Autonomous Bicycle Lock

Grant Proposal

Adnan Dembele

Massachusetts Academy of Math and Science at WPI

85 Prescott St. Worcester MA

Abstract (RQ) or Executive Summary (Eng)

Global warming is a worldwide issue that many people are trying to address by opting for more “green” transportation such as reducing their vehicle usage and riding their bikes as an alternative transport method. A problem that occurs with riding bicycles is where to store them when not enclosed on property. Many bicycle riders use a bike lock to tie their bike to a rack or nearby pole for safety. However, the process of securing a bicycle using a modern bike lock is quite complicated. To lock the bike, the bicycle rider must bend and attach the bike by making sure to lock the important parts of the bike and that there is not too much “blank” space for thieves to put tools in. Also, during transportation, bike locks are often cumbersome and in the way. The purpose of this project was to design and develop an autonomous bicycle lock that would be easier to transport, stronger than current bicycle locks, and that would execute the locking/unlocking process for the bicycle rider. To achieve this, proofs of concepts for each specific part of the mechanism were built, tested, and analyzed through a decision matrix. The proofs of concepts that did the best on the tests moved forward and were incorporated into the final design. Furthermore, an Arduino Uno was the microcontroller for the device. The expected result was a fully functional bicycle lock to make the entire bicycle riding experience better and to protect bicycles in public areas more efficiently.

Keywords: bicycle lock, theft protection, Arduino UNO, locking mechanisms, lock automation, RFID, Solenoid, Motor, Automation

Autonomous Bicycle Lock

More and more bicycle riders are starting to emerge because of global warming. Governments are encouraging people to travel green by reducing their car usage and using bicycles, so this has created an immense rise in bicycle riders (Galic, 2023). This rise in bike riders has also promoted bicycle thefts. The obvious answer for someone using a bicycle in their everyday life is to lock their bicycle. The issue with many current bicycle locks is that they are hard to use, require too much effort from the users, are hard to transport, and do not secure a bicycle correctly. All this makes bicycles vulnerable to bike thefts even if they are locked.

Research is constantly being done into bicycle riders' safety. Research has been conducted to prevent riders from riding their bicycle without their helmet by using radio-frequency identification (Gudavalli et al., 2017), and develop complex helmets with plenty of features. These features include the ability to detect a collision, send a message to emergency contacts in case of a crash, deployment of an airbag in case of a crash, warn other bicycle riders of unsafe road conditions, warn for rain, and a camera on the back of the helmet to detect danger that is not in the field of vision of the rider, with distance recognition (Solus et al., 2023). These advancements are excellent and needed, but other research needs to be done to protect a bike before and after the rider has ridden safely to their destination.

Locksmithing is an art that has been around for about 4000 years, starting in Ancient Egypt and Babylon (Seymour, 2022). Over the years, locks have been improved and developed for all kinds of uses. Today, electric and smart locks are being developed. For example, a smart home lock able to be unlocked using an ID-card and a mobile application (Najib et al., 2021), or a smart lock using a mobile application or voice call (Raju et al., 2018). Unfortunately, not that many advancements in bicycle locks have been invented. Despite the lack of interest in research into futuristic and different locks and the best ways to lock a bicycle, there are plenty of bicycle locks that have been developed in the past, each one with a specific attribute: U-locks for strength, chain locks for flexibility, cable locks for flexibility and their light weight, and foldable locks for their portability (Cavallari, 2023). Research has also been done into the creation of an electrical lock (Figure 1). This lock would simplify the entire locking/unlocking process by using Radio-Frequency Identification (RFID) instead of making the user go through the process of finding the lock's keyhole, inserting the key in it, and then turning the key, as all that can be hard, especially if the bike rack is full (Lewallen, 2017). As one can see from Figure 1, the problem is that these systems still cause problems in transportation, attachment of the lock, and the time wasted by doing so. Further digitalizing the whole locking and unlocking systems is not a bad idea, especially since the world is evolving into this path and more and more people feel comfortable with digital tools. Digital tools allow for much more access and flexibility while also allowing for ease of use (Vailshery, 2023). For the concern about portability and transport, there is only one current bike lock design specifically for this use: the foldable lock. Unfortunately, foldable locks and other locks that are good for transportation give up strength and sturdiness, which results in them being much easier to break (Vailshery, 2023). The purpose of this project is to make a more secure and easy-to-use bicycle lock to make the entire locking and unlocking experience, as well as the traveling experience, more efficient, to make bicycles safer in public areas.

Figure 1: Picture of the electrical lock using RFID (Lewallen, 2017)

This project is important because unlocking a bike is complicated and could get even more complex for people with disabilities or of older age. Attaching a lock around a bicycle rack and then securing it in order to keep the bicycle safe, and later having to turn a key or enter a passcode and unwrap the lock to be able to go home may prove much more difficult than one might imagine. Another issue for people going to work, school, grocery shopping, or anything else on a bicycle is the time it takes to lock and unlock it. The time might seem minimal, but anything done in a hurry takes much longer than expected (Risk Assessment Management & Prevention, 2019). With this information, when someone is in a hurry and running late, the already complicated process of locking a bicycle becomes much longer and much more difficult to execute. The above-mentioned provides evidence for the significance of an autonomous bicycle lock and how it would help locking and unlocking.

Section II: Specific Aims

The overall aim of this project was to create a more efficient and secure bicycle lock. The different parts of the system were tested and selected individually going from the previous part by doing initial testing with cardboard and plastic and comparing the results using a decision matrix. After all the parts were selected, they were assembled and built. The long-term goal was to maximize the utility that the bike lock could have, build it out of the optimal material, balancing weight and durability, and continue advancing and developing it with current and future technologies.

Specific Aim 1: Make the bicycle lock easier to use by testing and incorporating newer technologies.

Specific Aim 2: Increase the speed of the locking and unlocking through a more optimal design and using robotic technologies.

Specific Aim 3: Make the bike lock easier to transport through the development of an ideal design and analyzation of a specific place to attach it on the bicycle.

Specific Aim 4: Make the lock more durable and harder to break through the comparison of different designs and materials.

The expected outcome of this work was a more secure and easy to use bicycle lock, which would be faster, stronger, and easier to transport. This kind of device will help bicycle riders all around the world and will be further developed to have GPS tracking systems, helmet unlocking methods, and used in bicycle sharing systems.

Section III: Project Goals and Methodology

Relevance/Significance

This project is important because having a simple and reliable lock is becoming an increasing need. As bicycle riders keep increasing, the need to protect against bicycle thefts is becoming increasingly significant, and the way to do that in public areas is with a bike lock. Not all bike locks offer the necessary security for a bike, most are hard to use. The user must bend down, and for optimal locking, they should use a first lock to attach the rear wheel and the frame to the bike rack and another lock to attach the front wheel with the frame, the whole thing while leaving the less possible space between the lock and the bike rack (Norman, 2020). Most bike locks, especially the more resistant and durable ones, are a burden during transportation. For transportation, one must use a specific mount on the bicycle or store it in a backpack (Cavallari, 2023).

Innovation

The autonomous bicycle lock will have plenty of innovations compared to modern locks. Thanks to the changes in the interaction with the lock and lock design itself, it will be easier to use, increase the speed of the locking and unlocking, will be easier to transport, and be more durable, which in turn makes it harder to break. All these innovations will create a bicycle lock that will be harder for thieves to penetrate.

Methodology

Specific Aim #1: Easier To Use

The objective was to make this innovation easier to use. The rationale was that there are numerous steps to lock a bike currently, and even more if the rider wants to make sure the bike is secure. The rider must go all around the bike lock, find the minuscule hole for the key, or passcode, insert the key, or enter the passcode, and then remove the lock from the bike and bike rack to retrieve the open lock (Lewallen, 2017). All of this gets even more complicated when the bike rack is full, which is most likely getting more of a reality as more people ride their bikes (Galic, 2023).

The methodology for creating an easier to use bike lock was to make the whole experience digital. With the world growing digitally and everything becoming interconnected (Vailshery, 2023), having a digital User Interface (UI) makes sense. For this, the locking mechanism was built using a motor and solenoid, which are controlled using an Arduino UNO as a microcontroller. The Arduino UNO waits for a "signal" or an approval/event to proceed to the locking or unlocking process. To send this signal to the Arduino, the bicycle rider's interaction with the lock must be developed. To find the best interaction method, different methods for interacting with the lock were compared using a decision matrix (Appendix I). The first one was Radio-Frequency Identification (RFID) because it is fast by allowing for a quick tap of a keycard or fob. Another method for unlocking was a smartphone application because of the increasing spread of phone usage, which creates accessibility for riders. An additional interaction method was using a passcode because it does not require any external device. The final method for making the system work was fingerprint scanning because, like a passcode, it does not require any external device or remembering a passcode. Figure 2 shows the delay in information sent via a mobile app to the smart home lock (Najib et al., 2021). According to the Telecommunications and Internet Protocol Harmonization Over Networks (TIPHON) standards, the delay was categorized as perfect, meaning that it was within expected limits, which is less than the upper bound (150 milliseconds). This information is important as it may give a general idea of the delay

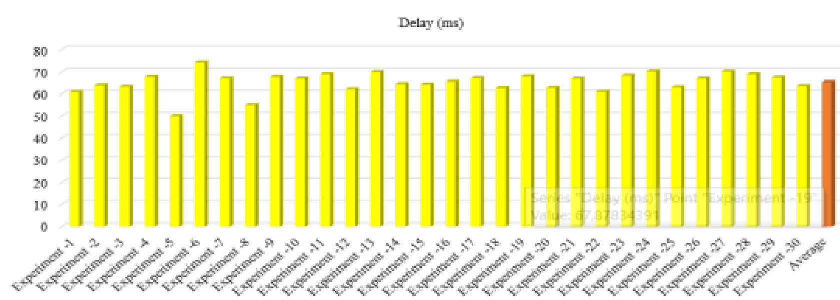

Figure 2: Table of the delay of a mobile application (Najib et al., 2021). Could be used to evaluate the final design of the lock by comparing delay times

similar types of technologies might have. The reason for choosing different methods to use the lock and comparing them using a decision matrix was because utilizing an interaction method without considering the rest will not guarantee success nor produce the most efficient way to use the device. It is possible that different methods will be combined. For example, combining the keycard and the app, or any other two, three, or maybe incorporating all four if optimal.

Summary of Preliminary Data.

A decision matrix analyzing all 4 different User Interface methods considered (fig. 3) was made with the criteria deemed most important. Each method was graded on a scale from 1 to 10 for each of those criteria. The RFID tag received the best score, so it will be used in the final design.

Decision Matrix (UI)				
Criteria\Designs	Passcode	RFID tag	Fingerprint	Mobile phone application
Ease of use	5	8	9	7
Tranportation ability	10	8	10	7
Action is not annoying to do	3	5	6	3
Speed to execute	3	9	7	6
Constraint on the bike (size)	2	7	2	7
Constraint on the bike (place)	1	5	1	10
score	24	42	35	40

Figure 3: Decision matrix for the different methods of interaction considered.

Expected Outcomes. The overall outcome of this aim was to incorporate the best possible interaction method to make it as easy for the user as possible while not being too expensive. This knowledge was used for designing the criteria for the decision matrix and choosing the best way for riders to use their lock.

Potential Pitfalls and Alternative Strategies. We expect to find the best interaction method overall, but some people might prefer other ways of using the bike lock. Alternative strategies are creating a pole, although the data does not represent the entire population, or including the option for either interaction method if the product is ever commercialized.

Specific Aim #2: Increase the speed of the locking/unlocking

The objective is to make the time to lock and unlock a bicycle less than it is currently. The rationale is that riding a bicycle may take more time to get to places compared to an automotive vehicle, and with more and more people riding their bicycles from place to place (Galic, 2023), time is becoming more important and less flexible, especially for people going to work. Furthermore, as mentioned previously, locking and unlocking a bicycle takes time due to the difficult process of having to bend down, reaching for the lock, finding the keyhole or passcode, enter the key in the hole and turning it or entering each number of the passcode, and then removing the lock to unlock, or doing the entire process the other way to lock. As one can see, when someone is running late to work, school, or anything else, having to unlock the bicycle before leaving and then locking it upon arriving at their destination will take time, which the rider may not have. That is a reason why a solution to faster locking and unlocking is necessary.

The approach that was decided for making a faster locking and unlocking bicycle lock was making proofs of concepts out of cardboard to test different designs and compare them using a decision matrix (Appendix II). Three designs were built, each one with strengths and weaknesses. The first proof of concept resembles a claw. This design was thought of because it would imitate the action done by a human with a modern bicycle lock. The second design was inspired by foldable locks due to their portability and adaptability to different bike racks or objects. The last proof of concept was done with the idea coming from snakes and circular motion. The lock would extend from one end and lock from the other, moving circularly. This design was considered for its smoothness and possible compactness. The three designs are going to then be tested for speed by being timed for the locking and unlocking processes. Their efficiency will also be compared. One design will be chosen to be improved and advanced additionally. The reason for working with different designs is to make sure to use the most efficient closing system regarding time and other factors like portability and strength. If only one design was chosen to be built without comparing it to the others, nothing would ensure that it is the best one and that it would improve in the best way possible bicycle locks. The reason for working step by step and building proofs of concepts instead of building all designs and then comparing the final products is because it is unnecessary. Doing so would be a waste of materials and time, while also not helping any more than the proofs of concepts. Another aspect to address the issue of time is the user-interaction. Different methods for user-interaction are going to be compared using a decision matrix (as talked about in Specific Aim #1), and this decision matrix (Appendix II) will include not only ease of use, but also time it takes to use. The methods analyzed will be keycard or fob, mobile application, passcode, and fingerprint. The grounds for doing so this way are to make it possible to analyze each design thoroughly by comparing their advantages and disadvantages to make the ideal choice. Different designs and comparing them using a decision matrix allows for variability and being able to choose what advantages are the most important and which inconveniences are the least important for the specific constraints and design the best possible lock.

Summary of Preliminary Data.

A section of the decision matrix comparing the different closing mechanisms (Appendix II) focused on the smoothness of the locking and unlocking (fig. 4), which was analyzed as a factor for speed. Each design was tested by replicating the open and close motinons by hand, and then grading each design on a scale from 1 to 10. Furthermore, a decision matrix (Appendix I) analyzing all 4 different User Interface methods considered (fig. 3) was made with the criteria deemed most important. Each method was graded on a scale from 1 to 10 for each of those criteria. The RFID tag received the best score, so it will be used in the final design.

Decision Matrix (Closing Mechanism Speed)			
Criteria\Designs	Design 1 (Snake mechanism)	Design 2 (Foldable lock mechanism)	Design 3 (Claw mechanism)
Smooth locking/unlocking	10	2	10

Figure 4: Decision Matrix for analyzing the 3 different closing mechanisms for speed

Expected Outcomes. The expected outcome of this aim was to figure out which interaction method was the fastest to use, as well as which lock design was the most effective at completing its task in a timely manner.

Specific Aim #3: Easier to transport

The aim here was to determine the best design for a bike lock that would be the easiest for transportation. Current bicycles made for transportation and portability are cable locks because of their light weight and foldable locks because of their compactness. The issue with those types of locks is that because portability has been emphasized in the design, strength and durability are compromised (Cavallari, 2023). From another perspective, locks that are meant for durability and strength lack portability because of being heavy, big, and without a proper place to put on a bike. The objective was to make a both strong and portable bicycle lock. The reason for this was that a bicycle lock is meant to protect bicycles from thieves breaking them. If the bicycle lock abandons its primary purpose of being strong enough to deter thieves because of being too portable, then the lock is bad. In contrast, if a bicycle lock is too strong and heavy that it is too much of a burden for a rider to take with them when going to work, then it is not going to get used and will have no purpose.

The steps to address the portability part of the problem were to develop different proofs of concepts out of cardboard to perform tests and evaluate them using a decision matrix (Appendix I). The three designs that were used to evaluate speed were compared. The first design was similar to a claw to mimic the action done by humans using current locks. The second design was inspired by foldable locks, and the third proof of concept took its design from snakes and circles. All three designs were tested (Appendix III), and the one with the highest score based on the decision matrix (Appendix II) was moved to the next phase. The first test was to temporarily attach the prototype on different spots on the bicycle. The prototype then received a grade out of 10 for how comfortable the ride was (0 being extremely uncomfortable and 10 being pleasant) which was inputted in a decision matrix. The second test consisted of measuring the amount of space the lock took up and the weight. The basis for this approach was that choosing the best design would not assure the right decision and variability between the designs allowed for improvements after selecting the best design. Furthermore, testing each proof of concept and evaluating them through a decision matrix eliminated any bias that may have been present and allowed for equal competition between all designs. The design with the most important benefits and least important inconveniences advanced forward thanks to this process.

Summary of Preliminary Data.

Many criteria in the decision matrix for the closing mechanism (Appendix II) revolved around the transportation ability. After being built, all 3 proofs of concepts were tested and graded on a scale from 1 to 10. Regarding the different materials to build the lock out of, 4 most common metals were put in a decision matrix and graded for weight on a scale from 1 to 10.

Decision Matrix (Closing Mechanism Transportation Ability)			
Criteria\Designs	Design 1 (Snake mechanism)	Design 2 (Foldable lock mechanism)	Design 3 (Claw mechanism)
Does not disrupt ride quality (for the rider)	10	10	6
Does not interfere with the bike's parts	9	10	5
Small size	8	9	6
< 7kg	N/A (Cardboard proof of concept)	N/A (Cardboard proof of concept)	N/A (Cardboard proof of concept)

Figure 5: Decision matrix comparing the different closing mechanisms for transportation ability

Decision Matrix (Metals)				
Criteria\Metals	Hardened Steel	Manganese Steel	Boron Alloy Steel	High-Tensile Steel
Weight	2	5	7.5	10

Figure 6: Decision matrix comparing the closing mechanisms for transportation ability

Expected Outcomes. The hoped-for outcome for this aim was to determine the design that allowed for optimal portability. Another outcome was the identification of lighter materials used in bicycle locks, that could be used for the final design.

Specific Aim #4: Be more durable and harder to break

The goal of this aim is to determine the best way to make a stronger, more durable lock. Every single bicycle lock can be destroyed by a bike thief with the right dedication and time (Cavallari, 2023). A bike lock does not guarantee that the bike cannot be stolen, just like door locks do not completely prevent all individuals from entering a house. The purpose of a bike lock is to deter thieves. The stronger the bike lock, the less thieves will want to break it due to the time it will take to do so. The objective was to find a design that allows for the least amount of theft opportunities, but also to find the best material to build the lock out of by balancing weight and strength.

The approach to making this bicycle lock stronger and more durable was to first build the optimal design and then choose the best material to build it out of. For the first part, building the optimal design, proofs of concepts were tested and compared using a decision matrix (Appendix II). As mentioned previously, there are three different designs: a claw design mimicking human actions using a bike lock, a snake design inspired by circular extension, and a foldable lock design which is an electrical improvement to foldable locks. The testing consisted of trying to insert tools like wires, and lock picking devices in possible holes or little openings that the designs may have. Further testing was conducted to analyze the space left open for tools like clippers and saws to go in when the lock is locked around a bike rack. The reason for proceeding in this manner was to make sure that the most secure proof of concept regarding its design is found without bias or personal preferences. If testing didn't go as planned, there would be no way to prove which design is the best for security, leaving it up to the assumption of which design should be moved forward. For deciding on the optimal material to build the final product out of, it was important to not only consider the strength of the material but also its flexibility and weight. A decision matrix (Appendix IV) was constructed to compare each material, without having to buy them, regarding the factors mentioned above. Weight and strength had an equal weighing for the criteria analyzed, but if either achieved its criteria without "damaging" the other, then the material fulfilling its other purpose better would be chosen. For example, if the different kinds of metal are all under the weight (7kg) limit, then the strongest one would be chosen. The result of the decision matrix was an idea of the material to build the lock out of, and if resources and time permit, it will be done. The rationale for using a decision matrix to compare each material was that it allowed for comparison of the materials and deciding on the material without prejudice. Also, it did not require buying each material separately for testing, which was not necessary.

Summary of Preliminary Data.

To find the optimal design, criteria from the closing mechanism decision matrix (Appendix II) were centered around the security of the lock (fig. 6). Due to the proofs of concepts being built out of cardboard, one of the criteria could not be tested, but it depended more on the material. For the optimal material to build the lock out of, another decision matrix was constructed (Appendix IV), and had specific criteria analyzing strength (fig. 7). Although Boron Alloy Steel received the better score overall, Hardened Steel is the material deemed optimal because it is stronger, and even though it is heavier, it was estimated to be under the weight limit.

Decision Matrix (Closing Mechanism Security)			
Criteria\Designs	Design 1 (Snake mechanism)	Design 2 (Foldable lock mechanism)	Design 3 (Claw mechanism)
Adjustable size (can lock around different sized objects)	0	5	0
Minimal space left for tools when locked	10	5	10
Resists bolt cutters	N/A (Cardboard proof of concept)	N/A (Cardboard proof of concept)	N/A (Cardboard proof of concept)

Figure 8: Decision matrix analyzing the security of each proof of concept

Decision Matrix (Metals)				
Criteria\Metals	Hardened Steel	Manganese Steel	Boron Alloy Steel	High-Tensile Steel
Strength	10	7.5	7.5	5
Durability	10	5	10	5

Figure 7: Decision matrix comparing the different materials for the lock regarding strength

Expected Outcomes. The anticipated outcome for this aim was to identify the design that provided the most security, based on the openings it left for thieves to put their tools in. Furthermore, it was expected to determine the material that balanced both weight and strength ideally to incorporate in the final product.

Section IV: Resources/Equipment

Every piece of equipment will have its specific and necessary purpose for the system:

- Arduino UNO acting as a microcontroller
- 9V battery to power the Arduino
- Motors acting as the mechanism to lock and unlock the lock
- Solenoid acting as the key locking mechanism
- L293D H-bridge acting as the motor controller
- 4x AA batteries to power the motors and solenoid
- Cardboard acting as the material for proofs of concepts and testing
- Breadboard to connect wires during proof of concept testing
- Wires to connect electrical components
- RFID reader, fingerprint scanner, passcode, or Bluetooth module for the User Interface
- Bicycle and protective gear (used for testing)

Section V: Ethical Considerations

The final testing of the product to measure the efficacy of the final design will be done on humans. They will need to ride the bicycle with the lock on, lock the bike on a bike rack, and unlock it. All riding safety measures will be taken:

- Use of a helmet and other protective gear
- Riding on a dedicated and isolated path
- Proper bicycle conditions (tires, brakes, pedals, chain, etc. all verified and good to go)

For the locking and unlocking on the bike rack, no safety issues will be present; the rider will only have to use the keycard as directed, which cannot be harmful in any way.

Section VI: Timeline

August:

- Initial Brainstorming
- Research on areas of interest

September:

- Brainstorming
- Narrowing down of focus to Rocket Propulsion, Electricity production, and Robotics
- Research

October:

- Project Identification (Autonomous Bicycle Lock)
- Research
- Materials list
- Constraints list

November:

- Obtaining necessary materials
- Proofs of Concepts
    - Sketch
    - Build
- Research

December

- Research
- Proofs of Concepts
    - Test
    - Improve
- UI selection
- Design selection
- Improvement of Design
- CAD design

January:

- 3D print final design
- Identification of optimal material if the lock is to be commercialized
- Significance testing to measure the innovations

February:

- Present results
- Build out of optimal material
- Significance testing

Section VII: Appendix

Appendix I: User Interface Decision Matrix

Decision Matrix (UI)				
Criteria\Designs	Passcode	RFID tag	Fingerprint	Mobile phone application
Ease of use	5	8	9	7
Tranportation ability	10	8	10	7
Action is not annoying to do	3	5	6	3
Speed to execute	3	9	7	6
Constraint on the bike (size)	2	7	2	7
Constraint on the bike (place)	1	5	1	10
score	24	42	35	40

Appendix II: Closing Mechanism Decision Matrix

Decision Matrix (Closing Mechanism)			
Criteria\Designs	Design 1 (Snake mechanism)	Design 2 (Foldable lock mechanism)	Design 3 (Claw mechanism)
Adjustable size (can lock around different sized objects)	0	5	0
Does not disrupt ride quality (for the rider)	10	10	6
Does not interfere with the bike's parts	9	10	5
Minimal space left for tools when locked	10	5	10
Small size	8	9	6
Smooth locking/unlocking	10	2	10
Resists bolt cutters	N/A (Cardboard proof of concept)	N/A (Cardboard proof of concept)	N/A (Cardboard proof of concept)
< 7kg	N/A (Cardboard proof of concept)	N/A (Cardboard proof of concept)	N/A (Cardboard proof of concept)
score	47	41	37

Appendix III Testing Strategies:

Testing Strategies
Attach to the bike and ride with it
Measure volume it takes up
Measure how much "blank" space it leaves while attached to a bike rack
Replicate locking and unlocking motion for speed and efficiency
Try to break the lock using bolt cutters
Weigh the lock using a scale

Appendix IV Metals Decision Matrix:

Decision Matrix (Metal)				
Criteria\Metals	Hardened Steel	Manganese Steel	Boron Alloy Steel	High-Tensile Steel
Strength	10	7.5	7.5	5
Durability	10	5	10	5
Weight	2	5	7.5	10
score	22	17.5	25	20

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