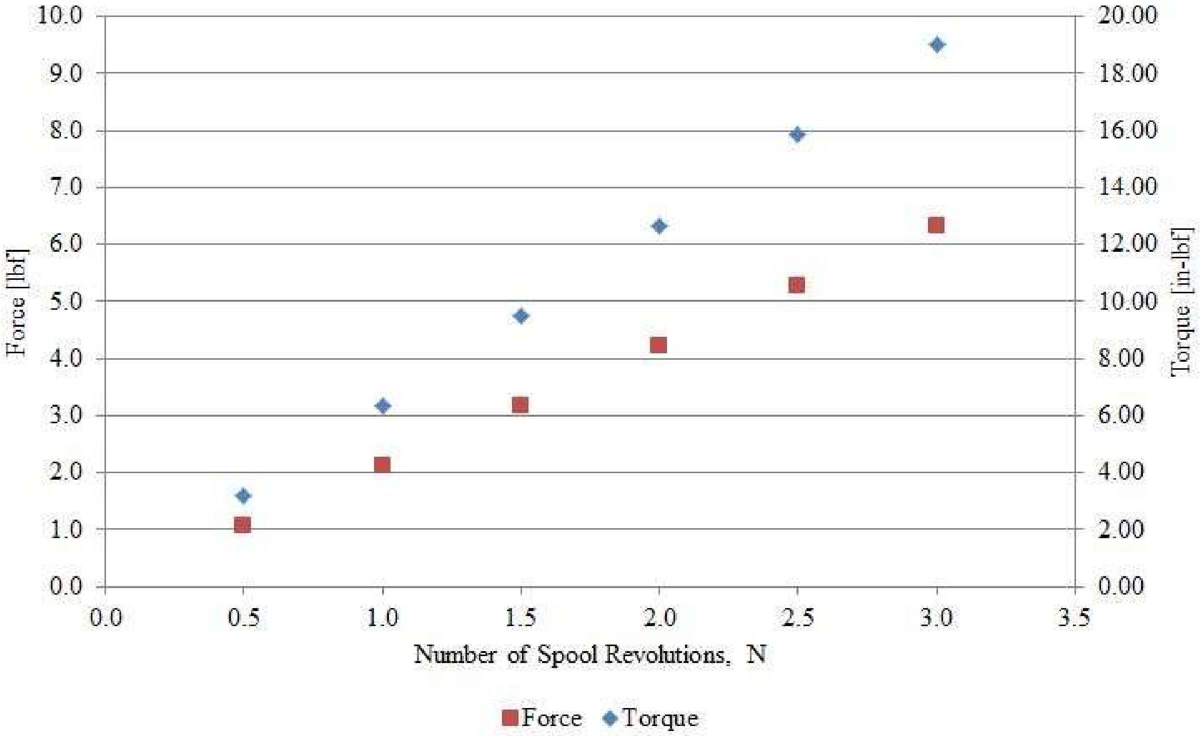


Figure 8. The relationship between revolutions of the spool, torque, and force on the cable.

e. Construction of the Retractable Cable Spool and Ratchet

Construction of the final *BorrowBike* lock began with the retractable cable spool and ratchet system. A 30ft retractable extension cord reel was purchased to form the basis for the device. The cord reel was fully disassembled, and the needed components were set aside for modification. The modifications were primarily focused on reducing the overall width and diameter of the device as much as possible given the size of the clock spring contained within the cable reel. The first step of modification was to reduce the thickness of the black plastic drum containing the clock spring; the flanged side of the drum was cut on a band saw to a final thickness of 2.1in, see Figure 9. Next, provision was made for mounting sheet metal disks to the edges of the drum to retain the cable during retraction. Nylon blanks were threaded and epoxied to the drum to facilitate the use of machine screws for this purpose, as shown in Figure 10. The existing cable retention lip was removed from the sheet metal spring cover as illustrated in Figure 11. Two replacement disks of smaller (7in) diameter were plasma cut, shown in Figure 12, to be mounted to either side of the drum. A 3/8in cable 5ft in length was chosen as the cable to be used in the final device. The looped ends of this cable were removed, as well as 1in of plastic covering from each end. The cable was attached to the drum as shown in Figure 13. The cable end was press-fit into a small bar of aluminum, secured with a set screw. This aluminum block fit snugly into the contour of the plastic, and as such, no other method of attachment was required. A wire was soldered to connect the cable end with the inner brush contact shown in Figure 14. This connection enabled the flow of current from the cable to the brushes, which would be attached to the spool mounting bracket. At this point, material was machined off both ends of the mandrel to match the final spool width of 2.1in. The finished mandrel and spiral clock spring can be seen in Figure 15. A replacement sheet metal mounting bracket was plasma cut and bent into shape. This bracket was required in order to match the final dimensions of the modified spool. Holes were drilled for mounting fasteners, and the brushes were added to the mounting bracket. See Figure 16 for the finished mounting bracket, and Figure 17 for the completed spool assembly.

Figure 9. The spool drum after being cut to 2.1in thick. Cut side opposite of shown.

Figure 10. The cut side of the drum with nylon blanks for machine screws.

Figure 11. The ratchet end-plate after removal of most of the flange.

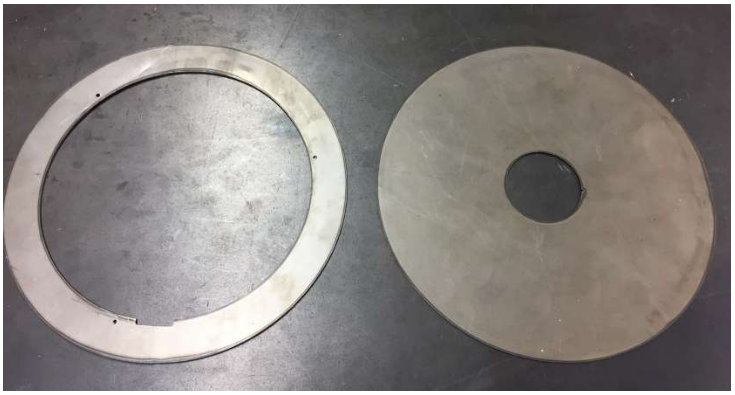


Figure 12. The replacement plasma cut disks for cable retention.

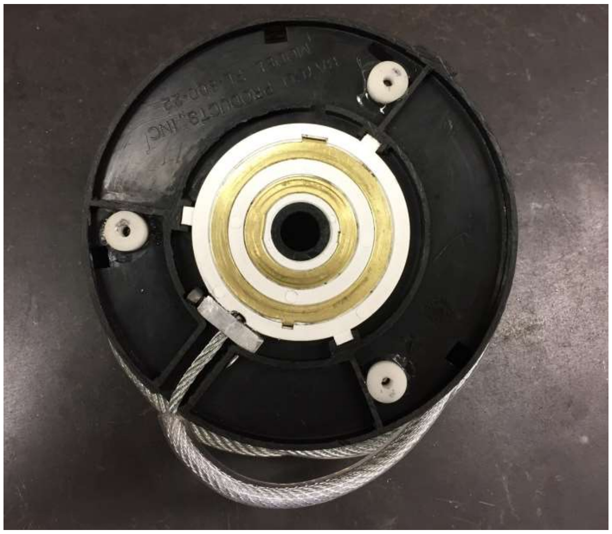


Figure 13. Cable attachment mechanism and the brush contacts recycled from the cable reel.

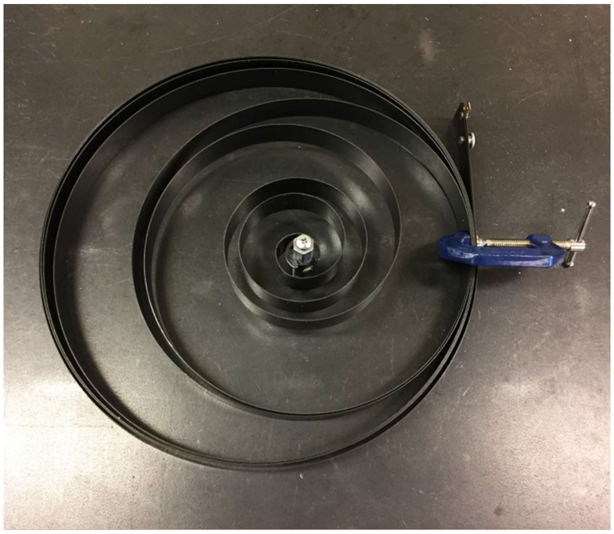


Figure 14. The final mandrel and coil spring.

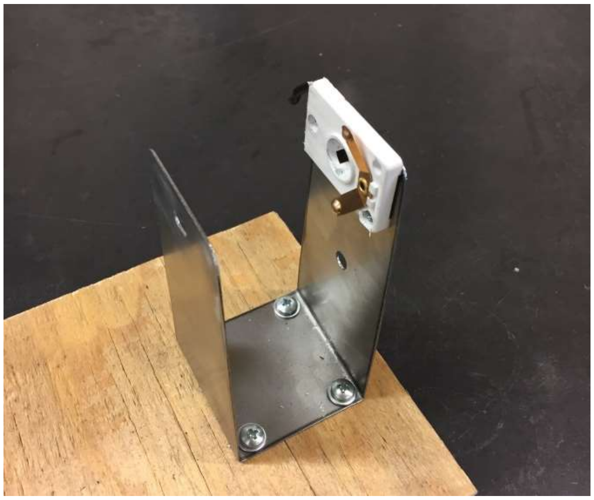


Figure 15. The sheet metal replacement spool mount and brushes recycled from the cable reel.

Figure 16. The finished retractable cable spool and rachet system.

f. Construction of Electromagnetic Lock

The construction of the lock began with the lock bolt and the lock casing. Carbon steel tube and rod stock were selected with diameters such that the rod fit inside the tube. The rod was then turned down a few thousandths on the lathe, and one end of the rod was tapered at a 45-degree angle. A mill was used to cut a small channel on the underside of the locking bolt, as shown in Figure 17. A drill press was used to place matching holes through the locking bolt and the receiving tube; see Figure 18. A locating pin was installed in the receiver tube to locate the slot in the locking bolt during insertion into the receiver. This pin was made by grinding down the threads on a screw to a diameter that matched the width of the slot. The pin was then mounted through the receiver pipe and retained using several hex nuts as depicted in Figure 19. The receiver tube was then press fit into a block of scrap wood as shown in Figure 19. A metal plate with a spring affixed to the interior was attached to the back of the lock housing in order to eject the locking bolt after activation of the electromagnet and subsequent removal of the locking pin. The locking pin was cut from aluminum rod and was shaped with a grinding wheel to match the approximate geometry depicted in Figure 6. This pin was then press fit into a steel plate with a pre-drilled hole for the pin. A counter sunk hole was drilled above the lock housing to make room for mounting the electro magnet. The electro-magnet was mounted on the top of the wooden block with two nylon cylinder spacers precisely defining the distance between the magnet and the locking pin as seen in Figure 20. This distance controlled the travel of the pin when the magnet was activated. Finally, the decision was made to remove the spring that returned the locking pin to its initial position once the electromagnet was deactivated. This change was necessary due to time constraints and locking pin alignment issues.

Figure 18: The locking bolt with hole for the pin

Figure 17. The slot on the underside of the locking bolt.

Figure 19. The lock reciever press fit into wood.

Figure 20. The finished lock assembly.

g. Construction of Shroud and General Assembly

After spool, electromagnetic lock, and circuitry fabrication was completed, the shroud design was revised to reduce the volume of the bike lock. The length dimension was reduced from 19in to 13.5in, the height was reduced from 10.5in to 8.5in, and the depth was reduced from 3.5in to 2.75in. This was accomplished by mounting the RFID scanner onto the electromagnetic lock, procuring a smaller battery (2.5in x 2in x 3.5in), mounting the Arduino to the bottom wall of the lock and mounting the breadboard to the top of the back wall clearing space for electrical harnessing between the two, see Figure 21. The shroud was fabricated using 16-gauge mild steel and was tack-welded at corners in rough 3-in increments. 16-gauge steel was chosen because it was thin, durable, and weldable for secure shroud encasement. Bike mounts were fabricated on the top of the shroud using stock aluminum block. Two sets of 1in by 2.5in bike mounts were created 10.5in apart avoiding interference with spool and electromagnetic locks. Allen head cap screws were counter-bored into the mounts into the top of the shroud wall fastening the lock to any 1in diameter bike top tubes.

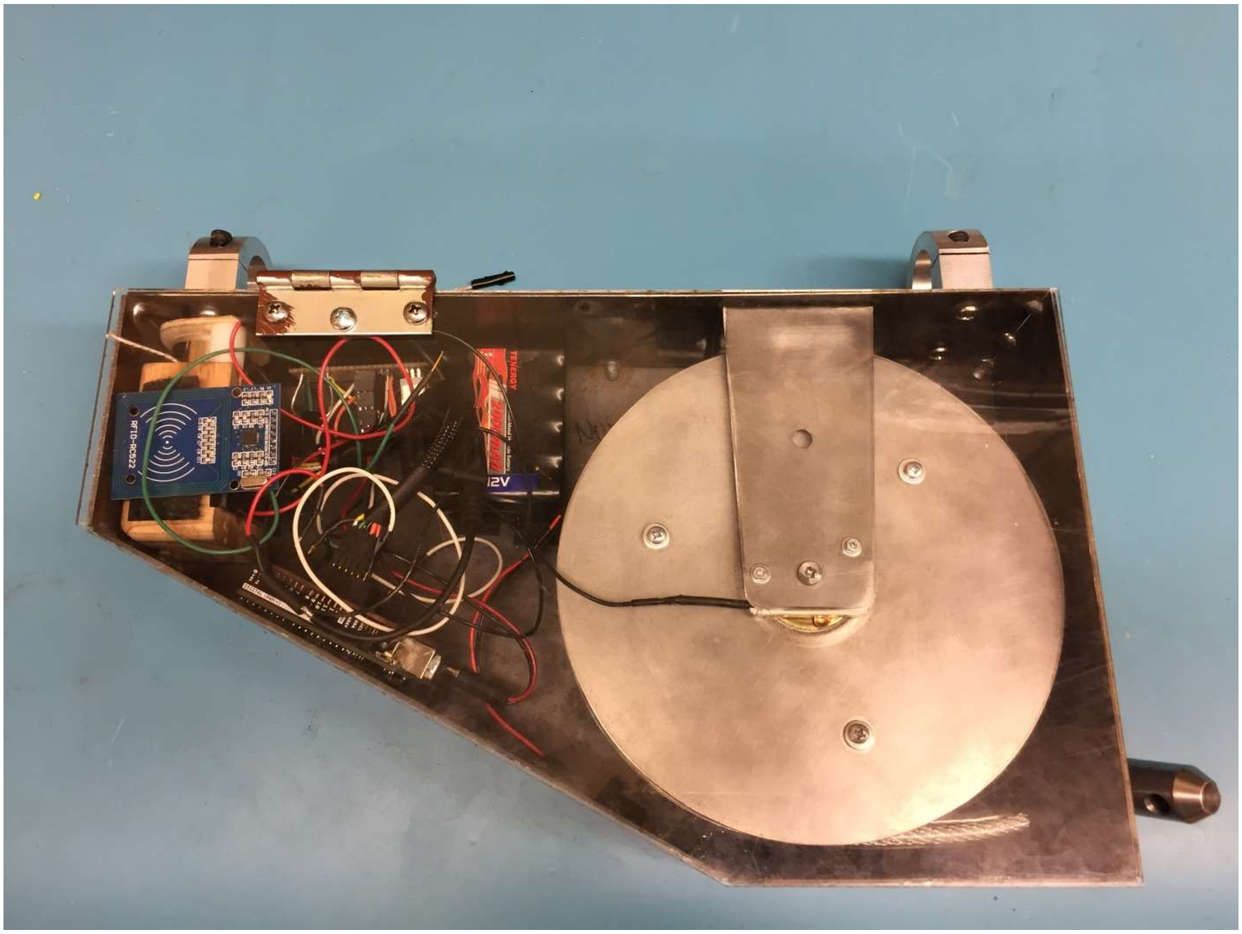


Figure 21. The final assembly of the bike lock proof of concept device.

h. Construction of the Circuit

The circuit began with the Arduino and was constructed off of this central point. The WiFi Shield was connected on top of the Arduino and then the circuit extend from there. Next, the RFID Scanner was connected and is powered from the 3.3V output on the Arduino. When it came to adding power to the circuit and adding in the electro magnet, the circuit became more complicated. We discovered that when the magnet is turned off and on, it can cause a negative back current that could be harmful to the Arduino. To fix this a diode was included, this allows for current to only flow in one direction, so when a negative current is sent back it cannot go through the diode. To power this entire circuit, a 12V battery was used, however the Arduino only requires 5V. To step down this voltage a mosfet was used. For added protection, a fuse was included in this circuit to protect from any excess of amps flowing through the system. A 2amp fused was used for this circuit. The last components to be added were the cable and the speaker. The cable acts as a resistor that is connected to the Arduino, this allows the Arduino to read if it is connected to the circuit and if it gets cut sound the alarm on the speaker. The speaker was able to be connected directly into the Arduino.

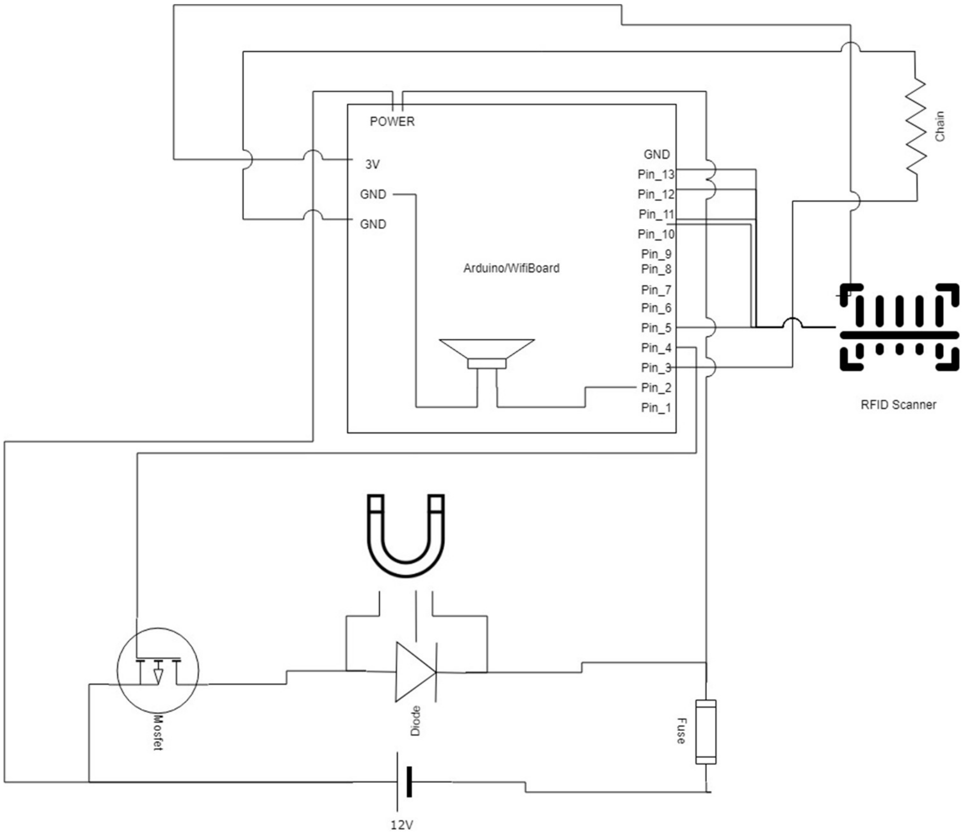


Figure 22. The finalized circuit diagram for the bike lock.

VIII. TESTING

a. Spring Testing

To validate the spring parameters determined in the calculations section, a simple test was performed using the half scale wooden spool mockup. The procedure for this test consisted of rotating the spool in half revolution increments from 0.5 to 3.0 revolutions, while measuring the force at the edge of the spool radius with a fish scale. See Figures 2 and 23 for the test setup and Figure 24 for the results of this test. The data were in agreement with the theoretical values from the calculations section for small revolution values. However, the relationship became significantly nonlinear after 2 revolutions as the spring plastically deformed. This deformation resulted in a small amount of permanent set that would negatively affect spring performance in subsequent trials unless the spring was bent back to the correct shape. As a result of this testing, the decision was made to replace the traditional torsion spring with a spiral clock spring. The relatively constant force output of a clock spring was also a factor in this decision, as a constant force would ensure reliable retraction of the cable from any position.

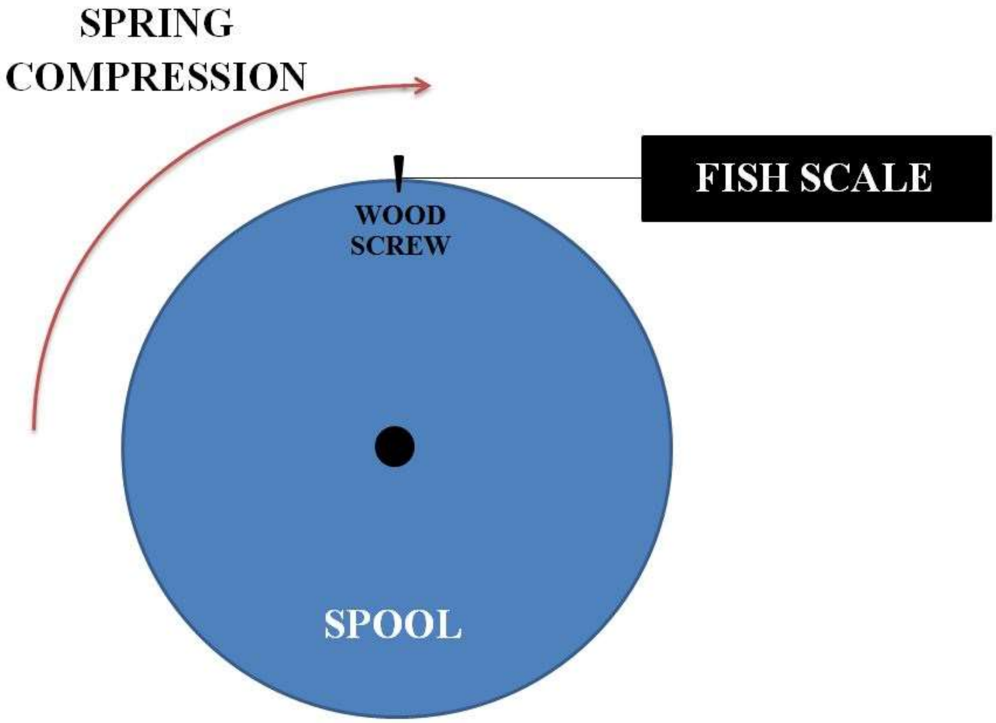


Figure 23. The test setup used to assess the performance of the 72558 torsion spring from Forney Industries.

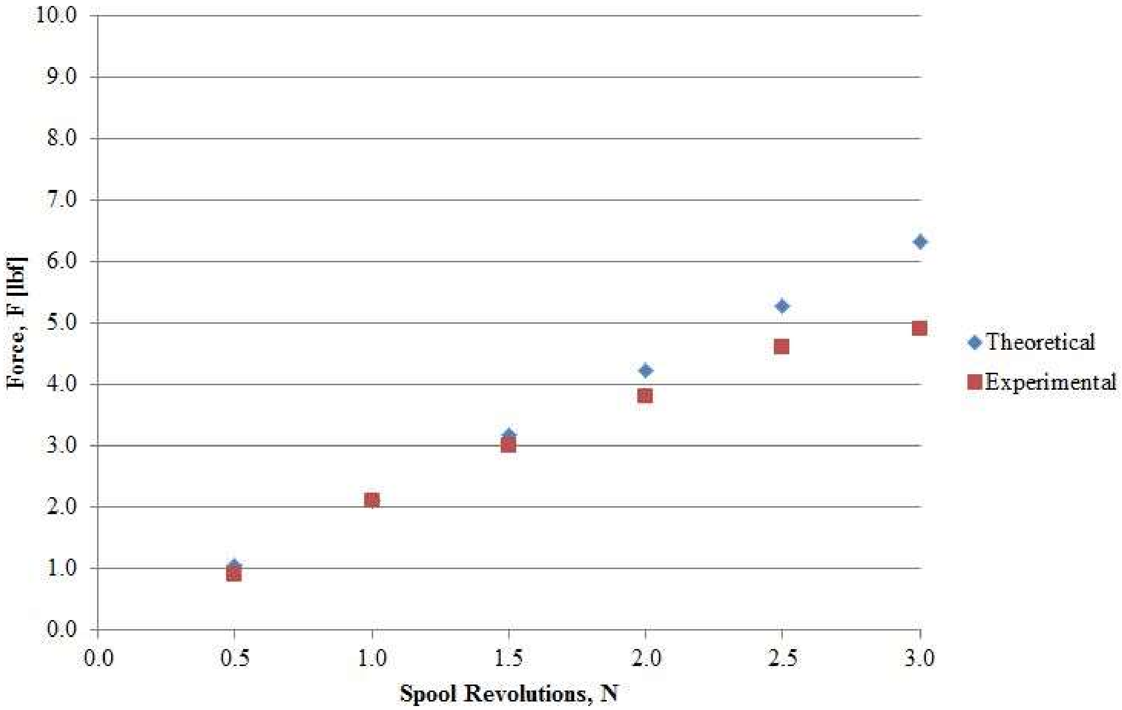


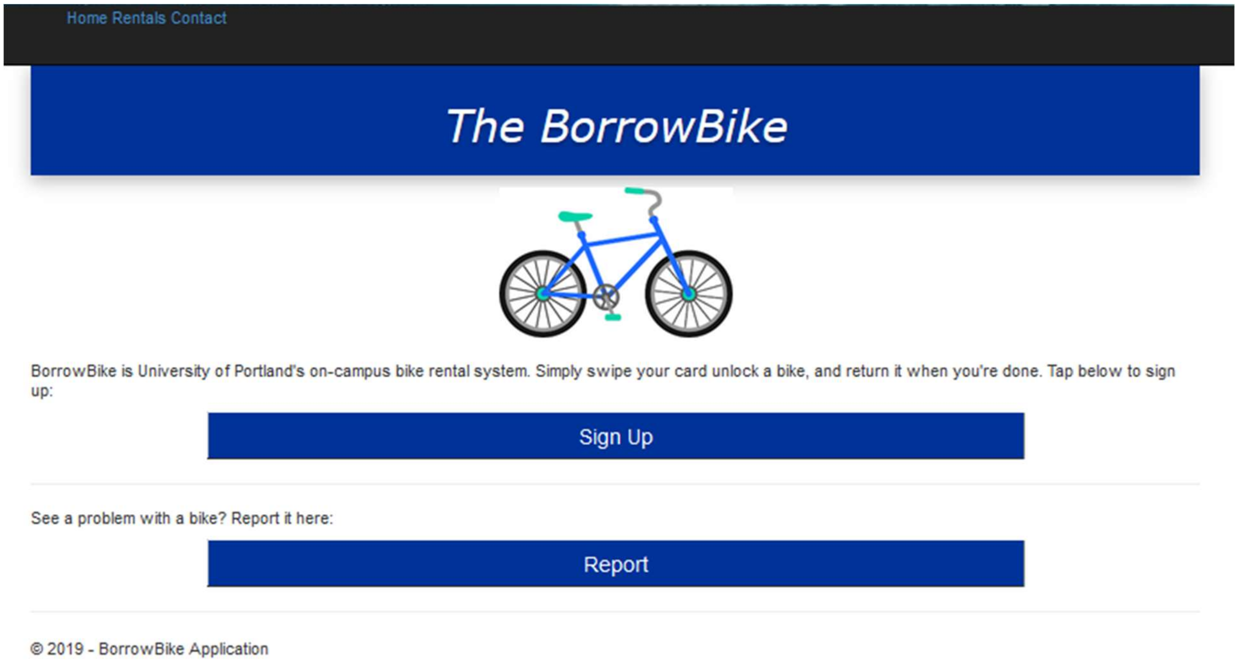
Figure 24. The force vs. revolution results of the 72558 spring test. Considerable deformation was observed past 2 revolutions.

b. Circuit Testing/Prototyping

For the testing and prototyping of the circuit, it was completed using an iterative testing and building approach. First, the Arduino, WiFi Shield, and the RFID Scanner were put together. This was then tested to see if it was capable of reading data from the card and send it to the website. Once this functionality was consistent the next step was to add in the electro-magnet. We tested the functionality of unlocking the bike using the magnet and the previous functionality of sending data to the website. Once it had consistent functionality of reading the card, sending to the website, and unlocking the lock, next step was the cable. The next round of testing was with the cable and the speaker. This test was adding in the functionality to the prototype that if the cable was cut the alarm would sound through the speaker and the website would be alerted. The final step in this process was putting it all together and fitting the circuit into the casing for the bike lock. Then the final testing was ensuring it all functioned together properly.

c. Website Testing/Prototype

A simple prototype of the website without interaction with data was created by the end of the first semester. It consisted of a mockup of the basic webpages, as shown below in Figure 25, along with a mock-table of the database of bikes, however, the bike list wasn't connected to a real database. Also, there wasn't a way for the Arduino to connect/talk to the website.



The BorrowBike

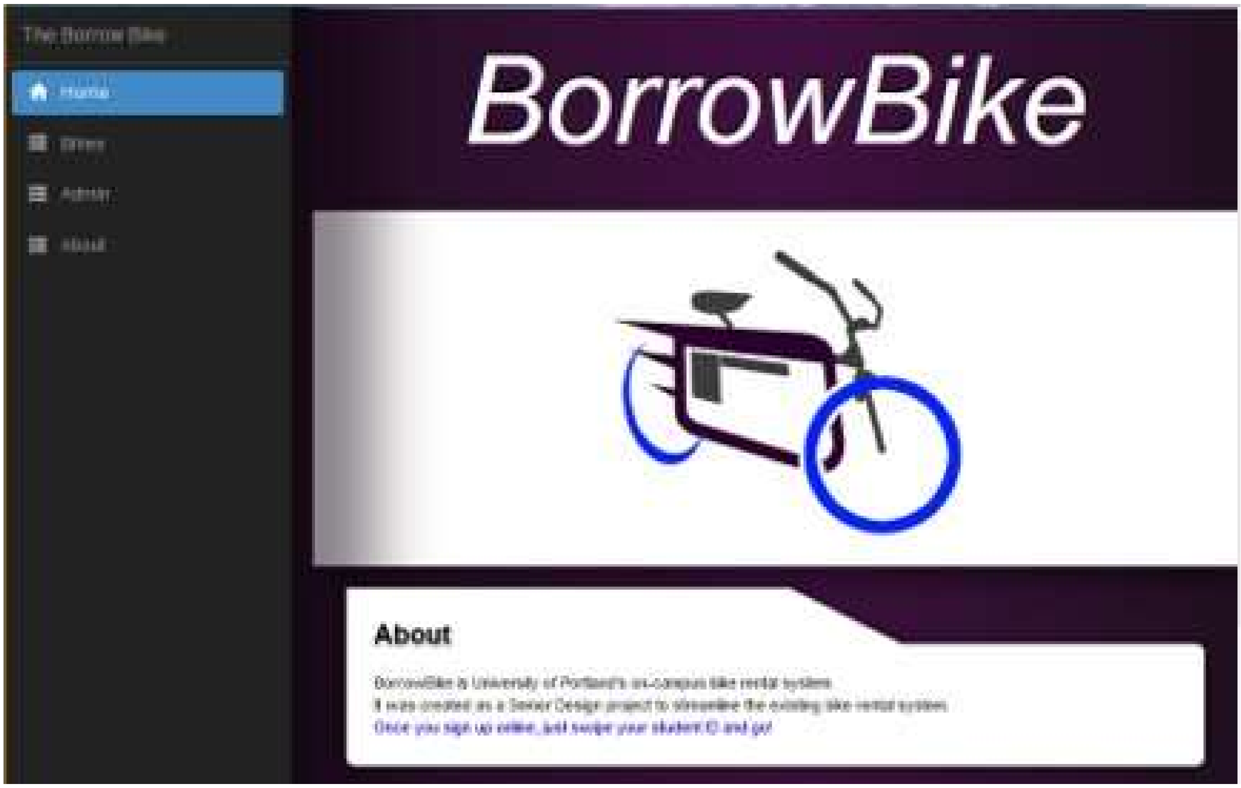
BorrowBike is University of Portland's on-campus bike rental system. Simply swipe your card unlock a bike, and return it when you're done. Tap below to sign up:

See a problem with a bike? Report it here:

© 2019 - BorrowBike Application

Figure 25. The front page of the website prototype.

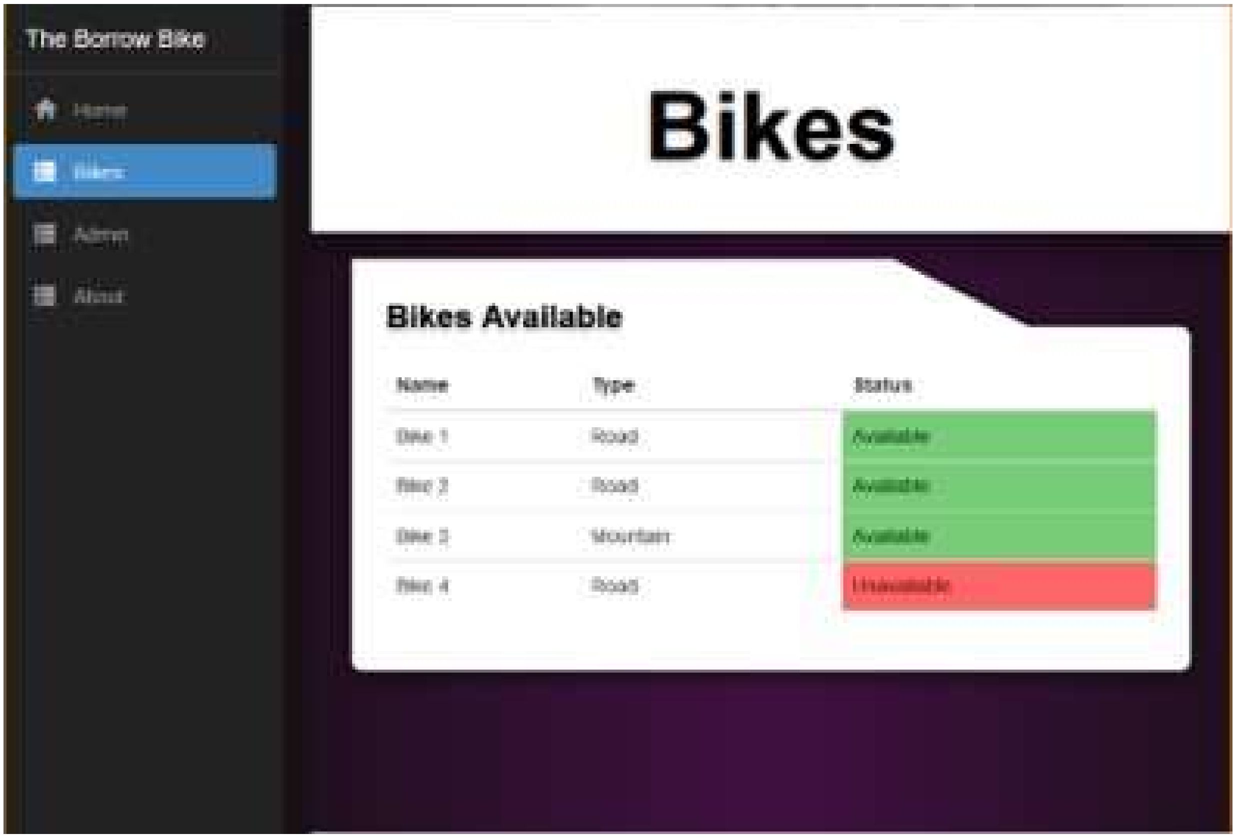
Later, we created a SQL database and refactored the website to use Angular. Thus, the website code is now cleaner, more scalable, and updates to a real database. The website interface was also reconstructed and fleshed out. Below are screenshots the two primary pages that users interact with. Figure 26 displays the final Home page, while Figure 27 shows the Bikes page.



About

BorrowBike is University of Portland's on-campus bike rental system.
It was created as a Senior Design project to streamline the existing bike rental system.
Once you sign up online, just swipe your student ID and go!

Figure 26. The final Home page in website mockup.



Bikes Available

Name	Type	Status
Bike 1	Road	Available
Bike 2	Road	Available
Bike 3	Mountain	Available
Bike 4	Road	Unavailable

Figure 27. Bike availability is displayed on the Bikes page in website mockup.

Because the Arduino code is developed separately from the website, there had to be separate way to test the transfer of data. A tool called ARC, Advanced Rest Client, was used to simulate HTTP requests to the website. Using this tool, we were able to mimic bike checkouts and check ins, as well as simulating which users checked out the bike.

Another element of the website that had to be tested separately was the database. During its initial development stages, the database had to be constantly updated with new tables, columns, and relational attributes. Because of the constant changes, a local copy of the database needed to be tested on first before pushing the updates to the live database. After making changes to the database, HTTP requests would be sent from ARC to test if it was being updated correctly and if the data was being stored correctly.

d. Relevant Engineering Standards

For the final proof of concept for the *BorrowBike* one of the most relevant engineering standards included the IEEE standard 1688-2015. This standard describes in detail the requirements for the control of electromagnetic bodies interfacing with replaceable electronic modules[13]. The abstract of the standard dictates that “this standard is suitable for items that have...electrical interconnections primarily through edge connectors that interface directly with a backplane...the standard is based on MIL-STD-461E system/equipment level electromagnetic interference (EMI) controls).” The team’s circuit revolved around the control of three components the RFID reader, the WIFI shield, and finally the electromagnet. All components plugged into an Arduino controller, which is essentially a ‘backplane’ (control pins wired in series). The pins the connect into the Arduino can be categorized as replaceable electronic modules (REMs). This standard is the reason that the circuit the *BorrowBike* team designed and put together in the final prototype had a diode wired in series with the electro-magnet. The diode prevented a back load of electrons flowing into the REMs when the current is cut to the electro-magnet. This in turn protects the input controller pins and the backplane device that the pins are connected to. The same phenomena happen with inductors. There are no specific metrics involved with this standard, just specifics for the orientation of the circuit.

IX. CONCLUSIONS

a. Project Summary

The goal of this project was to create a prototype for a bike share system exclusive to UP students. The idea behind this was to allow students to unlock/checkout a bike to rent using their student ID cards, while complying with the boundaries set up by Outdoor Pursuits. Over two semesters this prototype was created. First, to follow Outdoor Pursuits standards of locking up both wheels and the frames, that resulted in the cable design. The cable allows an ease of use that allows the user to lock up all the components of the bike and provide an easy spooling mechanism when unlocking. For, the power and control of this project, an Arduino was used. The Arduino allowed a RFID reader to be used so a student could swipe their ID, which resulted in the unlocking of the bike via the elector-magnet pulling a locking pin. The next aspect of this project was to allow the users and administrators access to information about these bikes. A website was built where the standard user could see the number of bikes available and their type. The administrator would see this information along with the students who would checkout the bike. This information was updated by the bike itself. Once again going back to the Arduino, when the bike was unlocked using the scanner, the ID information was logged. A WiFi shield was connected to the Arduino and allowed the transfer of data from the bike to the website. When the bike was unlocked and then locked back up, the check in process would be initiated and the website would set the bike back to available. In conclusion, this proof of concept was able to successfully use all these components to create a theoretical bike share system for UP. There is much more work to be done. If future teams decide to improve and move forward, then one day an actual product for UP can hopefully be developed.

b. Future Mechanical Work

Although the result of this project was an effective proof of concept, there are several improvements that would significantly upgrade the performance of the device. The most critical of these alterations is the implementation of a powerful speaker capable of startling any would-be thieves. This speaker is a fundamental component of the security criterion for the device, and as such, it would be the first addition pursued. Next, significant mechanical optimization work would be pursed with the goal of reducing the size and weight of all components. In particular, the current retractable cable spool is unnecessarily oversized, as the cable reel it was derived from enabled up to 30ft of extension. The reduction in size of components would also reduce the weight of the protective shroud of the bike lock. Finally, this shroud could be redesigned and fabricated with formed steel sheet to be more aesthetically pleasing. This new shroud would feature mounting plates welded to the interior for attaching internal components, further enhancing security. A maintenance access hatch and lock would be added to the bottom of the device, accessible for administrators with a key. The completion of these mechanical improvements would yield a final product exceeding the expectations described by the original design criteria.

c. Future Software Work

There are several future projects that can be taken on to improve the software of this project. First, one aspect would be to sync with University of Portland Accounts. This has potential to add many more features to this project. One such feature is it would allow the project to use real student info and verify that the student is a part of the UP community. Also, this would allow people to sign the safety waivers virtually (as needed by Outdoor Pursuits) and allow them to rent bikes without going into a physical location. This future feature would be a key element if this project would ever become adopted into the UP community. Another future feature would be maintenance info for the bike shop. This could alert the bike shop when the bike should be serviced; this could be information such as amount of time since last service, the number of miles the bike has been used (paired with GPS), or battery life information. The last aspect that can be improved upon is the security of data transfer between the bike and the website. Before sending data, a few things can be changed, such as having a three-way connection handshake before sending the information from the bike to the database and encrypting the data so that way if it is intercepted it can’t be read.

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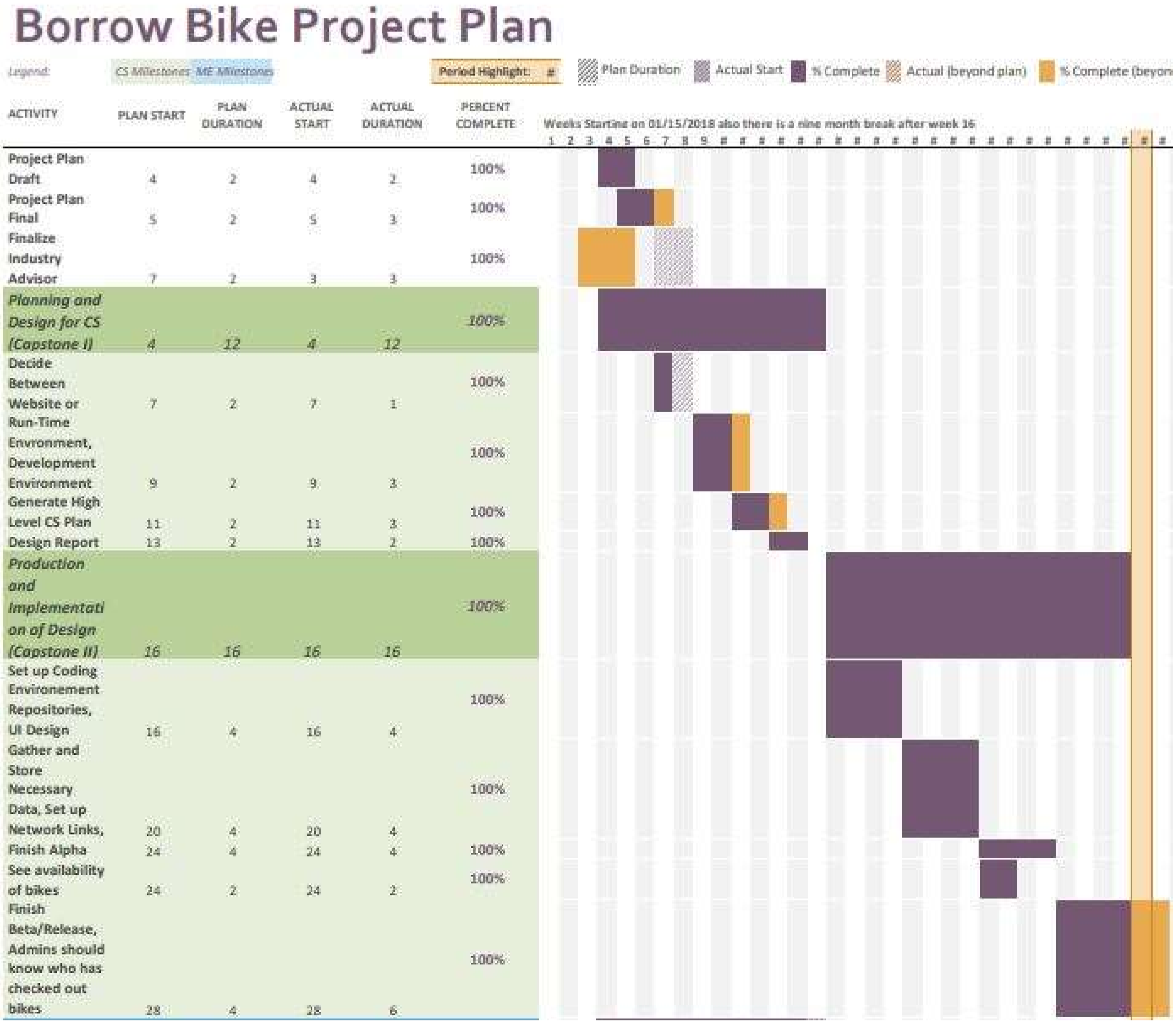
Appendix A – Final Budget and Expenditures

Arduino	$17.00
6 Foot Bike Lock	$9.99
7 Feet Bike Lock	$12.99
Fuses	$8.79
30ft Extension Cord	$40.00
Spring Assortment	$5.90
Wi-Fi Shield (x2)	$38.00
RFID Scanner (x2)	$13.00
Power Connector	$6.48
AAA Batteries	$12.78
Battery Holder Case	$8.00
Battery Pack	$21.98

Total:
$194.91

Appendix B – Final Timeline



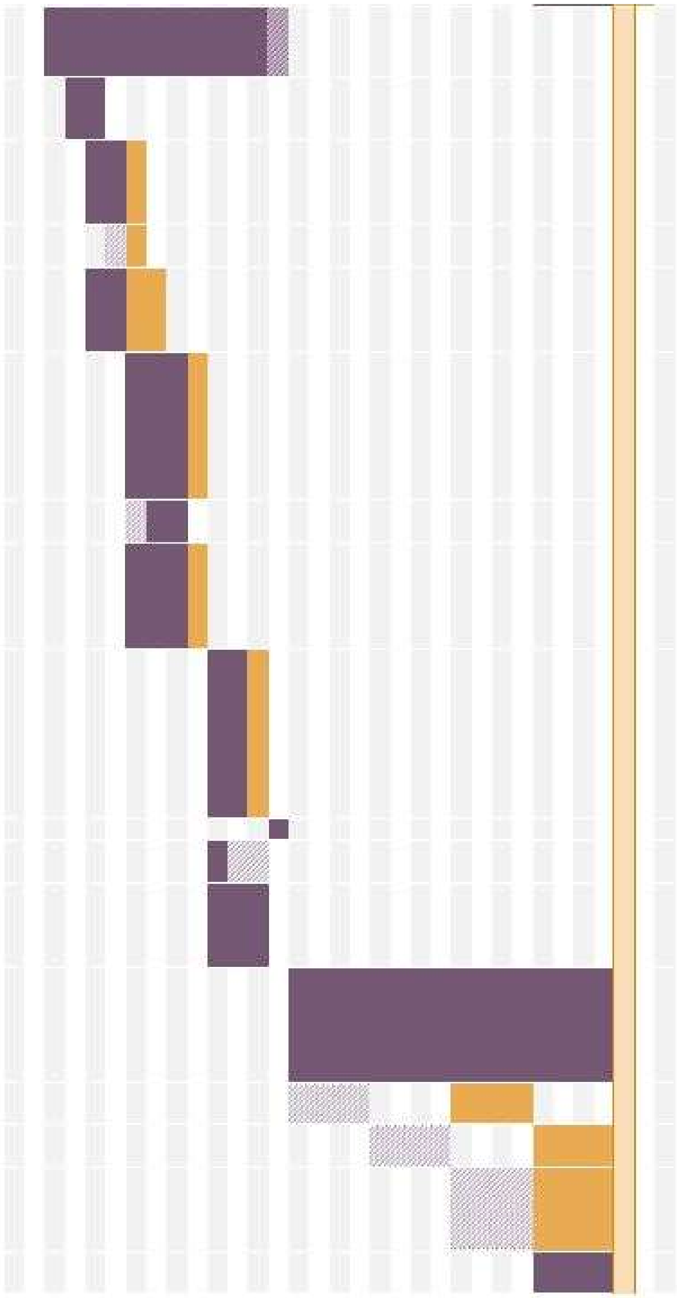
Borrow Bike Project Plan

Legend: CS Milestones ME Milestones Period Highlight: # ▨ Plan Duration ▨ Actual Start ■ % Complete ▨ Actual (beyond plan) ■ % Complete (beyon

Weeks Starting on 01/15/2018 also there is a nine month break after week 16

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Project Plan Draft	4	2	4	2	100%
Project Plan Final	5	2	5	3	100%
Finalize Industry Advisor	7	2	3	3	100%
Planning and Design for CS (Capstone I)	*4*	*12*	*4*	*12*	*100%*
Decide Between Website or	7	2	7	1	100%
Run-Time Envronment, Development Environment	9	2	9	3	100%
Generate High Level CS Plan	11	2	11	3	100%
Design Report	13	2	13	2	100%
Production and Implementation of Design (Capstone II)	*16*	*16*	*16*	*16*	*100%*
Set up Coding Environement Repositories, UI Design	16	4	16	4	100%
Gather and Store Necessary Data, Set up Network Links,	20	4	20	4	100%
Finish Alpha	24	4	24	4	100%
See availability of bikes	24	2	24	2	100%
Finish Beta/Release, Admins should know who has checked out bikes	28	4	28	6	100%

Planning and Design for ME	*4*	*12*	*4*	*12*	*95%*
Preliminary Design Criteria Completed	5	2	5	2	100%
30% Design Completed (high-level functionality	6	2	6	3	100%
Decide on final Design idea	7	1	8	1	100%
Complete Validation for Final Design Idea	6	2	6	4	100%
60% Design Completed (Locking Structure, Spatial Arrangement, Materials)	8	3	8	4	100%
Preliminary CAD Completed	8	3	9	2	100%
Draft of Compiled Design Doccumentation Completed	8	3	8	4	100%
90% Design Completed (Detailed Connections, Sourcing Human Interface reliabilty	12	2	12	3	100%
Design Report	15	1	15	1	100%
Finalized CAD Design	12	3	12	1	100%
Finalized Doccumentation for Design Justification	12	3	12	3	100%
Production and Implementation of Design (Capston II)	*16*	*16*	*16*	*16*	*100%*
Electronic Prototype	16	4	24	4	100%
Strucrual Prototype	20	4	28	4	100%
Validation (Testing and enhancments to proto type)	24	4	28	4	100%
Finish and Launch	28	4	28	4	100%



Appendix C – Individual Contributions

Ryan Dehart

Early on, I did research for needed parts on the CS side and got a cost estimate. In addition, I created our administrative website, which contains our project information, team bios, and documents such as weekly updates. I continued to improve and add to the site throughout the year. It was my job to post weekly updates to the site. In the latter section of the year, I worked on the UI of our CS prototype: the primary website. I also tended to fill in gaps when someone was overwhelmed.

During the second semester, I continued to fill in gaps where needed and recreated a second prototype of the website. The second prototype was scalable, connected to our real database, clean and improved aesthetics, and had all primary pages fully fleshed out. I also was generally the one starting and keeping track of deliverable documents, particularly during crunch time.

Aaron Leung

For the first semester, I was mainly involved in with the design and functionality of the website. While we didn't do much of the actual developing, I helped brainstorm all the requirements, functionality, and general layout of the website. I was also designated as the card holder and managed all the budget and finances for the project throughout both semesters.

The second semester I was more involved and developed most of the elements of the finished website. I developed the backend program, which handles all the incoming data and processes it into the database. I also setup the database and designed the tables that went into it. Another important element of the project was the Web API, which is how the Arduino is able to send information to the website. I worked closely with Grayson to develop that and cater the Web API to fit his needs. Lastly, I laid out all the basic functionality and web pages of the web application. Once all the components of the website were laid out, Ryan was able to take it over and redesign the UI. In the final presentation and report, I completed the subsystem/prototype sections that relate to the website and database, as well as the budget table.

Jack Padon

I contributed in project planning, researching, preliminary design, outreach, and reporting. I created the One Drive project folder, drafted a materials budget and role definition table for the project plan. I researched electromagnetic locking mechanisms, sourced a vendor, and designed ancillary components for preliminary design before CAD modeling. I co-created the human design survey and distributed it through email and UP Pilots Digest bulletin. I reached out to stakeholders such as Nathan Hingley, director of the existing bike share system, Kate Rohl, community partnership director, and Gerald Gregg, Public Safety Director. I successfully acquired a bike to use through Public Safety. I followed up with reporting the concept and selection sections of the design report. I also vetted the final poster for Founder's Day to improve conciseness and aesthetic appeal. Along the course of the semester, I also contributed efforts to ask clarifying questions to make sure the team is on the same page.

During the second semester, I fabricated the first iteration of a pawl ratchet system to access form, fit, and function. I identified spring sizing to avoid slippage from the pawl to the ratchet in rapid retraction. When the decision to procure a retractable spool assembly occurred, I refocused energy into spatial arrangement of the lock assembly. I dimensioned all components within the lock, arranged best spacial configuration, and fabricated the lock shroud and to house the lock and the acrylic siding for prototype presentation. I did research into bikeshare markets on campuses nationwide and assisted in enhancing our presentation through storytelling devices such as narrative, levity, and theme. I also completed introduction, background, and shroud assembly sections for the final report.

Jesse Rubenstein

My individual contribution includes helping to brainstorm and determining the general physical design for the *BorrowBike* locking system, through comparing other ideas and coming to a final design idea. I designed the electromagnetic lock and created the CAD for this component of the design. I designed several other small components in CAD specifically for the poster (which were also utilized for the design report) including the speaker, the card reader, and a mock Arduino unit. I also put together the basic analysis for the mechanical side of the project for the poster presentation and the final design report. For my contribution concerning the team in general, my title was Mechanical Engineering Lead and Design Engineer, which allowed me to look at designs from a larger picture perspective focusing on making sure the smaller components of design fit into the project as a whole. I developed the project description for both the project plan and the design report. I drafted the schedule for the team, attended meetings coordinating with factions outside of the team, and completed my sections for required documents.

Second semester contributions included working on the spool prototyping in the early stages. I assisted with the general construction of the prototype and testing. I completed the full construction and fabrication of our electromagnetic lock and locking systems. This phase also included the testing and redesign of the system to ensure that it was in working order. This led into my contribution to helping design, construct, and complete the circuit. The circuit was completed with Grayson as he had the know-how with the Arduino coding that determined whether or not our circuit was hooked up correctly. The final contributions included aiding in final assembly and finalization of our presentation and design report with the entire team. I also contributed content to the design criteria, the selection process, the modeling, construction, and the Gantt chart to the final report and presentation.

Grayson Taylor

For the first semester of this project, I had two main roles, Team Lead and Application Developer. As the Team Lead, I set up team meetings, ensured we met our goals and deadlines, helped delegate tasks to the team, maintained the team calendar, and kept the team organized and on task. As the Application Developer, I set up most of the backend data and servers. I set up our Azure Database, our version control on GitHub, and the AWS web server in order to host the website. I also linked all of these to the web application. I created the initial code set up for our User Interface and did some minor User interface modifications and editing. Other tasks that I accomplished was Resource planning for the Project Plan and the software concepts for this document, as well as two weekly updates. Also, for both of documents mentioned before, I did a lot of editing and various minor modifications.

For the second semester of this project, my technical role shifted, and my team role was less prominent. When it comes to my team role of Team Lead, this was not as prominent since early on we divided up work and everyone knew which technical aspects to work on. I always made sure to remind people of any work that they needed to do and keep us on schedule, but by stepping back from a traditional team lead role the team was more effective. Everyone became fairly independent and we were able to be more collaborative. When it comes to the technical lead I stepped away from the website and relinquished these tasks to Aaron. I moved into working on more hardware code and circuitry. My new goal was to program the Arduino and put together the circuit in conjunction with Jesse. Jesse and I collaborated on putting the circuit together, and then I coded the Arduino to make it function. I also helped put the circuit into the final casing for the prototype. Finally, I assisted on the presentation and the final report by doing many of the circuitry sections and editing the documents.

Martin Woodby

As the Documentation Officer for team *BorrowBike* my official role was to record meeting minutes for all team and advisor meeting throughout the semester. In addition to this role, I also functioned as an active team member during meetings and brainstorming sessions, while completing deliverables on time with a great attention to detail. For the first major deliverable, the Project Plan document, I contributed the entirety of the Background section including completing all necessary research. During the beginning of the design phase I played a key role in the development of our final design. The electromagnetic lock, retractable cable spool system, and mounting mechanism were design elements that I initially proposed. I completed the design work for the cable spool, torsion spring, and ratchet, including all relevant calculations listed in the calculation section. Additionally, I created most of the SolidWorks data displayed in the modeling section. For the final Design Report deliverable, I contributed half of the Background section, the entire calculation section, and both engineering drawings of the key component assemblies for our design.

During the second semester of this project, the emphasis of my contributions shifted from design to prototyping and construction. As the team prototype engineer, my contributions during the prototyping phase included the construction of the half scale spool mockup and torsion spring testing. Additionally, I constructed the final retractable spool and cable system, including the sheet metal mount and brush-contact system. I also assisted with the fabrication of the sheet metal shroud and designed and machined the aluminum mounting clamps for securing the lock to the bike frame. Finally, I contributed most of the material for the modeling, prototyping, testing, construction, and future work sections of the final presentation and report.