

# THE AUTOMATED CABINET FOR SUPPORTING SECURITY STORAGE WITH PASSLOCK SYSTEM AND AUTOMATIC TRANSPORTATION

Suchada Rianmora\*, Isarashmi Sarakichprecha, Pattaranan Eiawsakul and Voraporn Klaewthanong

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## Abstract

Product design development (PDD) is used in this research to translate customer's requirements to be engineering specification and design. The concepts of vertical carousel is used in a warehouse or a factory for storing products and the automated storage and retrieval system (AS/RS) are considered at the concept development phase to generate new idea for cabinet model. As the demand for tiny accommodations has grown, the automated cabinet is an alternative channel for supporting an innovative environment, flexible to the requirements of modern life with the vertical-styled storage. It can make small space living easier and save where the security system and the extra storage spaces in vertical direction are added to the traditional character of cabinet. The main mechanical components, controlling system, and functional test were expressed through form/fit/function concept. The reliability of the proposed cabinet was determined by considering three main modules; automatic doors, passlock, and rotation. The obtained calculation presented the good sign for launching this prototype to produce in the real world application. Moreover, for the common areas of condominium, apartment, department store, museum, or sport club, this cabinet can be used as a depository where things are safely kept or stored.

**Keywords:** Product design development, Maslow's hierarchy of need, automatic storage and retrieval system, cabinet, vertical carousel

## Introduction

Since at the moment with the evolutions of technologies, the basic needs of human are changed; some automated or luxury things have been come and played as the vital needs. Recently, humans might need only shelter or a place to live without any fancy facilities. Most people are not happy with their life, they have tried to find some facilities to make them more comfortable and more secure. In order to create a new item for supporting and

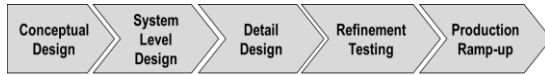
satisfying customer's requirements, the technology Called product design and development (PDD) has been applied in various types of manufacturers (Lester, 1998; Weigel, 2000; Dam and Siang, 2014; Adams, 2016). In the recent year, the increasing of new launching products is rapidly grown. Satisfying customer's needs becomes harder, since it has to consider both physical and mental factors. PDD method can help designing and developing

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*School of Manufacturing Systems and Mechanical Engineering (MSME), Sirindhorn International Institute of Technology, Thammasat University, Pathumthani 12121, Thailand. E-mail: suchada@siit.tu.ac.th*

\* Corresponding author

products, also the processing of the manufacturer to be more significant. PDD consists of five phases (Figure 1).



**Figure 1. Phases of Product design development**

The first phase, *Conceptual Design* is a phase which would gather variety of ideas together to generate a drafting model of a roughly product's outlook. Then the second phase is *System Level Design*. In this phase, manufacturer will go deeper into the product's details with a function of the product itself to be matched with the physical characteristics or the product architecture. The next phase is *Detail Design*. After the manufacturer knew what functions the product will have, to make it more realistic is to put details into the design. To match between *forms, fit, and function* of the product, such that it will be more visualize. Then other two phases are *Refinement Testing* where the testing of the product have been performed, and the last phase is *Production Ramp-up* where the improvement activities are performed and be ready to launch into markets (Aziz and Lokman, 2011).

Since the space is so valuable in a small accommodation and as the demand for tiny accommodations has grown, the manufacturers have tried to figure out the ways to extract the customer's feelings and transform them to be a new design with low price. The "automated cabinet" is a new product which tends to combine the existing technology with a normal cabinet. The machine was created base on the idea of serving humans needs in two main factor. The first one is to serve on the convenience purposed by using an automatic system to control the movement of each slot in the cabinet. The other purpose is to serve on the security factor, since the cabinet would have a passlock, which acts like a command to select on the desired slot and deliver it to the user. Hence, the automated cabinet would concern to be a mixed between safety need and social need. To compare with a normal cabinet, it is significant cheaper than an automated one. But with the automated cabinet, to manage or store customers' items inside are easier to make them in order and reduce the mess in the cabinet. The automated cabinet is not only for keeping stuff in-house, but for further used, it can be used in an organization to store small products or it can be used in public as a self-service storage.

## Materials and Methods

Before starting to design the automated cabinet, a set of questionnaire had been launched to define customer's feeling on an automated product or home automation, and the way to managing items in house. To know the direction of how the product should be designed. The area of interest for distributing the questionnaires is Bangkok metropolitan region where the target groups are the middle class to high standard of salary people. In order to identify and analyze customer's requirements on storage space, ten main topics were raised and mentioned; *customer's perception, product characteristics, new product development, home automation, vertical carousel, self-service storage, conceptual design, system level design, detail design, and refinement testing*. In this study, 118 respondents answered the questions.

### Customer's Perception on Home Automation and Managing the Storage Space

*Question 1: How do you mostly keep your items in the house? (Table 1)*

*Question 2: Do you have problem with the height of the slots from using a cabinet? (Table 2)*

*Question 3: What do you think about Home Automation? Does it increase the convenient in your life? (Table 3)*

*Question 4: Do you have any worries from storing your personal items when you go out? (Table 4)*

According to the results from *question 1* and *2*, most of the respondents keep their items in a cabinet (45.6%). But the height of the slots caused the effect on storing items with more than half of the responses (58.8%). That could be the reason of just leave item

**Table 1. How to keep items in house**

How	Percentage of response
In a shelf or a cabinet	45.6%
In a box	8.8%
On the table	11.8%
Just leave wherever	33.8%

**Table 2. Problem on the height of slot/storage space**

Decision	Percentage of response
Yes	58.8%
No	41.2%

**Table 3. Home automation is increased the convenient in life**

Decision	Percentage of response
Yes	89.7%
No	10.3%

wherever in the house (33.8%). to avoid the unreachable storage space. Such that, it can cause the mess in house and might need more time to find items in house with unorganized them.

From *question 3*, the result shows that most of people think that a home automation will increase the convenient in life. For example, nowadays one of the home automation that could be found easily is a vacuum machine. With this vacuum machine, it is not only increased the convenient, but it is also reduced the fatigue from doing housework. Such that, the home automations become more popular these days.

Therefore, with the results from question 1 to 3, to combine the usage of a cabinet as a storage space with a technology to construct a home automated product could be one of a new innovation. The product should be able to eliminate the problem of reachable of the storage space and be able to use all the spaces in the storage device.

From *question 4* which asked responses about storing personal items outside. It can be an opinion of a person who has to use public transport or has to do many activities in a day. Normally in a public near train station will provide a locker or a self-service storage, but as a locker, the problem is losing key or unreachable empty slot from the height of the users or the weight of the items. Such that, to provide a storage space for public used can be one alternative of the product to serve more user's needs both on the convenient purpose and the safety purpose.

### Product Characteristics

As mentioned that with the new technology had developed, number of new products launching are increasing rapidly. So, to understand what customers want or what is suit customer is important. To identify what customers really want is not as easy thing. But if instead of trying to find a direct opinion or did not give any scope, the producer or manufacturer give some characteristics to identify the meaning of each word to the customers, such that the customers are able to understand better on what is the real purpose of making a product. Also with the details of the characteristics, it is easier to merge the characteristics from customer's perception into an engineering task, to satisfy customers' needs or what they really want better.

i) *Automation*: Automation product is a product which can work as a self-acting or self-regulating mechanism by the controlling system to command directly with little or no direct human control. The main function is to work as the human's imitations or helping humans to complete tasks easier. Therefore, the automation provides convenience to

user such as the big factory used the automatic product for saving time, improving the accuracy and precision of the work, saving material cost and labor cost. Moreover, the product with the automated system can support humans to have an easy life with just a touch of finger. For example, a vine robot which is used for measuring the moisture level and control level of water in grapes trees where they are for making wine.

ii) *Safety*: Safety is the state of being safe, which could mean the condition of being protected from or unlikely to cause danger, risk, or injury. To increase the level of safety, it can be by staying in where you feel that it is safe, or on the other hand is to find a device for helping. For example, a high value item needs a high level of protection, such as a diamond ring or gold. That is how a safe become more important even in a house. Moreover, according to Maslow's hierarchy of need also identify a level called 'Safety Need' as the second important needs in the overall humans' need (Poston, 2009).

iii) *Flexibility*: Flexibility is characterized by a ready capability to adapt to new, different, or changing as requirements. With the ability of changing, to adapt this characteristic with a product can get more of customer's attentions. A product should be able to change for customize as what customer wants. Not only customize the outer components but also the function inside should be able to adjust too. Such that, the product will gain more ability to satisfy on customer's need and be able to compete with other competitors.

iv) *Alternative*: Alternative can be defined as one of purchased decision to buy a product to match with life style or needs. If in the market has many products with similarly property, then which characteristic is closest to the need will be easy to be selected. Therefore, when a new product is designed with more and advanced functions or by adding a new innovation, even the price might get higher, but customers might buy it anyway. Such that it is depended on each customer's perception. Although sometimes the product is not the basic need, but it also can be sold for customer who wants this kind of product or it effect on that customer's perception, they might willing to pay for it. Or it can be said that if the product's function is matched with a self-perception, it will have direct effect on the purchased decision of the customer as the alternative decision (Hwand, 2004; Jerath *et al.*, 2014).

v) *Universal design*: Growing old is one of the natural phenomenon which cannot be reversed. People may maintain good health by eating healthy food, performing exercises and taking proper care of their body in all the possible ways but as the people

grow old various functions in the body decline various kinds of changes such as physical, biological or psychological occur in the human body, and those might make them feel weak, less immune to diseases and forget things easily and quickly. According to the world population prospectus 2017, the number older people aged 60 and over is going to be doubled in the next 33 years that is by 2050.

Thailand will be in sixth place in 2035 among all Asian countries in context of super-aged society jumping from tenth rank in 2015 (United Nations, 2017a; 2017b; 2017c). The shrinking of height and decrease in weight is commonly seen in the old aged people (Hu, 2005). The gradual decline of the mass in muscle and content of the bone lead to shrinkage of ligaments and tendons affecting the pliability of the limbs in the elderly a result of which arthritis is becoming very common among the elderly people (Tao *et al.*, 2018). Grasping, holding, opening and closing something becomes difficult due to decrement in the range of the motion. Knee osteoarthritis is commonly seen in Thai people (Roopsawang and Suparb, 2015). Due to these changes various problems are seen in elderly people as the major cause of the incident. There has been several incidents where elderly people stood on some untrustworthy table, chair and got an accident falling from it while trying to pick some items such as cups, plates from the upper portion of the cabinet placed in home (An *et al.*, 2013) or in some cases while picking some beloved antique items from top portion of the cabinet. In some of the cases, they even tried ladders to pick something from the upper portion of the cabinet and got some major injuries like broken hands, broken teeth, and fractured legs. This is one of the most common problem seen in the elderly people. With aging as various changes and problems mentioned above occur, in order to tackle these problems, use of various technologies like mechatronics or information technology are made to include in product design and development to produce products that can solve the required problems. This falling accident problem can be solved if the top portion of the cabinet can automatically come to the comfortable height so that the elderly people can pick the items easily without an aid of a table or chair. The automated cabinet for supporting security storage with pass-lock system and automatic transportation can, not only solve the issue of automatic lowering of top portion of the cabinet but also provide the feel of safety, privacy and complete control over the cabinet. Flexibility in usage and usefulness are the crucial factors regulating the adaptability of the technology by the elderly people (Stafford *et al.*, 2010). Full position of power over the support devices is one of the

major preference of elderly people (Blythe *et al.*, 2005). Both flexibility and full control are included in this design. This cabinet design is even suitable for the handicapped people suffering from similar problem as faced by the elderly people.

As illustrated in Figure 2, the public lockers as wall lockers; traditionally, provide only a few areas (i.e., one with handicap symbol) for supporting handicapped people to keep their stuffs inside the locker(s) with a proper height that they can reach to the area of interest comfortably. These have led to the proposed design of storage that provides some convenient functions to avoid some disturbing points to keep stuffs in place.



Figure 2. The public lockers (Public lockers, 2020)

### New Product Development

Form Marketer define “*New product*” can be refer to original product, products, product improvement, and product modifications (Dam and Siang, 2014). The new product can be defined as an innovation, modification or invention of an existing product. Therefore, the new product development (NPD) is the way lead to success of many company then the development of efficiency new product is necessary when the company produce the new product replaced the out- of- trend product and introduce the completely new product for market needs (Weigel, 2000; Adams, 2016). For the automated cabinet is classified to be an innovation product which had modified a normal cabinet into the automated one. The NPD process can be called as product design development (PDD) method. Each stage of PDD is a guide of each step to create and launch new product. To start the process, the first stage is *conceptual design*. The conceptual design is to gather many ideas and try to put them into a drafting of the product. Not only the design, but the purpose of creating the product also concluded in this stage (Ahmad *et al.*, 2018).

The other theory to support the purpose of the product can be used is Maslow’s Hierarchy of needs (Poston, 2009; Kaur, 2013; McLeod, 2007). Designer or manufacturer needs to find the specific target group, such that to create a product is more definite. The product can be combined into more than one level of needs, to serve more customers demand. Since, the safety needs is now starting to

be merged with the basic needs or physiological, to support on this needs might not enough. Then to launch a product which is in the social needs is a little more advance. The product is based on the idea of ‘*Humans being might not need it to survive, but to have it will make life be better.*’

After the target group is clearly defined, the second stage of PDD is *system level design*. It is to identify the function of the product and make the system out of it. Not only the system of the product itself, but also the system to produce the product also. The designer and manufacturer must get clearly information to produce the product with the best performance. The third stage of PDD will come after that, which is *detail design*.

To go deeper into the design, not only the system of it, but it will consist of all little components through the big picture of the product. The prototype of the product might be needed to produce for the next stage of PDD; *refinement testing*. The testing is a very important part to evaluate the performance of the product, to know whether the product has any defect which could occur without knowing in the design. Then the launching stage is called *production ramp-up*, meaning the product is ready to be launched in the market.

### Home Automation

Since the technology formed its enormous influence in everybody’s life, the human-beings are continually seeking for its improvement and how to adequate its usage to their household daily tasks (Rouse, 2015; Semeon, 2015; Toschi *et al.*, 2016). The home automation is refer to a normal home equipment but the difference is that it is an automated equipment. Since people right now wants something more convenient for their life, so the home automations are become much more popular than before. The common categories for home automation were lighting control, security control and access control, HVAC (heating ventilation and air conditioning), and entertainment control (Semeon, 2015). Even though the customers have positive impressions and feelings about the technologies, the manufacturers might need to research and find some new inventions and inspirations for improving their existing items. Since the needs of home-automation products keep increasing day by day (Gronhoj, 2007). The other thing that should be concerned is the price of the product. Customers need to have and purchase something to make them feel more comfortable with the affordable price. So, each company would need to find an equilibrium between effectiveness and affordable prices.

### Vertical Carousel

A vertical carousel is one of the common transportations used in a warehouse or in a factory. The carousel is semi/fully automated rotating shelf storage and retrieval system (Figure 3).

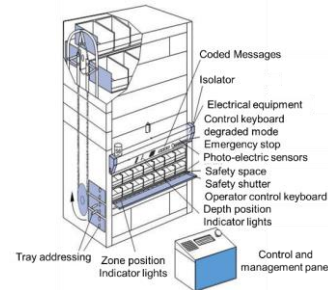


Figure 3. The structure of carousel

The shelves is connected in a closed loop system for rotating upside down, the position of the load and unload is fixed in front of the carousel. Therefore, the operator or the robot can pick up and drop of at the front. The vertical carousel is widely used in the storage that is not a large size (e.g., documents, shoes or spare parts) for orderly storage in the confined spaces. It is, therefore, used to reduce the horizontal space. For the movement of carousel, it can move or translate in horizontal and vertical directions, and it can rotate in both ways which are unidirectional (one-way rotating) and bidirectional (two-way rotating). Most of them are more commonly used in bidirectional (two-way rotating) for convenience and quick operation (Litvak and Vlasiov, 2010). The operation of the carousel has three main steps (Systec group; 2012; Patil and Khot, 2015);

- *Step 1:* Select item to store or unload, after selecting the item that want to storage in the carousel with suitable dimension and weight and fit for the carousel, and then choosing the storage by manually or automatically to access the carousel.
- *Step 2:* Rotate storage item by operator or computer tool with automatic or manual feed mode.
- *Step 3:* Deposition or pick up item, the item can be selected to storage or unload with or without identifying its location and then manage the stock by requirement.

### Self-service Storage

The system of self-service storage consists of multiple storage modules (Figure 4). To store the product, they will insert the product into the module. Then, the module will keep the product into the rack. To deliver the product to the customer, the system will select the product module and then load it to the dock automatically (Westfalia Technologies, 2017).

Self-storage electronic locker placed at BTS Sky train station is one of the popular examples. This locker is used for depositing luggage of the customer (e.g., stuff from shopping, cloth or others). It is accessible 24 h per day, 7 days per week, with CCTV in operation and service call center that are available at any time. There are 4 sizes of the space; starting from small size (20 Baht/h) to extra-large one (50 Baht/h) (Loh, 2017).

### Conceptual Design

The main concept used for designing the concept of automatic storage consisted of three main things; a vertical carousel, a normal cabinet, and a self-service storage (Figure 5). The purpose of combining these three are for two advantages. First is to use the mechanism of a vertical carousel which normally uses in a warehouse. To deliver user's items to automatic doors in front. The second one is to use the password lock system from the self-service storage as the security system. Then all these systems will be put into a normal cabinet as the housing of the machine.

### System-Level Design

The system of the automated cabinet can be classified into three main groups; system control (Table 5), movement control (Table 6), security control (Table 7). The system control is using an Arduino Mega 2560 board as the main controller board, and to connect between each equipment through wires as shown in Figure 6.

### Detailed Design

After analyzing the results from questionnaire and the system of the cabinet had designed, the next step is to design the housing of the cabinet and also each component in detail to make them work efficient between each component. Also to choose the capacity of the motor and material used for the prototype model to make sure the machine will work properly. The method used in this phase is called "Form Fit Function" model.

i) *Form*: The form of the product has been designed to be easy to be placed in any place by using a geometric shape as the shape of the cabinet. The universal design concept is applied for the size of chain, gear, and motor, such that it can work for the prototype and can be adjusted to the real size of the machine. The details of component dimensions via the engineering drawing form are shown in Figure 7. At the front of the cabinet contains 2 automated doors with the size related to the rack's size for easily to take item in and out. Control panel with LCD screen has been placed in the middle between 2 doors for telling the steps to customer and take customer's command to the system.



Figure 4. The example of electronic locker (Self-service Storage, 2020)

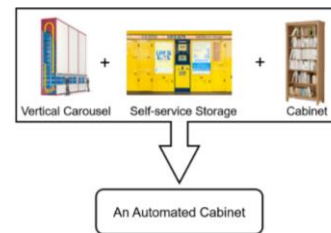


Figure 5. Conceptual design

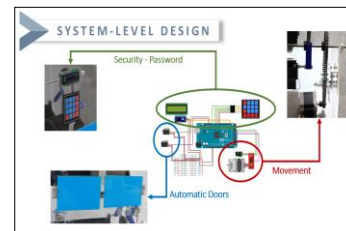


Figure 6. The controller board connected with the main components

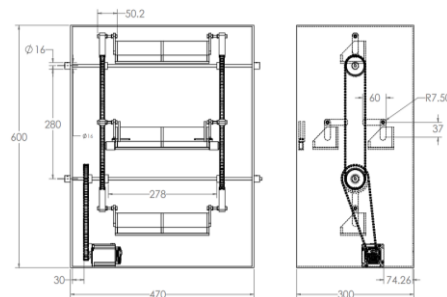



Figure 7. The engineering drawing of the proposed system



i) *Fit*: It is designed to be easy for the movement and the accessing. Since the movement of racks would be automatic, the alignment between racks and doors are very important. Moreover the racks must have a good balance between 2 sides and connect with special mechanism on the racks and chain, to prevent them from going upside down while moving along the path. The doors in front of the cabinet are designed to be big enough to take items in and out without stuck. For more convenient



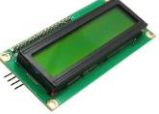



**Table 5. System Control**

System Control	
Illustration	Description
 <p>Arduino Mega 2560 Board</p>	It is used for controlling an overall system as the main controller board.

**Table 6. Movement Control**

Movement Control	
Illustration	Description
 <p>Stepper motor</p>	It is used for controlling the number of steps applying to control the number of angle, which will deliver the desired rack to the automated door.
 <p>Motor Driver</p>	It is used for controlling the value of current which will be sent to the motor.

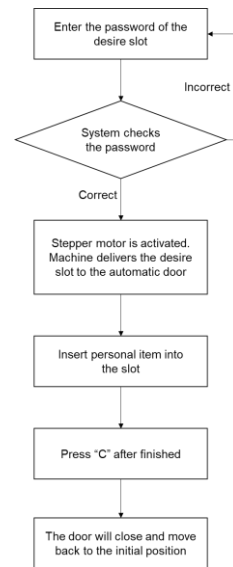
**Table 7. Security Control**

Security Control	
Illustration	Description
 <p>LCD screen</p>	It is used for showing the command, to tell users what is going on, and what to do next.
 <p>Keypad</p>	It is used for inserting command or password to the system.
 <p>Servo motor</p>	It is used for controlling automated doors to make them close or open.
 <p>Automated Door</p>	The automated door was attached with the servo motor and it was controlled by "Arduino controlling platform". The acrylic material was applied for making the frame of the door.

to apply this mechanism with an old existing cabinet, every component must be aligned perfectly to make it easy for a self-assembly.

ii) *Function:* The cover of the cabinet is to protect items inside and the system from the dust and other damages. The moving mechanism is set along a vertical direction of the cabinet, so the racks could move along smoothly. The control panel must work properly to be able to send the signal from

customer's command to make stepper motor activated. The doors are working related to the servo motors since when the stepper motor stops, the servo motors for the doors must be activated. Therefore, the user can access to the racks easily in seconds. The overall steps required for the proposed system are presented in Figure 8.



**Figure 8. The overall steps required for applying the automated Cabinet**

**From Perception to Automated Cabinet**

Presented in this section are about the three main functions which are required for accomplishing the proposed machine where the starting point was generated by applying the physical characteristics and functions of the existing products. Making use of these details, the expected design might be in the position to successfully hit the customers' requirements. All of the observations usually are meant to boost the ability and inspire the skill of creating. The three main functions are:

- "Basket it and get it"

A holding area or an area used for the temporary storage of materials is one of the most important parts of the developed design where the stuff(s) will be positioned, moved and stored. That area should provide the shape as a nice deep basket where the stuff(s) can be stored and placed safely. Illustrated in Figure 9(a) is the various styles of "Basket". For moving mechanism with a container that has deep-basket shape, the concept of "Excavator and Loader" is applied (Figures 9(b) and 9(c)).

After extracting the physical designs and functions of the existing products, the prototype of "Basket it and get it" portion was created as shown in Figure 10.

- “Move it and Leave it”

In order to move the basket up and down where the position of the basket can be adjusted, the “Arduino” controlling system was applied. The reference model of this concept came from “bicycle” where the chain and chainring are the key components, and “ferris wheel” as shown in Figures 11(a) to 11(c). The user can put the stuffs inside the basket attached with a jointed device or flexible piece for supporting turning and moving. From these concepts and applications, the prototype was created as shown in Figure 12.

- “Press it and Save it”

In order to protect a cabinet, master key systems are required. Lost keys and the fear of losing them lead to cabinet doors left open and unsecured. Keyless cabinet locks (Figure 13) might be the bright direction for solving this issue. The concept of this keyless was applied in the proposed design of automated cabinet as shown in Figures 14, 15, 16, and 17.

All the wires are connected to the main microcontroller, “Arduino”. The system consists of 4 main equipment; Two servo motors, Stepping motor with a driver, LCD screen 16×2 with I2C, and Keypad 4×4.

### Refinement Testing

The evaluation of the machine’s efficiency is one of the important factor. Since the automated cabinet has combined several equipment together, such that to evaluate it, there are many factors to be concerned. Since the main function of the machine is to deliver user’s desire rack to the front door, hence the alignment of the rack and the door must not exceed the allowance range. The rack (basket) should be rotated to the position which is align with the door perfectly. The different high between top edge of rack (basket) and bottom edge of the door is considered. Otherwise, the users would not be able to get their stuff in and out.

After finishing the prototype, the number of people who tested and used the machine was 84. Their feelings and comments were recorded and applied for the further modifications and corrections. Moreover, time is one of the key components for the design stage where the design engineers have to pay attention, and, in this study, the properties of “gear and motor” are considered and applied to identify “time spent for moving the basket or rack to the door”. Presented in Figure 18 are the main components required for creating machine where the time calculation is explained briefly. In conclusion, time spent for moving basket to the door area is about “2.87 seconds”, and its status is shown as “ready for service”.



Figure 9. The existing designs of the basket (a), excavator (b), and load (c) (Basket, 2020; Excavator, 2020; Load, 2020)



Figure 10. The prototype created from the concept of “Basket it and get it”

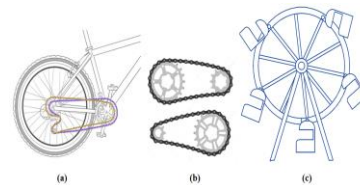


Figure 11. The reference designs from the existing objects: (a) Bicycle, (b) Chain and chainring, and (c) Ferris wheel



Figure 12. The prototype created from the concept of “Move it and Leave it”

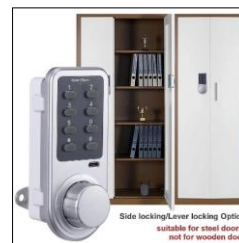


Figure 13. The existing design of the “keyless cabinet” (Keyless lock, 2020)

The other factor which is a standard test of the machine is the reliability test. It is to test on each equipment of each sub-system in the machine and find the probability of the reliability of the system.



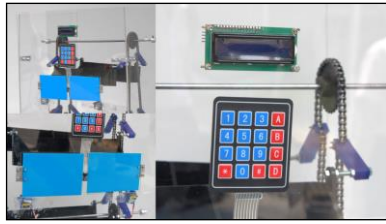


Figure 14. The prototype created from the concept of “Press it and Save it”

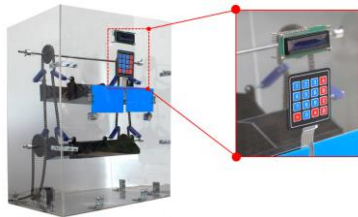


Figure 15. The keypad applied for “Keyless Cabinet”

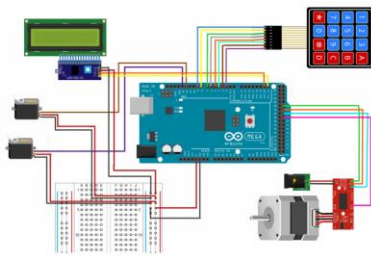


Figure 16. The wire connection for “keyless” controlling system

To do the test, the *Fault Tree Analysis* diagram (FTA) is required for helping to analyze the performance of each component and combine into sub-system then the main system (Ericson, 2005; Marshall, 2012; Kabir, 2017).

FTA method is used for describing the viewer about cause of error in each case. The main failure will be placed at the top of the tree as a top event, the cause of top event failure will be shown below the top event and link together with gates. There are 2 types of gate which are ‘AND’ gate and ‘OR’ gate (Figure 19).

**‘AND’ Gate**

The AND gate means that, to make the system fails, both of the equipment or sub-causes below must fail to make the whole system fails.

To calculate the reliability of system

$$R_{system} = R_A + R_B - R_A \cdot R_B \tag{1}$$

where:  $R_{system}$  is Reliability of the system.  
 $R_A, R_B$  is Reliability of event A and event B.

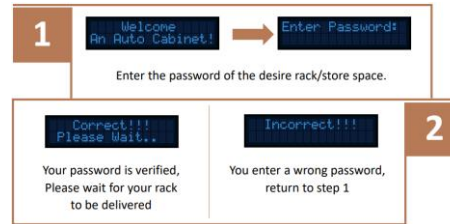


Figure 17. The screen used for displaying the “keyless” application

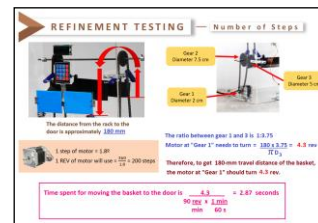


Figure 18. The way to calculate “time spent for moving basket to the door”

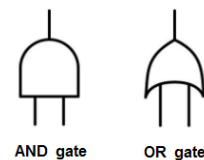


Figure 19. AND and OR Gate

**‘OR’ Gate**

The OR gate means that if one of the equipment or sub-causes below fails, it will make the system above fails automatically.

To calculate the reliability of system

$$R_{system} = R_A \cdot R_B \cdot R_C \tag{2}$$

where:  $R_{system}$  is Reliability of the system.  
 $R_A, R_B, and R_C$  is Reliability of event A, event B and event C.

Each event would represent with rectangle or circle symbols to identify the detail of causes of failure. The rectangle is represented the event which still has sub-cause as the cause of its failure. The circle will represent the event which has no more event causing it to occur or no sub-cause. Then to determine the reliability of the system, system must be tested to find the failure rate, probability of failure, or the reliability of each component and use the formula to calculate, according to the sensitivity of the case.

The FTA diagram of the automated cabinet had been constructed (Figure 20). The experiment took three months for testing with the expected that

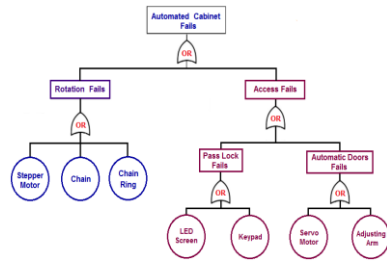
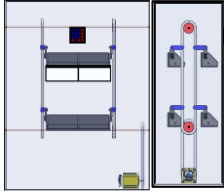
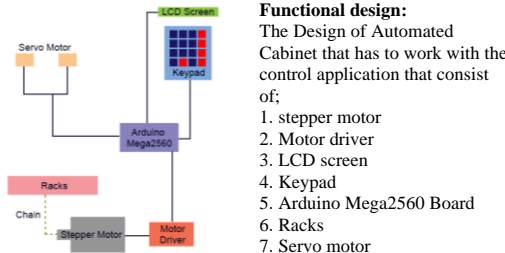
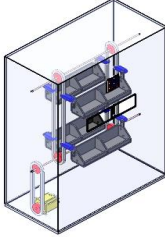
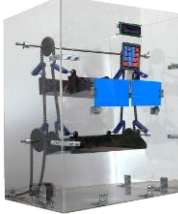


Figure 20. Fault tree analysis of automated Cabinet

Table 8. Detailed design of the automated cabinet

Illustration	Description
	<p><b>Main requirement</b> The design of Automated Cabinet consist of;</p> <ol style="list-style-type: none"> <li>1. Security system: Receiving the password from the keypad for sending the signal through Arduino Board to the motor</li> <li>2. Changing the position of the rack: Automatic mode</li> <li>3. Providing the automatic door</li> </ol>
	<p><b>Functional design:</b> The Design of Automated Cabinet that has to work with the control application that consist of;</p> <ol style="list-style-type: none"> <li>1. stepper motor</li> <li>2. Motor driver</li> <li>3. LCD screen</li> <li>4. Keypad</li> <li>5. Arduino Mega2560 Board</li> <li>6. Racks</li> <li>7. Servo motor</li> </ol>
	<p><b>Drafted final design</b> The drafted design of the Automated Cabinet is used for showing the position of the each component.</p>
	<p><b>Final prototype</b></p>

The access failure can be indicated as the malfunction of the pass lock or the automatic door. A defect of LCD screen or keypad can cause the pass lock failure. If the servo motors do not work for adjusting the arm, the automatic door will fail automatically. If the stepper motor does not work properly or the defect of chain or chain ring is found, the rotation system will fail to position the object from one place to another. Moreover, the error found in the program could also cause the system failure.

To find the reliability of the system, the testing of each event must be performed. To find reliability of access failure, it is to test the alignment between the automatic doors and racks, such that the users would be able to access to the desire rack. The automatic door system is based on the activated of the servo motors and the adjusting arm. The adjusting arm must work proper without the stuck to open the doors continuously. The servo motors must work followed the command to open and close the doors. Also, the keypad and the LCD which will be the medium to send the command to the controller must be in a good condition, to send the right signal and accuracy to the controller.

To find the reliability of rotation failure, the movement equipment must be concerned. The stepper motor must work proper and follow the command which tells the number of step that it must rotate. The chain and chain ring must be a proper specification to make the movement flow without any interrupt or missed the steps. Such that to make the system has a high accuracy level. The results from testing and observation values which are mean time between failure (MTBF), mean time to failure (MTTF), mean time to repair (MTTR), failure rate and reliability had been computed (Table 9).

## Results and Discussion

Presented in this section are the result and discussion of the proposed automated cabinet design. The reliabilities of the subsystem are calculated for identifying the reliability of the automated cabinet (main device). The specific characteristics and functions of the subsystem are mentioned and analyzed in the discussion section.

### Results

The values of the reliability of each subsystem and the main system from the testing is shown in Table 10. The other factor used for determining the performance of the automated cabinet is the repeatability of access. The value of the error of the accessing is calculating by using the formula (3).

the efficiency of the automated cabinet should be at least 80 percent of the full performance. After testing, the result shows that the failure of the system can be classified into two sub-systems; rotation and access failure. If one of the component failed, it will directly effect to the system failure.

**Table 9. Observation of the Reliability of Automated Cabinet**

Item	MTBF (Hour)	MTTF (Hour)	MTTR (Hour)	Failure rate (Failure/Hr)	Reliability	
Rotation	Stepper Motor	100	92	8	0.0109	0.9891
	Chain	100	97	3	0.0103	0.9897
	Chain Ring	100	98.5	1.5	0.0102	0.9898
Passlock	LCD Screen	100	98	2	0.0102	0.9898
	Keypad	100	99	1	0.0101	0.9899
	Servo Motor	100	98	2	0.0102	0.9898
Automatic Doors	Adjusted Arm	100	96	4	0.0104	0.9896

**Table 10. The reliability of each subsystem and the main system**

Subsystem	Reliability
Passlock	0.9689
Accessing Area	0.9597
Rotation	0.9798
Automatic Doors	0.9795
<b>Automated Cabinet</b>	<b>92.99%</b>

$$\text{Error of Accessing} = \frac{r - b}{b_{max} - b_{min}} \times 100 \quad (3)$$

where:  $r$  is the reference point  
 $b$  is the measured point  
 $b_{min}$  is lowest point of accessing  
 $b_{max}$  is highest point of accessing

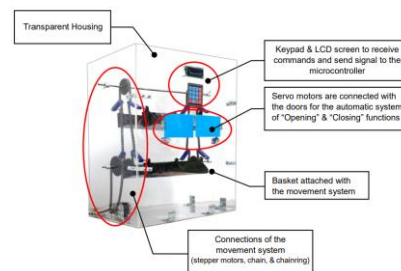
The reference point is measured from the floor to the lower border of the automatic doors. The measured point is measured from the upper border of the front of the rack and the lower border of the automatic doors. The lowest and highest point of accessing is  $\pm 10$  of the reference point where the user still can access to the rack. After calculating all the data of the experiment, the average error of accessing is 27.35%.

### Discussion

The prototype of the automated cabinet was built (Figure 21). The housing is made by an acrylic sheet with the transparent color for seeing the mechanism of the movement system inside. Storage spaces had been designed to be a rack with a plate to separate into 2 partitions, such that for increasing number of storage spaces. To be related with the spaces of racks, the machine also provided 2 automatic doors to serve on each side of the slots. Servo motors will make each door opens automatically when the racks arrived at the inserting point. The stepper motor at the bottom is the main component for delivering or moving system. This motor will be connected directly to one of the chain ring at the bottom, then 3 chain rings at the bottom are connected to each other through a shaft. Using the characteristic of the chain ring with teeth, the chain had been used for connecting to the upper chain rings to make

the automated moving system. The microcontroller gets the commands through the keypad at the front and LCD screen to show what user has to do step-by step.

The speed of stepper motor is controlled to be at the optimal speed where is not too slow or too fast. The controlled of the speed to be not too fast is to prevent the missing steps which will be effected on the alignment of racks and also could cause the fall-off of chain and chain ring. In the other hand, when the speed is too slow it will cause a high vibrating of the motor. Hence, it is effected directly to the bolts and nuts used for connecting chains and chain rings. To prevent this problem, a special glue had been applied on each pair of bolts and nuts for the better attached. Such that the gap between each chain ring is controlled to be at the proper position,



**Figure 21. The prototype of the automated Cabinet**

for the smoothly movement of the system.

With the combination of several concepts to be the automated cabinet, such that there are still some different between the original product comparing with the automated cabinet which had compared the automated cabinet with 3 products which are a vertical carousel (Table 11), a locker (Table 12), and a self-service storage (Table 13).

**Table 11. Comparison between Vertical carousel and automated Cabinet**

Factors	Vertical carousel	Automated Cabinet
Security	Password is used for logging to the system, and can see any shelf.	Password is used for a specific slot, which will increase the security.
Size	The products come out with the specific size without the adjusted.	Customers can customize the size of the Cabinet to fit with the placed space.
Material	The products come out with the specific material without any choices.	Customers can customize the material of the Cabinet to match with the purpose of using.
Functional	The product is fixed with only the function of manufacturer.	Customers can add an extra function to the Cabinet to support other purpose of using. For example, control by smartphone via application.
Price	Approximately \$45,000 – 90,000	Approximately \$1,000

**Table 12. Comparison between locker and automated Cabinet**

Factors	Locker	Automated Cabinet
Storage Space	Less number of slots. It is easier to break into each slot, since it can be known whether which slot has been using.	More number of slots, since each rack is divided into 2 slots. The used slots cannot be known, such that to steal things the cover must have been broken.
Security	An empty slot might not be in a reachable position in some cases; at the top.	Any slot can be used, since it has only 2 gates which are placed in a proper height.
Automated		

**Table 13. Comparison between self-service storage and automated Cabinet**

Factors	Self-Service Storage	Automated Cabinet
Storage Space	Less number of slots. It is easier to break into each slot, since it can be known whether which slot has been using.	More number of slots, since each rack is divided into 2 slots. The used slots cannot be known, such that to steal things the cover must have been broken.
Security	An empty slot might not be in a reachable position in some cases; at the top.	Any slot can be used, since it has only 2 gates which are placed in a proper height.
Automated	Signal might have been interrupt since there is no wire connected between controller and slots.	The wires are connected between controller and motor directly, hence no signal interrupted.
Signal		

## Conclusions

The compact living is a global trend that in the future will become stronger, the designers have tried to create vertical-styled furniture to support the owner who has a lot of things to be kept in the small studio or micro apartments. After adapting the automatic system into a normal cabinet, it is changed to be the automated cabinet with the vertical storage spaces. The automated cabinet used a vertical space to store stuffs by applying the idea from a vertical carousel which it saved more of the horizontal spaces, then it used the ground area less than other cabinet type that has the similar storage spaces, and no need to reach for inputting or taking out of user's stuffs. Meanwhile, the automated system is controlled by using the Arduino board with the code to assign the command to the automated cabinet. So it is possible to act as a security cabinet by assigning the code of Arduino to be finger scan, password or keycard. Therefore, only user who knows the code can take the stuff off. In the market, the automated cabinet can respond to the needs of customer in the social needs by it is a new innovation in the market. So if anyone has used or has it who is considered to be a modern person. Furthermore, the automated cabinet can also respond to the customer needs in the safety needs by it has a system that randomly generates the password for customer and changes it every day, then these will make the

user feel secure in the stuff stored in the automated cabinet.

In conclusion, the automated machine is used for facilitating and reducing repetitive work time which are the customer requirements from the automated machine, then the automated cabinet was built for responding to the customers' needs on convenience in everyday life.

The automated cabinet can serve various target groups, so most of the targets can use it as a safe-boxes for safety purposes directly. Such as at fitness, factory, company, spa, school, temple and etc. can use it as a locker that can input the stuff and create their own password by the desired code.

Besides it can also be used in the pharmaceutical industry such as, hospitals or a medical clinic. They can also use the automated cabinet as a medicine cabinet in the hospital. It can be facilitated by assigning the code of the drug type to the machine, the pills then will be delivered to the user without requirement of skilled operators. Moreover it can reduce the cost of hiring the skilled operator and reduce the time to find the pills such that, it would reduce waiting time of patients who have to wait the dispensing from the pharmacist. Furthermore, the automated cabinet can also adapt to be a storage cabinet in the organization where it would help to manage and arrange a large number of files into order, by using the code to classify the type of the files, instead of wasting time to find.

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