SYSTEMS ENGINEERING: SMART HOUSE LOCK SYSTEM

Contents

Abstract

This project pertains to the development of a Smart House Lock system. This is a keyless, smart solution which aims to solve the shortcomings of the traditional lock system. The first phase of the product development deals with research about customer needs and wants, establishing boundaries for the scope and the technical performance measures. After establishing a baseline for the product, the next phase of the project deals with ensuring that the product delivers its promises. Measures like reliability, maintainability, availability illustrate how the product operations will be maintained through time. Finally, a detailed life cycle cost analysis and a high-level project plan conclude the research by establishing timelines and the associated costs.

Problem Identification

One of the common problems in day-to-day life is misplacing the house keys. We spend an inordinate amount of time searching for them and waiting for someone else to help us get in the house. The security is compromised the moment a key is lost and requires the whole lock to be replaced. There is also a dependency that the traditional mechanical/deadbolt lock creates on the owner to be present at home to unlock the door for guests/maintenance personnel.

At times, even after locking the door, we often are unsure if we locked and want a better way to validate that than having to go back physically to check the door lock. There is no security surveillance system present in the traditional lock system which could provide information about the possible attempts to unlock the door.

Our Solution

We aim to solve the problem by taking a smart approach to security. We are engineering a battery operated electromechanical Smart House Lock System, which can perform locking and unlocking operations when it receives such instructions from authorized user(s).

The Smart Lock can be installed on existing mechanical/deadbolt locks. This eliminates the need to replace the existing system, while upgrading the door lock to operate with a physical key as well as with a smart key.

The door can be locked/unlocked with a simple tap on the lock, which reads the fingerprint and grants access. It can also be operated using digital remote keys shared by the owner, iOS and Android mobile application, web application, and popular smart home devices like Google home, Amazon Alexa, and Apple Siri

Customer should sign up as the owner and then assign special privileges to friends, family members, or maintenance staff, who will then be recognized as authorized users. Owner can either give full access or limit the access to certain days of the week or even certain times of the day. The lock can also be operated using the mobile app or web app. The app also shows the status of the lock (locked/unlocked) and battery life.

It has a built-in Wi-Fi bridge that allows the lock to be controlled from anywhere as long as the lock is connected to the home router. It can be controlled from anywhere, with features like remote lock control, push and email notifications, and tamper alarms.

There is an in-built camera and memory in the lock. Not only will the device allow the house owners to lock and unlock the door with ease, it will also monitor who is entering and leaving the house while they are away and maintains an activity log. The camera helps the owner see the person requesting access and can provide the access remotely.

With the lock status shown on the app, you'll never have to worry if you locked up before you left the house. You can easily check it on the app.

With all these features, we aim to engineer a reliable, secure, convenient, easy-to-use, and well-designed smart lock to solve the problem.

Customer Wants or Needs Validation

Validation Process Overview:

After listing out the customer needs and wants meticulously, the important process is to validate that these are in line with the customer's expectation from the product. The validation process chosen was customer surveys to understand the customer's current viewpoint of the problems accompanied with the traditional lock system and their openness to trying out a smart solution for the same.

Customers were also asked to rate the enlisted features of the product solving different parts of the problem, in order of importance to understand the most value adding feature and the least value adding feature of the product.

Validation Process Results:

To understand the customer preferences and requirements priority in the new Keyless smart lock technology, customer survey was conducted. Five essential and fundamental questions were asked to analyze the customer needs. (Read more in Appendix)

a. Customer Wants and Needs - Relative Importance based on Validation Process

Customer Wants/needs	**Importance Rating** (higher value indicates the want/need is more important)	**Priority Rating** (1 indicates highest priority)
Quick keyless entry to the home	5	1

Highly secured Access & Information Security	5	1
Ease of everyday use	4	2
Compatibility with iOS and Android	4	2
Support multiple users	3	3
Remote access for guests	3	3
Cost-Effective	3	3
Battery Powered	3	3
Ease of installation	2	4
Activity log of people who enters the house	1	5

Table 1: Relative Importance based on Validation Process

Scope of System Under Consideration

Physical Boundaries

- The smart lock device is mounted on the existing mechanical/deadbolt lock by the user.
- Smart lock is battery-powered. These are rechargeable batteries.
- The door can be locked/unlocked using authorized fingerprint, remote key shared by the owner, iOS and Android mobile application, web application, popular smart home devices like Google home, Amazon Alexa, and Apple Siri.
- The device has fingerprint sensor to respond to the commands of the user.
- The device has an in-built camera which captures pictures and maintains activity log of people who tried to enter the house.
- The status (Locked/Unlocked) of the device can be known by the mobile application that is compatible with all software.

Business Boundaries

- Orders are accepted online and in-store.
- Device maintenance and support provided. Customers can call the customer center for assistance with mounting/operations/maintenance of the device.
- Smart lock is covered by a one year manufacturer's warranty.
- Since the batteries are outsourced, no warranty is provided for the batteries.
- The minimum fee for the smart device project including mobile application development is $300 per device.
- The delivery order contains smart lock device, rechargeable batteries, mounting support, and an instruction manual. Instruction manual provides details on lock assembly, app information, set up details, and lock usage.
- The device works only on popular smart home devices Google home, Amazon Alexa, Apple Siri. The mobile application is compatible with iOS, Android, and Windows only, not any other third-party software systems.
- Warehouse access to customers and third-party businesses are out-of-scope

Process Boundaries

- Customers can place orders online or in-store.
- Order processing: while online orders take a certain time for delivery (depending on customer address), the store pick-up orders can be instantly fulfilled (depending on device availability).
- Device mounting assistance provided through instruction manual, online help center, or through customer care; depending on customer preference.
- Mobile application supporting the device available for free on iOS, Android, and Windows platforms. Users can create their profiles and add their friends, family, and maintenance personnel in the app.
- The app can be used to remotely control the lock, share remote keys, set access times, and check the current status of the lock.
- The door can be locked/unlocked using authorized fingerprint, remote key shared by the owner, iOS and Android mobile application, web application, popular smart home devices like Google home, Amazon Alexa, and Apple Siri.

- This key can be sent to the recipient smartphone over standard messaging protocols such as email or SMS. Once this key is received the recipient will be able to unlock the smart lock during the time previously specified by the sender.
- Maintenance and support provided by customer care center via email or call.
- Defective devices can be returned for an exchange or full refund within 30 days of order delivery.
- At-home assistance is out of scope.
- Smart lock is covered by a one-year manufacturer's warranty. Within 1 year, any repairs and maintenance will be done free of charge.
- Repairs done after 1-year warranty expires, is charged based on standard rates.
- Sold through third-party sellers like Amazon, Best Buy, etc.

Information Boundaries

- List of color options (Black, White, Steel, Gold, Brass) for the smart lock, their compatibility with mechanical locks, and other specifications will be provided to the customers.
- Owner account information will be encrypted and stored securely.
- The app allows unlimited fingerprint storage and infinite remote key option.
- The in-built memory has the capacity to store 1 week’s activity log which saves the picture of people who tried to unlock the door along with the timestamps.
- Information regarding installation instructions, app availability and usage, and other maintenance related information will be shared with the client.
- Production inventory information will not be available to the customers.
- Batteries are bought from a third-party vendor. The vendor information is not shared with the customers.

Operational Requirements & Technical Performance Measures

After identifying the wants and needs of the customers, validating them with surveys and establishing the scope of the system, the engineering process of the system can finally be started.

The first step in system engineering the Smart Home Lock System is to understand what operations are required by the system to perform. These operational requirements form the stepping stone in developing a system which is engineered to serve the customer’s wants and needs.

SL.No.	Customer Wants and Needs	Operational Requirement	Technical Performance Measure
1	Keyless entry	• Keyless entry using fingerprint of owner(s)/authorized users stored in the system	
2	Highly secured Access & Information Security	• User authorization process through mobile application only • All user data must be stored with state-of-the-art encryption technology in the database • Camera activates when someone tries to open the door • Camera records feed of front door when it is activated • The entry will be flagged to authorized users if the person trying to enter is not one of the authorized users	• A user authorization process must be finished by the user within ~10 minutes of it being started; If not completed, it must be started over by the user • All data stored in the system must use state-of-the-art encryption to yield 0% security breaches • The camera must activate within a period of ~1 sec when it senses the fingerprint • The camera must keep recording for 10 min and switch off only after 10 min of inactivity • The entry flagging communication (email, text) must be sent within ~2 min of activity
3	Ease of use	• Mobile application/web application for the	

		Smart House Lock system should be intuitive • User should not have to spend a long time trying to open the door • Fingerprint sensors must be good quality and maintained	• The process of unlocking the door should be triggered within ~10 seconds of fingerprint being placed on the lock • The maximum duration for fingerprint scanning and verification should be ~5 seconds
4	Compatibility with iOS and Android	• Mobile application for both iOS and Android platforms should be available and up to date with all security measures	• Mobile applications should be maintained and updated every 15 days • All reviews for the mobile application must be read and recorded in the database within 3 business days of being uploaded on the platform
5	Supporting multiple users	• Customers must have the option to add multiple owner(s)/ authorized user(s)	• At least 5 owner(s) must be available to the customer to be added • Minimum 1 owner must always be added in the system database • Maximum of 8 owner(s) may be stored in the system at a time • The addition of the authorized user to the Smart Lock's database should not take more than 2 hour(s)
6	Remote access for guests	• Customers must be able to produce digital keys to visitors which would make them authorized user(s)	• Digital remote keys must be generated within ~10 seconds in the mobile application • Unlimited digital keys maybe issued per day per authorized user

			• No more than 5 keys may be sent to a single receiver for a particular entry date and a particular entry duration • The remote key(s) must activate and deactivate within ~5 seconds of their activated duration
7	Cost effective	• The system must be reasonably priced and offer a competitive advantage as per market standards which are similarly priced	• The price point must be between the range of $250 - $350 based on the market research • Minimum offered warranty duration must be 3 months
8	Battery powered	• System must be battery powered to avoid the hassle of wiring to the customers • The system must have a battery status to alert the customer • The system must send a notification to the customer when it needs battery change • For any maintenance related issue, the system must display a notification as well as an error code to help customer understand and diagnose the issue	• Batteries are expected to last an average of 3 months • Every 180th day the system will send a notification to the customer of the battery status • If the system crosses the battery storage of 8%, it will send a notification and display an alert continuously on the mobile application • In case of hardware malfunction or other maintenance issue, the system must notify the customer every 1 hour on the mobile application • For regular maintenance, a notification will be sent every 6 months to the customer
9	Ease of installation	• The system must be capable of mounting the device on existing mechanical	

		lock which eliminates the need to replace the entire lock • The system must be designed based on the standard/popular locks so that it can be added onto the existing locks causing least inconvenience	
10	Activity logging	• The system must maintain the history of the activity to refer to	• The system must maintain at least 15 days of previous activity and camera footage

Table 2: Operational Requirements & Technical Performance Measures

House of Quality

House of Quality is a popular matrix technique which is used for product planning and development. House of Quality helps to understand customer wants and needs, prioritize customer priorities, and convert customers' needs into the organization's technical objectives and goals.

Steps that were taken to build the House of Quality for Smart Lock Device:

- Identified customer wants and needs
- Identified TPMs and operational requirements that satisfy the customers wants and needs.
- Development importance ratings for these operational requirements
- Identified correlation between the design characteristics
- Prioritized design criteria and TPMs
- Set a target value to meet customer requirements and TPMs
- Compared how well the competing companies meet the customer requirements. The competing companies that were considered are Nest X Yale, August Smart Lock pro, Lockly Secure Plus.

Relationship matrix		
◉	Strong	9
○	Medium	3
△	Weak	1
	No assignment	0

Correlation matrix	
+ +	Strong positive
+	Positive
–	Negative
– –	Strong negative
	Not correlated

Figure 1: Correlation Matrix

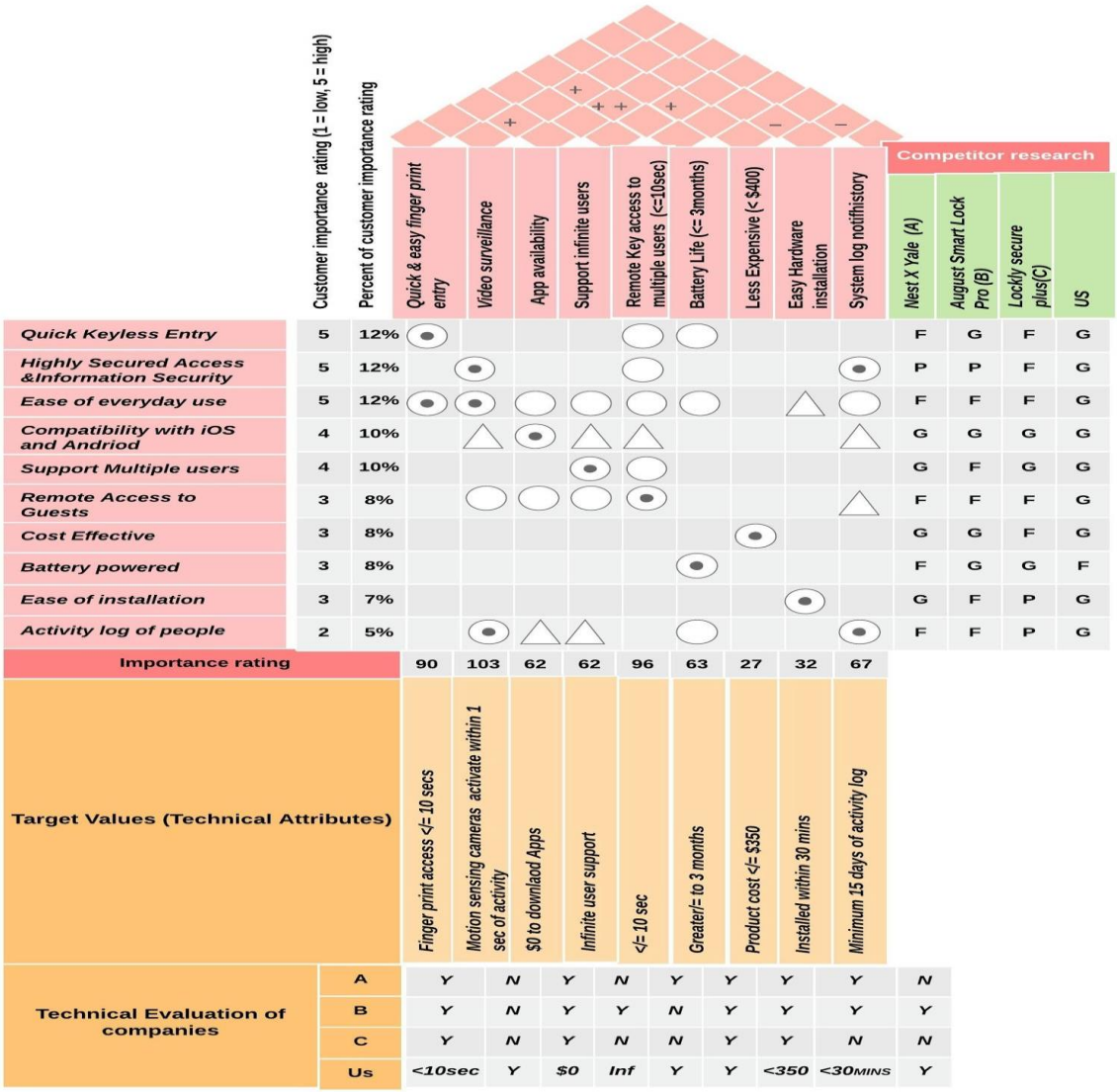


Figure 2: House of Quality

Functional Analysis

Functional analysis is the process of illustrating the working of the system being engineered, in as detailed steps as necessary. There are levels in a functional analysis and with each level, the working becomes clearer due to the increase in granularity. Hence, the complexity of the system decides the number of levels required to fully understand the system's working.

Operational Functional Analysis

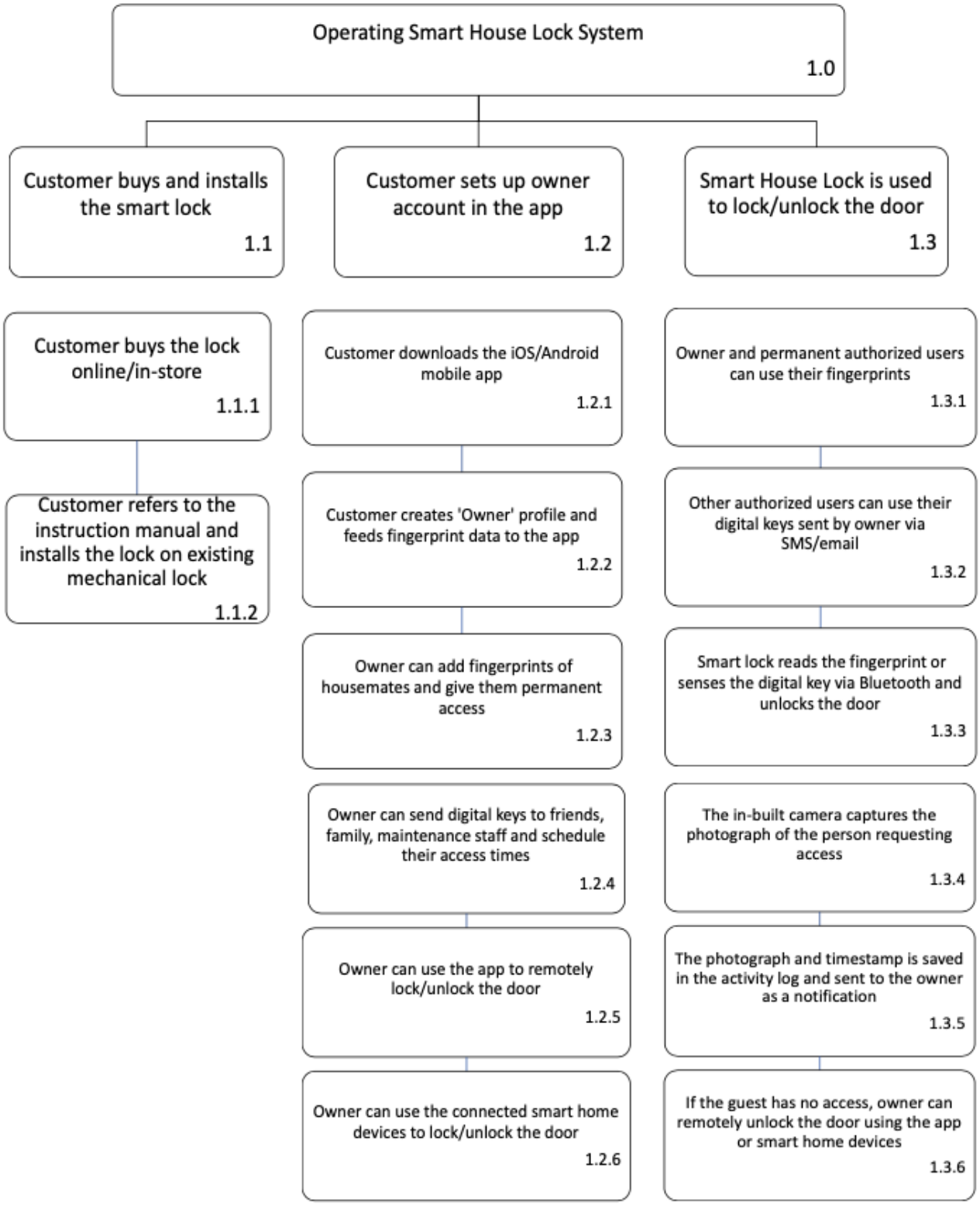


Figure 3: Operational Functional Analysis

Maintenance Functional Analysis

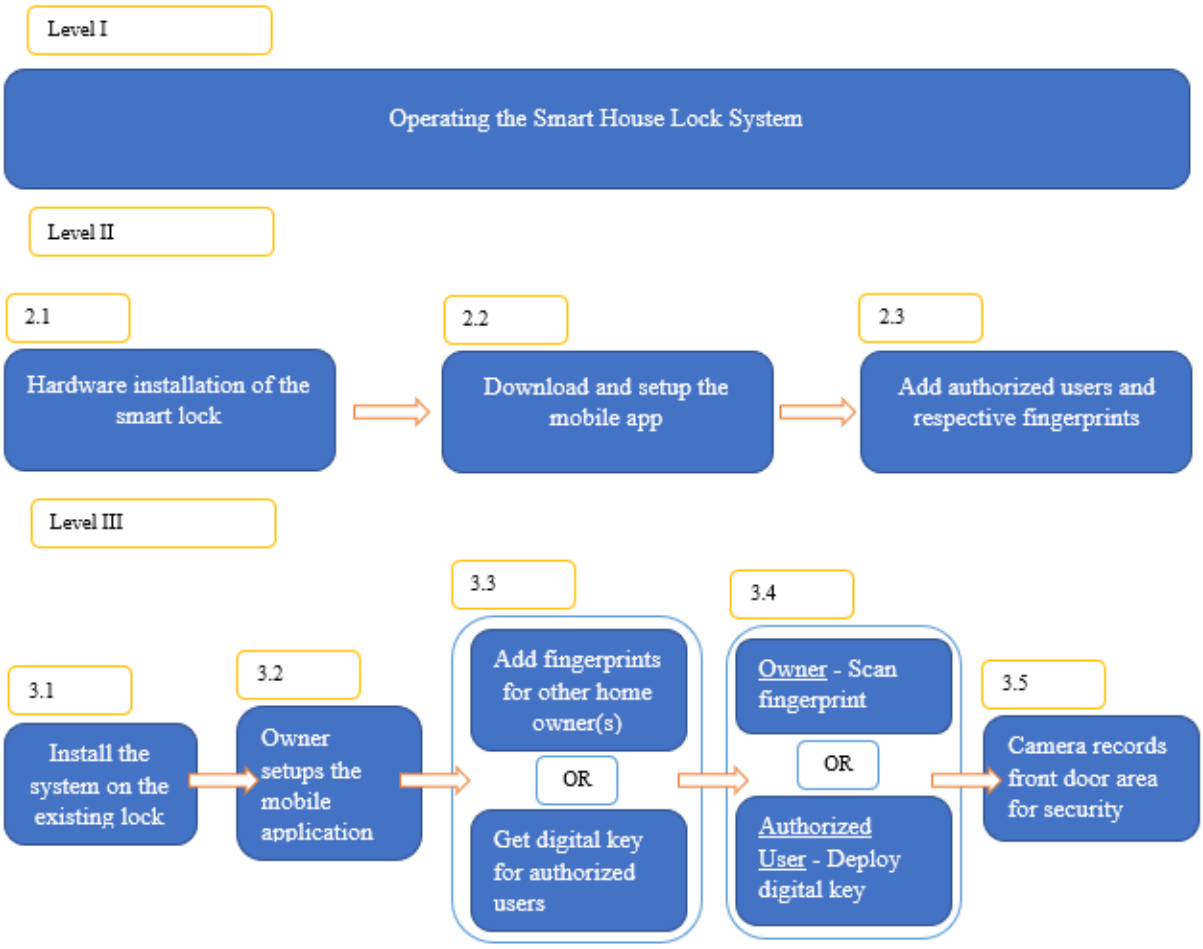


Figure 4: Maintenance Functional Analysis

Developing Maintenance Concept – Level of maintenance

This process defines the maintenance provisions for the product. Maintenance concept discusses in detail how the system's operations will be supported and maintained throughout the system's life cycle.

Criteria	**Organizational Maintenance**	**Intermediate Maintenance**	**Supplier/Manufacturer/Depot Maintenance**
Done where?	*At the operational site or wherever the prime elements of the system are located* At the customer's home	*Mobile/semi mobile/fixed* Fixed units available in specific locations Mobile units available as on-call executives who will visit the customer's home location	*Supplier/manufacturing facility Specialized repair activity or manufacturer's plant* Company facility

Done by whom?	• on-call executives who visit customer's home location for small/regular repairs	• On-call executives in this category are more skilled and trained • Their assistance is requested when the problem cannot be solved by the regular repair/maintenance procedures	• Senior design team or a member would be involved • The team or the required members may need to visit the location to understand the exact problem • The design team will further coordinate with the manufacturing team/software team to develop an efficient solution keeping in mind the given constraints
On whose equipment?	• The executives will be using company provided repair kits	• The executives will be using company provided repair kits	• The executives will be using specialized resources available at the headquarters/primary office of the company

Type of work accomplished?	• Visual inspection of camera, LCD screen, etc.
	• Checking the operation of the lock by unlock through all modes of unlocking
	• Any rusting/mechanical adjustments needed for smooth functioning
	• Replacement of rechargeable lock batteries, if needed
		• Detailed inspection of the lock equipment – the trigger system and unlocking mechanism
		• The lock mechanism may have to be uninstalled and re-installed
		• The trigger system may need complicated adjustments to be repaired and in a working condition
			• Detection of a problem that requires system redesigning. Causes can be due to security issues developing with time/outdated technology, changing vendors, changing material used in the lock mechanism, updating the lock mechanism, Environmental factors may also cause additional feature(s) to be built in
			• Lock mechanism redesigning
			  ○ Prototype development
			• App rebuilding
			  ○ Bug fixes and security patches
			• Unlocking system redesigning
			  ○ Identifying loopholes – physical/online

Table 3: Maintenance Concept - Levels of maintenance

Determining System Reliability, Maintainability, Availability, Sustainability, Usability

Based on the operational requirements and the functional analysis, potential failure points were identified as follows:

1. The fingerprint sensor could stop working
2. Connectivity with any of the smart home device(s) could fail
3. Mobile application supporting the smart lock system could fail
4. Remote keys shared could stop working as intended

For each of these potential failure points, failure rates and maintenance timelines were assumed (See more in Appendix). These data points were further used to calculate other system parameters.

Reliability

The probability that a product or a piece of equipment or system performs its intended function in a satisfactory manner for a stated period of time under specified operating conditions.

With respect to the Smart Lock System, the following can is noted -

- **Probability**: Probability of Smart Lock operating in 100 Hours is 99.98%
- **Intended Function**: Smart Lock should sense the fingerprint and unlock the door in less than 10 seconds
- **Period**: The smart lock system should last for 2 years
- **Operating Condition**: The smart lock system should last for an average of 2 years under normal use when operated outdoor in all regular seasons

Hence, the calculated reliability of the system is 99.98%.

The reliability of a system is calculated using the formula $R=e^{-t/M}$, where t is the operating time and M is the mean time between failures. Smart lock is considered to be a parallel component system as the lock can be operated using various methods - fingerprint sensors, mobile app, smart home devices, and remote key. This system is not considered to have failed unless all the lock/unlock mechanisms have failed and hence we have considered the smart lock to be a parallel system. Reliability for the Smart Lock System for t=1000 hrs was calculated in Table 10. (See more in Appendix)

Reliability Curve

The following Reliability curve was obtained based on the calculations for the Smart House Lock System.

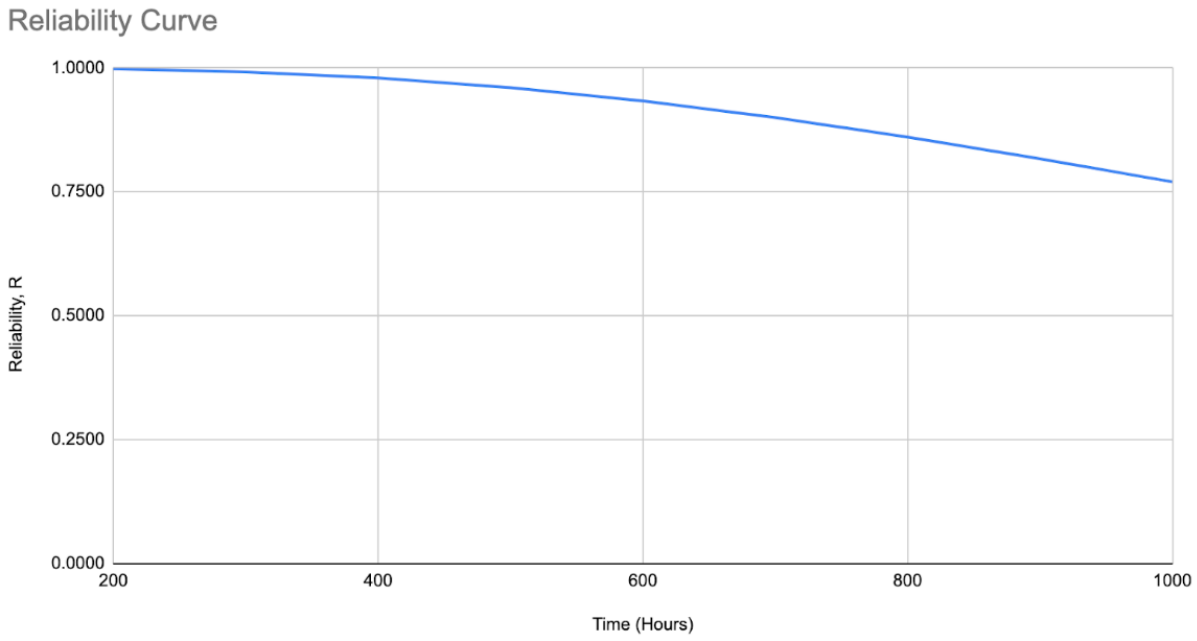


Figure 5: The Reliability curve obtained

Maintainability

Maintainability is the ability of a system to be maintained. It has the following characteristics:

- **Maintenance Time**: Probability that an item will be restored to a specified condition within a given period of time, when maintenance is performed in accordance with prescribed procedures and resources
- **Maintenance Frequency**: Probability that maintenance will not be required more than *x* times in a given period when the system is operated in accordance with prescribed procedures
- **Maintenance Cost**: Probability that the maintenance cost for a system will not exceed y dollars per designated period when the system is operated and maintained in accordance with prescribed procedures.

In the case of the smart lock system, the assumed maintenance times and frequency are listed in Table 9. (See more in Appendix)

Here, ***Mct*** is the corrective or unscheduled maintenance accomplished, as a result of failure, to restore a system or a product to a specified level of performance. The corrective maintenance cycle includes detection of failure, diagnostics, disassembly, removal and replacement of faulty component, reassembly, adjustment and/or alignment and final verification.

Mpt is the preventive or scheduled maintenance accomplished to retain a system at a specified level of performance by providing systematic inspection, detection, servicing, or the prevention of impending failures through periodic item replacements.

Points of Failure	Fingerprint sensor	Smart Home Device Connectivity	App Failure	Remote key failure
MTBF (Hours)	1000	800	900	700
λ	0.001	0.00125	0.0011	0.0014
Mct (Hours)	8	12	4	4
Mpt (Hours)	6	10	2	2

Table 4: System calculations for system's Maintainability

Maintainability Strategy

Corrective	If the hardware fails, or the device fails to recognize triggers from the authorized user(s); the camera recording gets interrupted - check the instruction manual or contact customer support.
Preventive	Check the device at least once a year to prevent future failures; Check if the device is mounted securely and is not altered by daily use, verify if all the authorized users are able to lock/unlock; check the camera recordings to ensure it is performing as expected.
Predictive	Notification in the mobile application at regular intervals to verify device standards. If there is a future failure possibility, the device can be disengaged, and help can be sought from the customer support team.

Table 5: Maintainability Strategy

Availability

Availability is defined as the probability that a system when used under stated conditions, will operate satisfactorily at any point in time as required.

It is affected by the different types of delays from administrative and logistics as well as the corrective and preventive maintenance durations as these are downtimes and affect the operation of the system. Hence, availability is dependent on the reliability and maintainability of the system and the environment during the utilization.

- **Inherent availability** excludes preventive maintenance time and other administrative and logistics delay
- **Achieved availability** gives a better picture as it includes preventive maintenance time
- **Operational availability**, as its name suggests, is the actual operational availability of the system which includes all kinds of delays including administrative and logistics delay

Inherent Availability	Achieved Availability	Operational Availability
88.17%	93.35%	81.57%

Table 6: Availability related parameters of the system

Sustainability

Sustainable design of the product makes sure that the product is manufactured with minimal environmental impact during all the life cycle phases of the product which includes research and development, manufacturing, distribution, maintenance, and disposal. The sustainability measures that have been planned to implement on different phases of the product life cycle are explained below.

Research and Development

- All the R&D offices are powered by renewable power throughout all the stages of the product. Solar power will be used in the majority in all the production phases.

Production and Construction

- Product is designed using the cradle to cradle approach by reutilizing all the products that have been used in the final product that can be safely dismantled and reused for new products as technical nutrients with no contamination of the ecosystem.
- All the materials used in the manufacturing of the product will be ethically sourced from the Sustainable Forestry Initiative (SFI) certified resources.
- The main body of the lock system is made of 100% recyclable aluminum and the number pad is made up of 100% recycled plastics.
- Renewable power is used throughout the construction and manufacturing phase of the product.

Operation and maintenance support

- Solar energy is used during the operations and maintenance support of the product.
- During the preventive or corrective maintenance of the product, only the faulty parts are being replaced instead of replacing the entire product with a new one.

Supply chain and Sales Phase

- During the sales of the product 100% recyclable packing materials are used to pack the product.
- Also, extra packing materials are being avoided during the shipping of the product.
- During the supply chain and shipment of the materials/products the vehicles or trucks used should be biodiesel-powered and solar-powered, which would help to reduce CO2 emissions drastically.

Disposal

- The product would be recycled for free of cost at the end of the product lifecycle.

Life cycle stage	**Sustainability and consideration**	**Sustainability strategy**	**Resources Affected (positively or negatively)**	**Metric**	**How do you propose to measure it?**	**Anticipated Importance (High, Low)**
Construction phase	Product designed using Cradle to Cradle approach	· Using 100% recyclable aluminum for the lock · Use recycled plastic for number pad and other internal parts · Only green materials are used for the product.	Landfill or disposal sites would be positively impacted as there won't be any waste material burial.	Gram recycled/recyclable of material /per lock	By measuring the weight of recyclable/recycled material used per year to manufacture the smart locks.	High

Construction/production phase, & operations and maintenance phase	Harvesting clean/renewable energy during the operations, manufacturing, and maintenances of the product	Using solar energy panels	Conventional power would be affected negatively by the use of renewable energy resources.	· PG&E cost per year · CO2 or Green House gas emissions/ per month	CO2 or GHG can be measured for a particular location using carbon dioxide meters	High
Production phase	Avoiding Conflict-free sourcing of minerals/materials	Using Sustainable Forestry Initiative (SFI) certified sourcing of minerals or products	Unethical miners of raw materials would be negatively impacted	Lbs Conflict-free minerals used/year	Calculating the amount of ethical SFI certified materials sourced per year	High
Sales Phase	Avoiding plastic packaging materials and using minimal packaging materials	Using 100% recyclable packing materials and avoiding extra packaging materials during shipment	Conventional shipping and packaging suppliers are negatively affected.	Lbs of Recyclable packages/per day	Weighing the number of recyclable packaging materials used per year.	High

Operations and Maintenance	Reusability of the nonfaulty parts	Replacing only the faulty parts during the maintenance phase instead of replacing the entire product with a new one.	Inventory of other parts will be affected negatively	Number of materials replaced/month	By taking the inventory of the replaced parts of the product.	Medium
Supply chain and sales	Sustainable transportation	Using biodiesel-powered and solar-powered vehicles/trucks for supply chain and sales	Conventional type transportation system gets negatively affected	CO2 emission reductions/mile	CO2 emission reductions can be measured using carbon dioxide meters	High
Retirement and Disposal	Avoidance of electronic waste	Free product recycling	E-waste landfill will be positively impacted as the amount of E-waste landfill will become less	Lb of recycled e-waste/per year	Weighing the amount of E-waste recycled per year.	High

Table 7: Sustainability for the House Lock System

a. Usability

Usability is the ease of use and learning ability of a device. It is the degree to which a system can be used by specified consumers to achieve quantified objectives with effectiveness, efficiency, and satisfaction in a quantified context of use. Table shows the usability factors for the smart house lock device.

Function	**Human Task**	**Skill level**	**Potential Hazards**	**Potential errors**	**Total Cost/ Cycle**
Designing and installing the system	The design of the system (Prototype) must be developed by the designing team considering the customer requirements and convenience. The components must be assembled, shipped and installed.	This part requires high expertise and knowledge.	Improper designing, assembling, or installing may lead to system failure.	Improper analysis of customer requirement. Errors in assembling or installing the system.	$15-$20 per hour (labor cost) (Approx.) Since this requires high skilled labors the cost might be high.
Periodical safety check	To periodically visit the customer's house and perform quality check of the device.	Skills to analyze and identify if any damages in device or errors in software of the system.	If any damage or error is left unnoticed, might disturb the proper functioning of lock/unlock of the door.	Unnoticing any hardware damages or software errors. Misinterpreting the error to another. Taking incorrect	$10-$15 per hour (Approx.) This requires moderately skilled labors.

				actions for errors.	
Device Replacement	If the device requires replacement, it must be replaced.	Basic skills to remove and install the device.	May cause damage to the device. May cause interruptions in the service to customers.	Improper installation.	$8-$10 per hour (Approx.) This requires labors with basic skills.
Periodically checking the device efficiency	The capability of the device must be periodically checked to maintain device efficiency.	Skills to test the device working and other process speed of the device.	May increase the device response time in locking/unlocking the door (reduce the system efficiency) if not tested properly.	Error in testing. Delivering incorrect results.	$10-$12 per hour (Approx.) This requires medium skilled or trained labors.
Charging	Device is charged using AA batteries. Done by the customers.	Basic knowledge to install batteries and operate the device.	No potential hazards or damages might be caused. Basic operating instructions will be provided in the device manual for the ease of understanding	Incorrect way of inserting batteries. Discharged batteries inserted.	This is done by the customers.

Table 8: Usability for Smart House Lock System

Control Concept of the System

The control system is referred to when a number of components combined together to achieve the desired output. Each component that is being connected to form a single system has its own effect on the desired outcome. If a component fails to meet the control limit or exceeds the control limit, then necessary actions should be taken to meet the desired expectations.

The control system we are choosing for the Smart Lock System is the Closed Loop control system. The table below shows the control concept of the important components in the Smart Lock Device.

System Component	Performance characteristic	Purpose	Units	Frequency
Fingerprint Sensor	Time to unlock the system	The keyless entry of the authorized users through their fingerprints. Unlocking of the smart lock device should happen in less than 10 sec and the fingerprint sensor should be able to authorize up to 10 users per smart lock device.	Less than 10sec per unlock	100% of the time(monthly) the smart lock device should unlock the lock when users try to unlock them using fingerprint should be less than 10 sec. Measured monthly.
Mobile App	Availability of the App	A mobile app is provided to the customers to give authorization to the users and to control the smart lock device from anywhere/remotely.	Mobile app downtime/day	100% of the time(daily) the Mobile App should be up and running without any downtime. Measured Daily.
Secured encrypted passcode	Reliability of the generated encrypted passcode	The customers must be able to produce a highly-secured encrypted passcode to give access to anyone who might be visiting them.	Secured passcode generated/ day	100% of the time(daily) the Mobile app should be able to generate a highly-secured encrypted passcode that unlocks the door. Measured daily.
Data storage by Trusted Execution	Reliability of the Data Storage	Trusted Execution Environment system is used to store the fingerprint information	Number of authorized users/ smart lock	100% of the time(monthly) the customer should be able to add to a

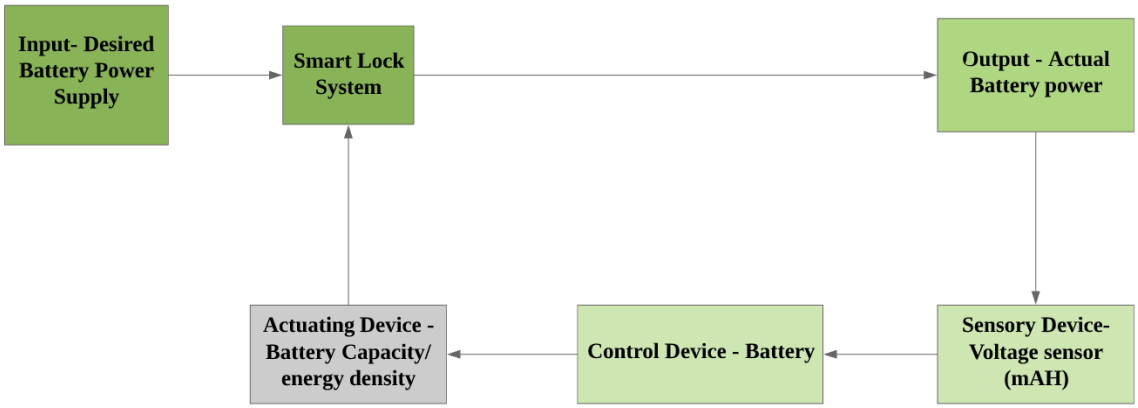
Environment system		about the authorized users of the Smart Lock system. Customers should be able to add a minimum of 1 to a maximum of 5 authorized users. The smart lock device can be unlocked only by authorized users defined by the house owner. The permanent authorized users can use their fingerprints to unlock the door.		minimum of 1 to a maximum of 5 authorized users per smart lock. Also, fingerprints and other data should be 100% secured. Measured monthly.
Battery Power Supply	Quality of the Battery Power	The system should be battery powered with high quality of batteries and notifications should be sent to the users when it is low powered.	Batteries should last up to 180 days/ 365 days	100% of the time (measured every 3 months) the battery should last up to 180 days peruse. Measured every 3 months.
Inbuilt Camera	Reliability and Availability of the in-built camera	The in-built camera which records and saves all the activities. Camera records feed of the front door when it is activated or when someone tries to open the door. The main purpose of installing a camera is to make the smart lock system highly secured for the users.	24/7 motion censored video recording per day	100% of the time (monthly) camera should up and running 24/7. Measured monthly.
Push Notification System	Reliability and Availability of the push notification system	When someone tries to open the door the Smart Lock device sends an alert notification to the owner's phone	Number of time smart lock device failed to send alert	100% of the time (monthly) the smart lock device should send alert notification to the owner's smartphone

			notifications per month	when someone tries to enter the house. Measured monthly.

Table 9: Control concepts for different system components

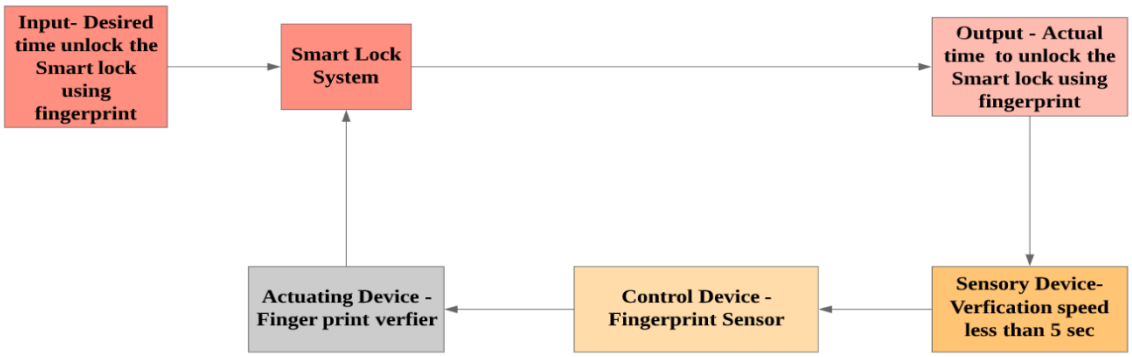
Control Concept model of Battery

The figure below shows control concept model of the Battery system in the Smart Lock Device. The desired power of the batter or desired life of the battery would be Input. The output would be the actual output. The control device is a battery and the sensory device would be a voltage sensor that measures the voltage generated in hours (mAH). The actuating device is the Battery Capacity system or Energy Density.



Control Concept model of Fingerprint Sensor

The figure below shows the control concept model of the Fingerprint sensor of the Smart Lock System. The input would be the desired time to unlock the lock using the fingerprint sensor. And the output of the control system would be the actual time taken to unlock the lock using a fingerprint. The sensory device is the verification speed of the fingerprint sensor and it should be less than 5 seconds. The control device is Fingerprint Sensor and the Actuating Device is a Fingerprint verifier.



System Technical Effectiveness Measures

System effectiveness is defined as the probability that a system can successfully meet the objectives for which it was intended.

Availability: Availability is the function of maintainability and reliability. From the calculations, the inherent availability is 88.17%, achieved availability is 93.35%, and operational availability is 81.57%.

Dependability: Dependability is the function of availability and reliability. It is the quality of being trustworthy and reliable. From the calculations, the device is 99% reliable and trustworthy. The device has increased convenience as it can be remotely used using the smartphone door lock/unlock application, improved security with fingerprint locking system, and heightened connectivity with smartphone applications.

Performance: The response time for the device to lock/unlock the door is less than 10 seconds. While the fingerprint area can quickly identify fingerprints, we can press down the door handle to open the door. In addition, the bottom of the smart door lock is the USB power jack for charging. After entering the door, turning the button, and anti-locking the door, the security performance is higher. Although the biggest selling point of the smart door lock is to let people say goodbye to the trouble of the key, as a door lock, an emergency key is still necessary to open the door. The key hole is available on the external panel of the device and an integrated concealed design is adopted.

Life Cycle Cost Analysis

The life cycle cost of the Smart House Lock System has been deduced from operational requirements, maintenance requirements, TPMs, and functional requirements of the product. Also, a Cost Breakdown Structure of the system is designed from these system requirements. The parametric costing approach is used to identify the total system life cycle of the product.

Cost Breakdown Structure of the product

The figure below shows the Cost Breakdown Structure of a Smart Lock product throughout its entire lifecycle. The total cost of a Smart Lock system is $349.99 inclusive of Research and Development cost, production and construction cost, operation and support cost, and disposal cost.

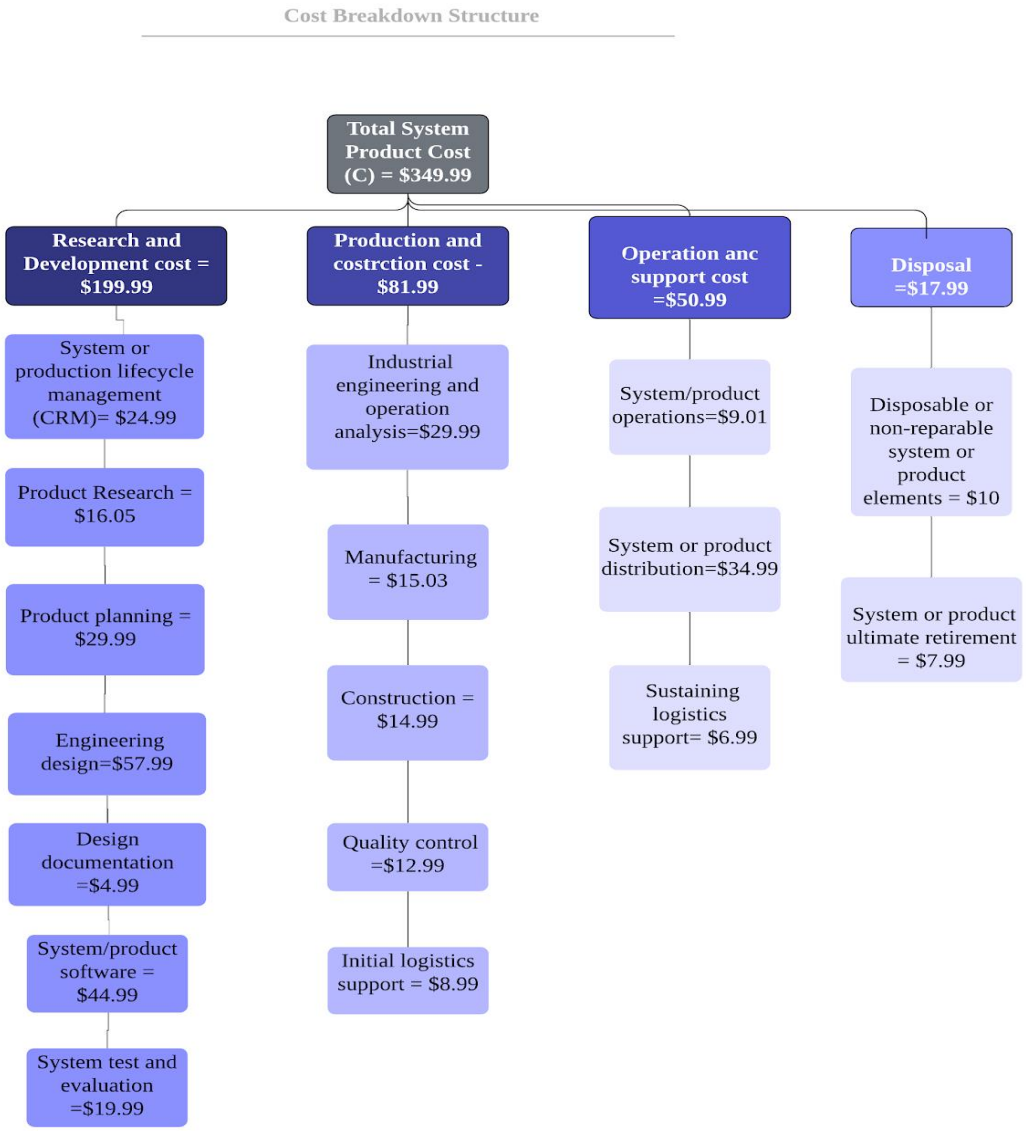


Figure 6: Cost breakdown structure for the entire life cycle

The Figure 7 below explains the Cost Breakdown Structure of the engineers/technicians/managers/designers involved in different stages of the product life cycle. Also, the cost for warehouse, storage spaces, production cost, maintenance service cost, and call center support are provided below.

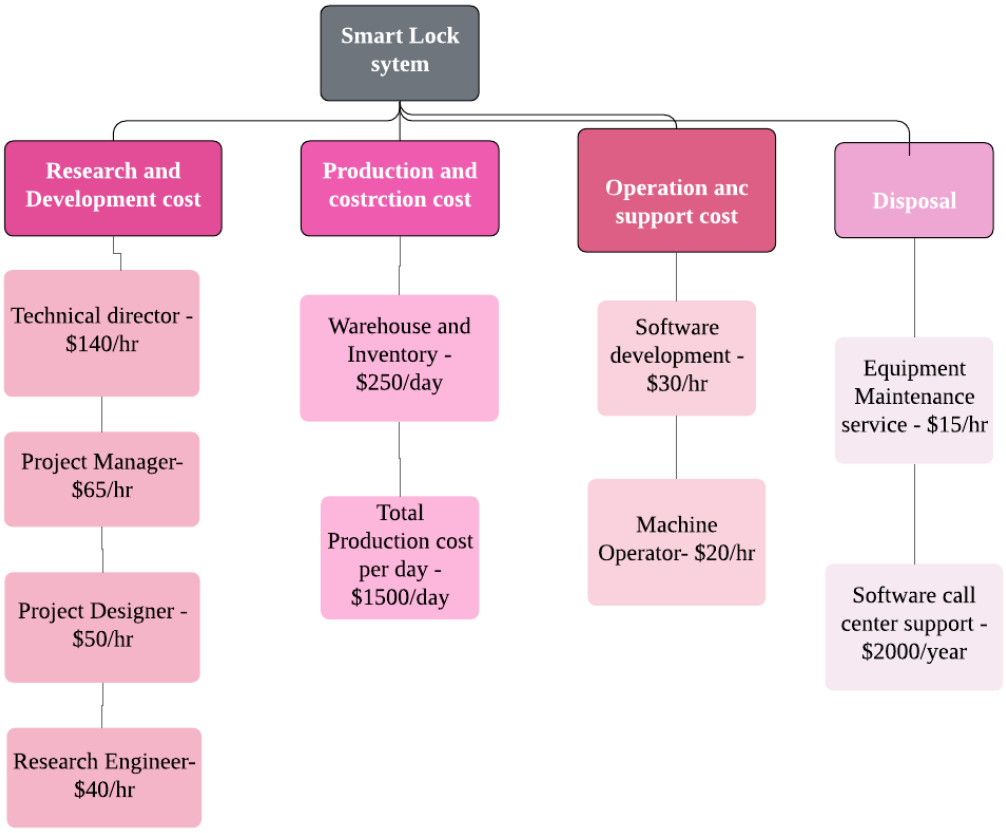


Figure 7: Cost breakdown structure for specific resources

Economic Life of the System

The economic life of a product also known as service life or useful life mentions how long the product remains profitable or economical. The following table represents the assumed costs for various parameters for the product's life cycle.

Fixed Cost, P	$349.99
Salvage value is zero at any age	$0
First-year Operating or Maintenance cost	$24.99
Maintenance cost increases by	$8 every year
Economical life of the equipment n=sqt(2*P/M)	**9.35 Years**

Table 10: Product life cycle cost parameters

Life Cycle Costing (LCC) Illustration

- Life Cycle Costing (LCC) of the Smart Lock system has been calculated for the economic life period of the product.
- The total life of the product is taken as 10 years which includes the disposal phase of the product.
- The production unit including the number of machines and employees are set up to make 100 products per day.
- For the first two years, the production unit runs all the working days i.e 261 days per year.

The Table 12 below shows the yearly cost for the entire economic product life cycle of the Smart Lock System. (See more in Appendix)

Research and Development Phase

It is a pivotal stage in product planning and development which happens for the first three years of the Smart Lock product life cycle. The total cost estimated for the Research and Development stage is 1.12 million dollars.

Production and Construction Phase

Starts from the second year of the economic life cycle of the product and ends in the sixth year. The manufacturing unit, machines, and resources are planned to produce 100 products per day for 261 days in the initial stages of the product life cycle and the number of units produced will change every year according to the forecast or trends of the previous years/quarters purchase. The Production and Construction cost of the Smart Lock system for its economic life cycle is estimated to be 2.2 million dollars.

Operations and support Phase

Operations and support of the Smart Lock system start from the third year of the economic life of the product. The operation and support costs include maintenance cost of the product gradually increases every year by $8 lasts until the end of the product life cycle. The total Operations and Support cost of the Smart Lock System is 8.8 million dollars for 9 years which includes material support, supply chain, maintenance, customer care, inventory management, etc.

Disposal Phase

The disposal cost of the equipment starts at the end of the economic life cycle and it costs 1.5 million dollars in total for the last 4 years of the product life. Product disposal cost includes dismantling, e-waste recycling, recycling facility, etc.

The graph below shows the economic life cycle cost of the product for various life cycle phases of the product.

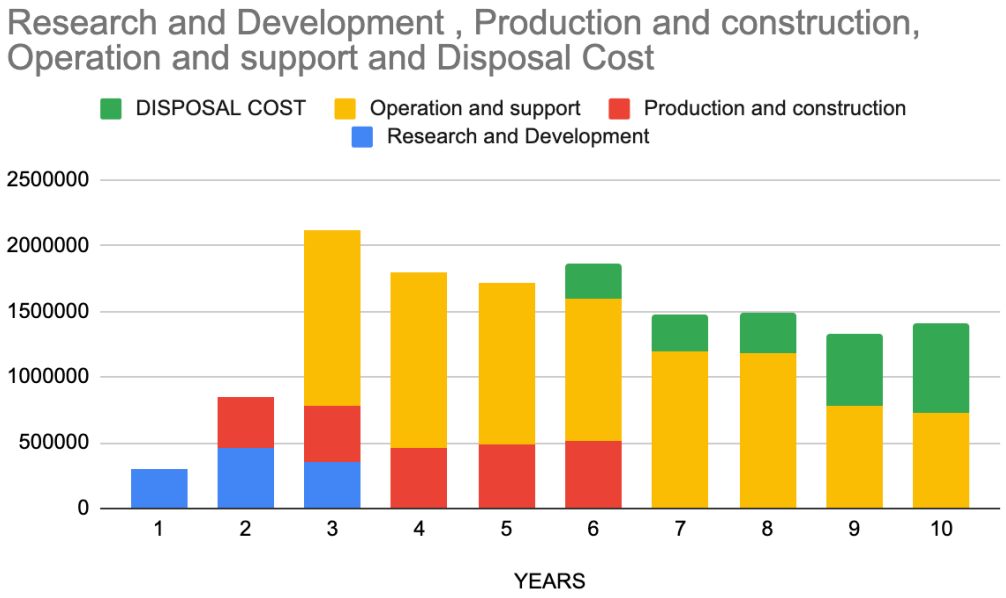


Figure 8: Economic life cycle cost for life cycle phases

High Level Project Management Plan

Figure x shows the Gantt chart for the entire lifecycle of the Smart Lock system.

The tasks to be performed are listed on the vertical axis which constitute the work breakdown structure of the entire project. The horizontal axis shows the time intervals in years. The teams that are responsible for each task is listed and the detailed resource requirements are included in the previous section of this report. The width of the horizontal bars shows the duration of each activity under various phases - acquisition, requirement, and phase down.

This chart is created by following an early start time approach (each task is scheduled to start immediately after its prerequisite is completed) and helps in understanding dependency/precedence between tasks.

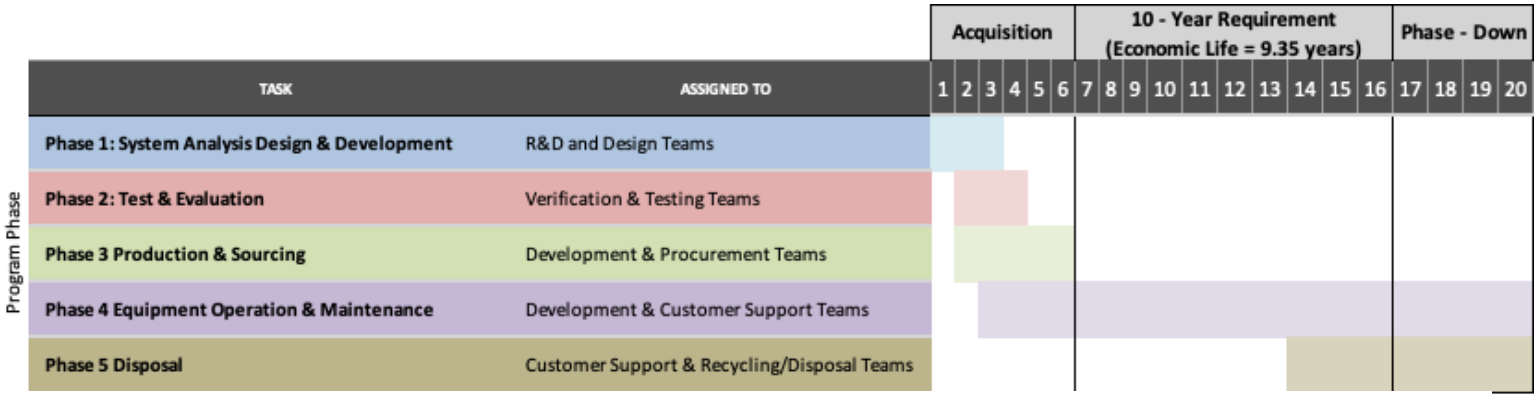


Figure 9: Gantt chart for Project management plan

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2. https://store.google.com/us/product/nest_x_yale_lock?hl=en-US&gclid=EAIaIQobChMIzf6_6K2k5QIVg9dkCh0WnQLCEAAYASAAEgIzkPD_BwE&gclsrc=aw.ds
3. https://lockly.com/products/lockly-secure-pro
4. https://lucidchart.zendesk.com/hc/en-us
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APPENDIX

SURVEY RESULTS

Timestamp	How often do you forget your house keys?	How much time do you spend in finding your keys?	Would you like to give access to your frequently visited guests?	Would you prefer a key-less technology to replace the traditional lock system?	Please rank the following smart lock features according to your priorities. [Security]	Please rank the following smart lock features according to your priorities. [Ease of every day use]	Please rank the following smart lock features according to your priorities. [Ability to support multiple users]	Please rank the following smart lock features according to your priorities. [Remote access for authorized users]	Please rank the following smart lock features according to your priorities. [Mobile application compatibility for Android and iOS platform]	Please rank the following smart lock features according to your priorities. [Cost]	Please rank the following smart lock features according to your priorities. [Ease of hardware installation]
2019/10/07 12:16:06 pm GMT-6	Never	Zero! I always know where my keys are		Yes	High Priority	High Priority	Medium Priority	Medium Priority	High Priority	High Priority	Medium Priority

2019/10/07 12:17:17 pm GMT-6	Always	Long enough that it's a problem		Yes	High Priority	High Priority	High Priority	High Priority	High Priority	High Priority	High Priority
2019/10/07 12:23:52 pm GMT-6	Always	Long enough that it's a problem		Yes	High Priority	High Priority	High Priority	High Priority	Medium Priority	Medium Priority	Medium Priority
2019/10/08 1:06:52 pm GMT-6	Once a month	Long enough that it's a problem	Maybe	Yes	High Priority		Medium Priority	Low Priority	High Priority	Medium Priority	Low Priority
2019/10/08 2:14:45 pm GMT-6	Never	Zero! I always know where my keys are	Maybe	Yes	High Priority	Medium Priority	High Priority	High Priority	High Priority	High Priority	High Priority

2019/10/08 5:10:40 pm GMT-6	Once a month	Zero! I always know where my keys are	No	Yes	High Priority	High Priority	Medium Priority	High Priority	Medium Priority	High Priority	High Priority
2019/10/08 5:12:29 pm GMT-6	Never	Zero! I always know where my keys are	Maybe	Maybe	High Priority	High Priority	Medium Priority	Medium Priority	Medium Priority	High Priority	High Priority
2019/10/08 5:13:15 pm GMT-6	Never	Zero! I always know where my keys are	Yes	Yes	High Priority	High Priority	High Priority	High Priority	High Priority	High Priority	High Priority
2019/10/08 5:33:21 pm GMT-6	Once a week	Long enough that it's a	Yes	Yes	High Priority	High Priority	Low Priority	Medium Priority	Low Priority	Medium Priority	Medium Priority

		problem									
2019/10/08 5:42:32 pm GMT-6	Never	Long enough that it's a problem	Maybe	Yes	High Priority		Medium Priority	Medium Priority	High Priority	High Priority	High Priority
2019/10/08 6:00:56 pm GMT-6	Never	Zero! I always know where my keys are	Maybe	Yes	High Priority	High Priority	Medium Priority	Medium Priority	High Priority	High Priority	Low Priority
2019/10/11 12:00:15 pm GMT-6	Never	Zero! I always know where my keys are	Maybe	Yes	High Priority	High Priority	High Priority	High Priority	High Priority	High Priority	High Priority
2019/10/11 12:13:24 pm	Once a month	Long enough that it's a	Yes	Yes	High Priority	High Priority	Medium Priority	Medium Priority	High Priority	Medium Priority	Low Priority

GMT-6		problem									
2019/10/12 11:25:57 pm GMT-6	Once a week	Long enough that it's a problem	Maybe	Yes	High Priority	High Priority	Medium Priority	Medium Priority	High Priority	High Priority	High Priority
2019/10/12 11:26:19 pm GMT-6	Never	Zero! I always know where my keys are	Maybe	Yes	High Priority	High Priority	Medium Priority	High Priority	High Priority	Medium Priority	High Priority
2019/10/12 11:26:23 pm GMT-6	Once a month	Zero! I always know where my keys are	No	Maybe	High Priority	High Priority	Medium Priority	Low Priority	Medium Priority	Medium Priority	Medium Priority
2019/10/12 11:27:46 pm	Never	Zero! I always know	Maybe	Maybe	High Priority	High Priority	High Priority	High Priority	High Priority	High Priority	High Priority

GMT-6		where my keys are									
2019/10/12 11:33:25 pm GMT-6	Never	Zero! I always know where my keys are	No	Maybe	High Priority	High Priority	Medium Priority	Medium Priority	High Priority	Medium Priority	Medium Priority
2019/10/12 11:33:51 pm GMT-6	Once a month	Long enough that it's a problem	Yes	Yes	High Priority	High Priority	Medium Priority	High Priority	Medium Priority	High Priority	High Priority
2019/10/12 11:33:58 pm GMT-6	Never	Long enough that it's a problem	Maybe	Maybe	High Priority	Medium Priority	High Priority	High Priority	High Priority	Medium Priority	Medium Priority
2019/10/12 11:47:16 pm GMT-6	Once a week	Long enough that it's a	No	Yes	High Priority	High Priority	Medium Priority	High Priority	High Priority	Medium Priority	High Priority

		problem									
2019/10/13 12:02:06 am GMT-6	Never	Long enough that it's a problem	Maybe	Yes	Medium Priority	Medium Priority		Medium Priority	Medium Priority	Medium Priority	Medium Priority
2019/10/13 1:33:00 am GMT-6	Never	Zero! I always know where my keys are	No	Yes	High Priority	High Priority	Low Priority	Low Priority	High Priority	Medium Priority	Medium Priority
2019/10/13 2:25:42 am GMT-6	Never	Long enough that it's a problem	Maybe	Maybe	High Priority	High Priority	Medium Priority	Medium Priority	Medium Priority	High Priority	Medium Priority
2019/10/13 9:54:46 am GMT-6	Once a month	Long enough that it's a	Maybe	Yes	High Priority	High Priority	Medium Priority	High Priority	High Priority	High Priority	Medium Priority

		problem									
2019/10/13 12:00:13 pm GMT-6	Once a month	Long enough that it's a problem	No	Yes	High Priority	High Priority	Medium Priority	High Priority	High Priority	High Priority	High Priority
2019/10/14 12:56:05 am GMT-6	Once a month	Long enough that it's a problem	Yes	Yes	High Priority	High Priority	High Priority	High Priority	High Priority	High Priority	High Priority
2019/10/15 10:20:21 am GMT-6	Never	Zero! I always know where my keys are	Maybe	Yes	High Priority	High Priority	Medium Priority	High Priority	High Priority	Medium Priority	High Priority
2019/10/15 4:31:47 pm GMT-6	Once a month	Long enough that it's a	No	Yes	High Priority	High Priority	High Priority	High Priority	High Priority	High Priority	Medium Priority

		prob lem									

Customer Survey

Link to Survey: https://docs.google.com/forms/d/e/1FAIpQLSdM4r4Zaz5UujvsAE6r4irAdUQ8YinRUWxx_TMCzeZp-mEp2g/viewform?usp=sf_link

From figure 1, we infer that approximately 50% of the people who have taken the survey forget the house keys.

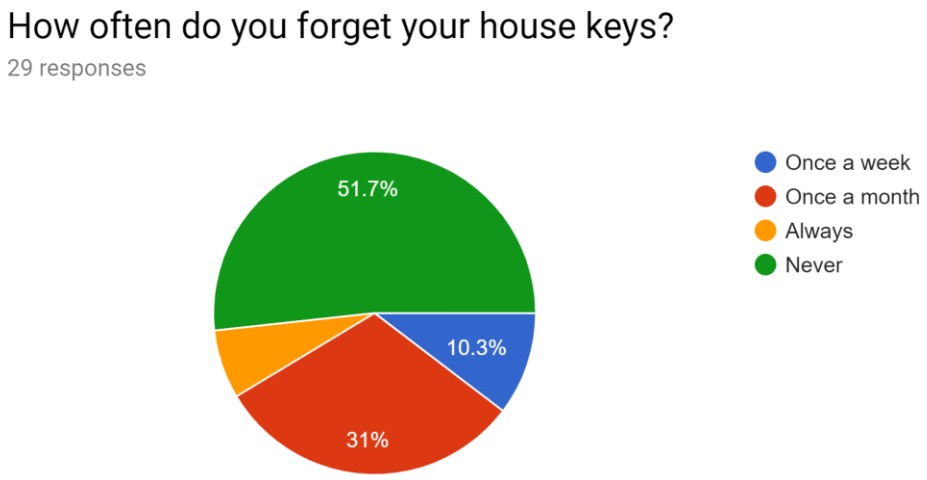

Figure 1. House Keys Carried by Customers

From figure 2, the time spent searching the house keys is analyzed. As seen below, the majority of the survey takers feel that they spend long enough time searching for the house keys for it to be a problem.

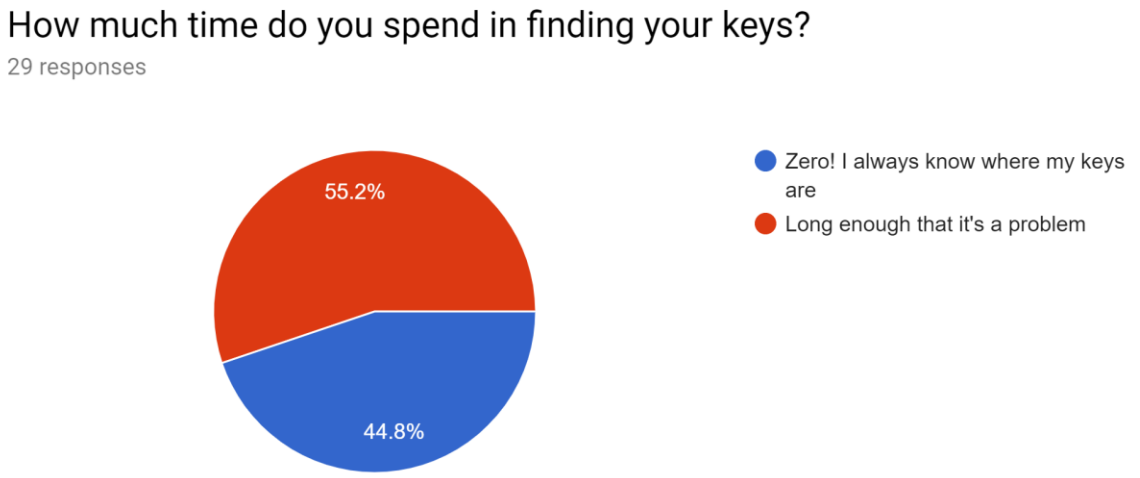

Figure 2. Time spent on searching house keys

From figure 3, the willingness of the owner to provide access to frequently visited guests are analyzed. About 19% agree to provide access, 27% do not agree to provide access, and 54% may provide the access.

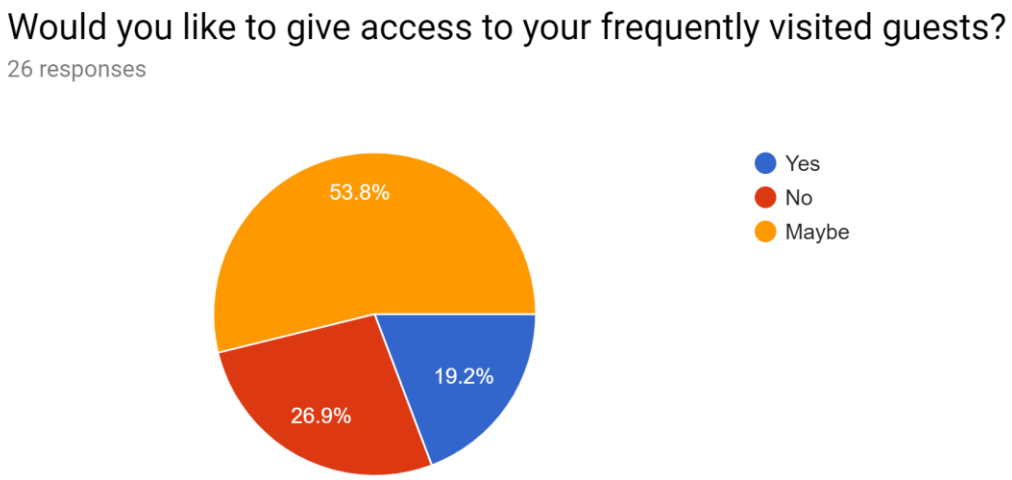

Figure 3. Willingness to provide access to frequently visited guests

From figure 4, the transition to keyless technology from traditional key house lock system is analyzed. About 79% prefer keyless technology and 21% may consider the keyless system.

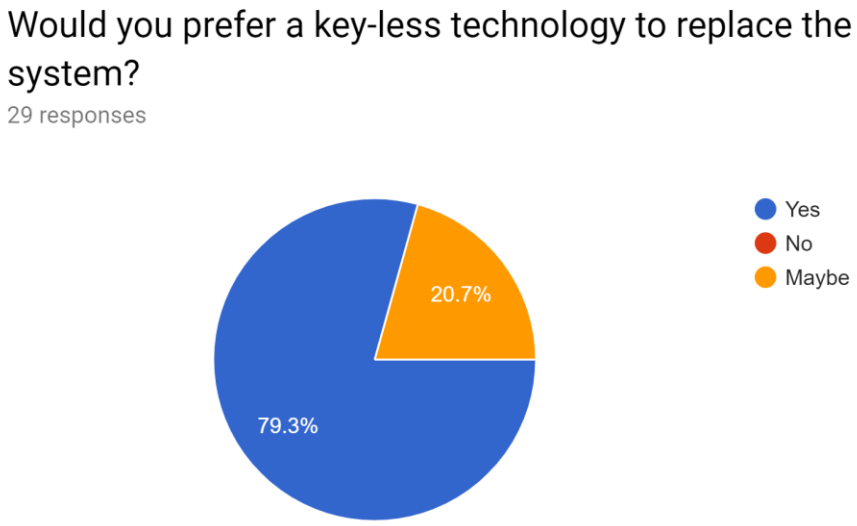

Figure 4. Preference for keyless technology or traditional lock system

From figure 5, the priorities for the fundamental needs are analyzed. 28 users give highest priority to security, 17 users give high priority for feasible cost of the device, 24 users give high priority for the usability of the device to be easy and simple, 17 users give medium priority for the support of multiple users, 16 users give high priority for remote access to authorized users, 21 users give high priority for the smart lock mobile application to be compatible with Android and iOS platforms, and 15 users prefer high priority for easy installation of the device.

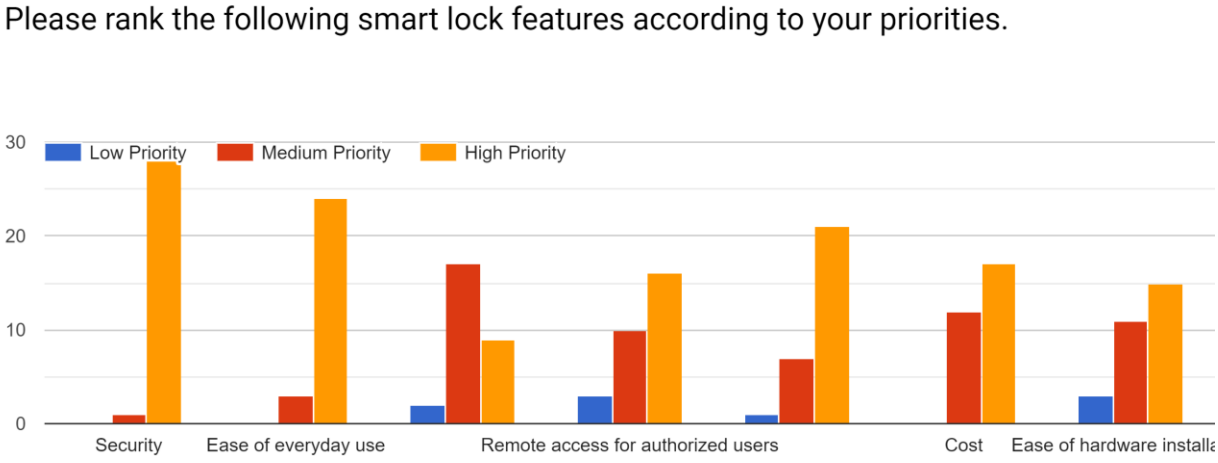

Figure 5. User needs ranked according to priority

System Reliability, Maintainability, Availability, Usability, Sustainability

t (hours)	Reliability					
	Fingerprint sensor	Smart Home Device Connectivity	App Failure	Remote key failure	System (Assuming Series Connection)	System (Assuming Parallel Connection)
100	0.9048	0.8825	0.8948	0.8669	0.6194	0.9998
200	0.8187	0.7788	0.8007	0.7515	0.3837	0.9980
300	0.7408	0.6873	0.7165	0.6514	0.2377	0.9920
400	0.6703	0.6065	0.6412	0.5647	0.1472	0.9797
500	0.6065	0.5353	0.5738	0.4895	0.0912	0.9602
600	0.5488	0.4724	0.5134	0.4244	0.0565	0.9333
700	0.4966	0.4169	0.4594	0.3679	0.0350	0.8997
800	0.4493	0.3679	0.4111	0.3189	0.0217	0.8604
900	0.4066	0.3247	0.3679	0.2765	0.0134	0.8167
1000	0.3679	0.2865	0.3292	0.2397	0.0083	0.7700

Table 11: System calculations for system's Reliability

	Cost per year											TOTAL ACTUAL COST (DOLLAR
		1	2	3	4	5	6	7	8	9	10	
Research and Development	Cr	305689	458533.5	358600								1122822.5
Production and construction	Cp		391500	428040	456750	482850	508950					2268090

Operation and support	Co			1330839	1341780	1238400	1087500	1191950	1177500	786000	726000	8879969
Total actual Cost (C)		305689	850033.5	2117479	1798530	1721250	1596450	1191950	1177500	786000	726000	12270881.5
Total Preset Cost C (10%)		277899.0909	702507.0248	1590893.313	1228420.19	1068760.827	901154.4056	611658.819	549312.4402	333340.728	279904.4281	7543851.267
Cumulative PC		277899.0909	980406.1157	2571299.429	3799719.619	4868480.446	5769634.852	6381293.671	6930606.111	7263946.839	7543851.267	**46387137.44**

Table 12: System cost analysis per year

MARKET SURVEY

Product	August Smart Lock HomeKit Enabled	August Smart Lock Pro + Connect	Schlage Sense	Nest X Yale Lock With Nest Connect	Schlage Encode Smart WiFi Deadbolt	Lockly Secure Plus	RemoteLock OpenEdge RG Deadbolt	Yale Assure Lock SL (YRD 256)	Gate Smart Lock
									
Best For	HomeKit Users	Third-Party Compatibility	Voice Control	Nest Users	Amazon Key Users	Fingerprint Scanning	Vacation Rentals	Design Fans	Built-In Camera
Connectivity	Bluetooth, Wi-Fi	Bluetooth, Wi-Fi, Z-Wave	Bluetooth	Wi-Fi	Wi-Fi	Bluetooth	Wi-Fi	Z-Wave	Wi-Fi
Integration	Amazon Alexa, Apple HomeKit, IFTTT, Nest	Amazon Alexa, Apple HomeKit, IFTTT	Amazon Alexa, Apple HomeKit, Google Assistant	Nest	Amazon Alexa, Google Assistant	N/A	N/A	N/A	N/A
Installation	Interior Escutcheon	Interior Escutcheon	Exterior Escutcheon, Interior Escutcheon	Exterior Escutcheon, Interior Escutcheon	Exterior Escutcheon, Interior Escutcheon	Exterior Escutcheon, Interior Escutcheon	Interior Escutcheon	Exterior Escutcheon, Interior Escutcheon	Exterior Escutcheon, Interior Escutcheon
App	Mobile, Web	Mobile	Mobile	Mobile, Web	Mobile	Mobile	Mobile, Web	Mobile	Mobile
Notifications	Email, Push	Email, Push	Push	Push	Push	N/A	Email, Push	N/A	Push
Geofencing/Location Services	✓	✓	–	✓	–	–	–	–	–
Guest Access	✓	✓	✓	✓	✓	✓	✓	✓	✓
Tamper Alarm	–	–	✓	✓	✓	–	–	✓	–
Touchpad	–	–	✓	✓	✓	✓	✓	✓	✓
Voice Activation	✓	✓	✓	–	✓	–	–	–	–