

CHAPTER 4 – RESULTS AND DISCUSSIONS

This chapter focuses on describing the results of the key components and final product proposed in chapter 3.3.5. The details of the problem encountered and tweaks done to achieve the desired result then will also be discussed with the analysis regarding the data result for future improvement.

4.1 Preliminary Data Taking

The data taking was done in one of the largest PT. XYZ Warehouse in several days of with the most order fulfilled. The data is taken by doing onsite observation on the actual situation to count the maximum number of queues in a line during the day and roughly the average processing time. Where the processing time is the time needed for the online delivery courier to claim their package once they get into the front of the queue. The day chosen is a “double-date” where the number representative of the day is equals to the number representative of the month. On these days, e-commerce in Indonesia commonly doing large campaign with large discount to attract customers.

Table 4.1 Preliminary Data Taken in PT. XYZ Warehouse in Busy Day

Date	09/09/2023	10/10/2023	11/11/2023
Number of Counter	10	12	12
Max Queue in a Counter (Person)	40	36	45
Max Queue Time (Minutes)	80	72	90
Average Processing Time (Minutes)	2.2	2.1	1.9
Max Waiting Time (Minutes)	82.2	74.1	91.9

The Table 4.1 above shows the data taken from internal PT. XYZ warehouse data team to get more insight and verify the data that are being used in simulations. The data taken is combination between the forecast data and onsite observation to verify the integrity. Based on the data above, the average processing time is at around 2 minutes that are being used in the simulation. The number of the counters match the one being used in the simulation of 12 counter in October and November. However, the maximum queue number is much higher compared to the simulation result of maximum 29 person. This situation could be mainly caused by unpredictable issues that occurs in the actual

implementation such as different queueing distances between person that could make the queue with less person seem to be longer.

Furthermore, most of the handover time consumes by the warehouse workers try to find the user's package. As the warehouse process the incoming orders and ordering the online delivery services by the principle of First in First Out (FIFO), the arrival time of the couriers are uncontrollable. Those situations create issues where the package that are ready in the staging area are commonly the carryover package from the previous days. In contrast, the top of the courier's queues might consist of a combination from the carryover order or even new orders that are still not ready in the staging area. With the physical queueing system, it is impossible to reverse the process by doing the handover based on the FIFO of the packages. All of the couriers have their own short SLA and wants to do the handover as soon as possible. In those situations, the warehouse management are being forced to do the handover process based on the FIFO of the courier's arrival time. This situation could be solved by digitalized the queue so that the courier could wait outside the area before the package is ready and only be allowed to go in once the package is ready inside the lockers.

From the warehouse management side, the long queueing problem in the handover area could not be solved by solely add more manpower's. The behaviour of the queues only occurs or high in early morning due to the presence of initial queue. Where at the opening time of the warehouses, hundreds of couriers are queueing already in the front gate. Once the early morning queues resolved after around 3 to 4 hours, the handover area does not require that much manpower resulting in the initial productive manpower in the morning might be less or even not productive at all in the afternoon. Having a hybrid manpower between division also not possible due to the unique workload behaviour in the handover divisions does not applies or counters by other divisions that are commonly have constant workload during the day. Having a smart locker system could solves the problem by dynamically scales the usage of the lockers.

From the package point of view, in some days the queue also could be caused by the presence of big product that are hard to be handled without any tools. The handover process consumes more time compared to the standard product due to the needs more

than single person or even needs a help of material handling equipment to move the products. Those kinds of special deliveries could occur sometimes in the warehouse with low quantities. A separate queue is commonly used by the warehouse management team to handle the big product section whenever the big product order forecast is quite high. This kind of product could not be handled by the smart locker system due to the limited space of the lockers resulting in the needs of a dedicate human-based counter to handle the big product handover process.

4.2 Assembly and Fittings

This part of the chapter discusses the execution of every part fabricated for this research.

4.2.1 PCB Enclosure Fabrication



Figure 4.1 3D Printed PCB Enclosure

The Figure 4.1 above shows the 3D printed enclosure for this research. This part will be attached at the door leaf and act as the electrical component enclosure and acting also as the door handle. The part is printed using PLA materials by vendor to achieve the flexibility properties so that it will not easily torn apart when someone pull it to open the door and also achieve beautiful looks due to PLA 3D printing accuracy. Furthermore, using PLA is more than enough since the locker will only be placed in semi-outdoor location without direct sun rays. Stronger material such as ABS, resin, and PETG for fully outdoor applications or direct sun rays might more suitable.

As could be seen also in the Figure 4.1 above, the “orange skin” texture shown in the front face of the 3D printed part caused by the “orange skin” texture in the printing bed. This kind of looks also improves the visual of the enclosure. The middle picture in the Figure 4.1 above shows all holes for the insert nut perfectly made. Only some minor part to hold the holes stringing.

4.2.2 PCB Fabrication and Assembly

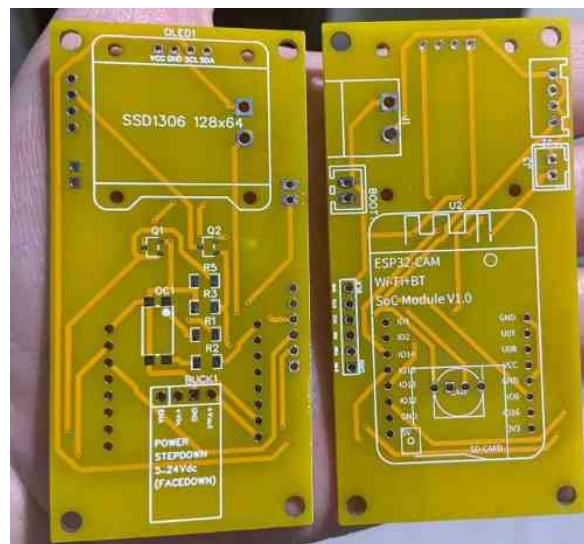


Figure 4.2 PCB Fabrication Result

The Figure 4.2 above shows the PCB fabrication result by vendor. The PCBs were made by vendor based on the exported Gerber file from the PCB design software. The left side of the figure show the top layer of the PCB and the right side of the figure show the bottom layer of the PCB. As could be seen and compared to Figure 3.8, the fabrication results completely match the design shown in the PCB designer software. Furthermore, the fabricated PCB could be easily soldered due to the presence of the tin surface finish on each pad indicated by shining silver colour on each pad.

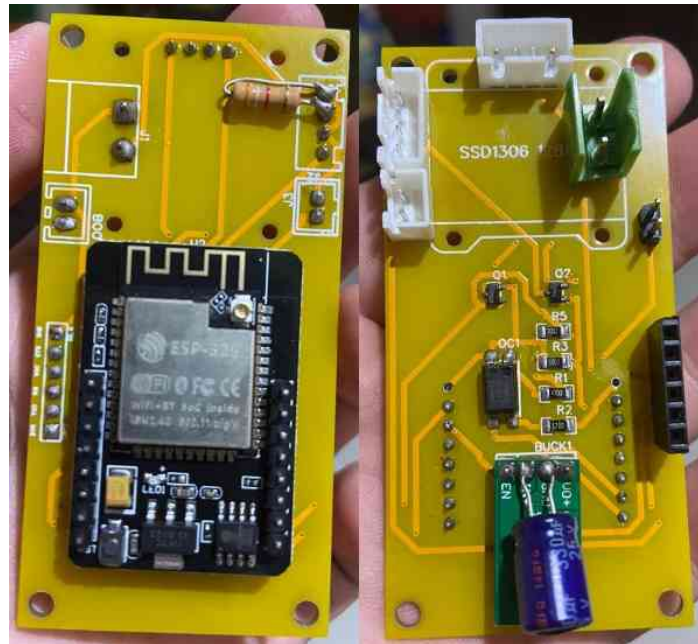


Figure 4.3 Assembled PCB

The Figure 4.3 above shows the assembled PCB. As could be seen all components could perfectly sit in the pad or go through the holes. However, there are two minor adjustments being done to the assembly which are adding a buffer capacitor and an external pullup resistor. The capacitor is added due to the connectivity issues that might occurs sometimes where the ESP32 is failed to connect to the Wi-Fi due to not enough current supplied by the small buck converter. Adding a small buffer capacitor could solve the problem. Furthermore, the external pullup resistor is added to the limit switch or door sensor input pin to ensure no noises occurs due to the length of the sensor cable and the presence of power cable in the same cable duct as the sensor cable. Furthermore, an internal pullup resistor is also being used internally in ESP32 due to the usage of optocoupler to interface between the input pin of the ESP32 and the input port of the limit switch.

4.2.3 Door Handle Assembly



Figure 4.4 Assembled Door Handle

The Figure 4.4 above shows the assembled door handle as the physical interface with the user. The left part of the figure shows the inserted insert nut to secure all components. As could be seen, all insert nuts could be fit perfectly to the predefined holes. The insert nut is being inserted by applying force and heat at the same time using the tip of a soldering iron. The heat transferred from the soldering iron to the outer side of the insert nut slowly melt the PLA walls. The melted PLA walls in combination with applied force resulting the insert nuts slides into the holes. Once it got into the desired place, the heat and force then removed. When the PLA walls cooling down and harden, the liquid PLA walls fills the gap in the insert nut outer side pattern making a strong mechanical bond.

After all of the insert nuts being secured in place, all electrical components then could be secured using nuts as could be seen in the middle part of the Figure 4.4. The right part of the Figure 4.4 shows the front view of the assembled door handle. As could be seen the indicator lamp is securely mounted and the OLED screen is neatly secured behind the rectangular holes.

4.2.4 Overall, Locker Assembly



Figure 4.5 Component Wiring Installation and PCB Enclosure Mount

The Figure 4.5Figure 4.5 above shows the overall component wiring installation inside the locker. All of the wire running from the locking mechanism to controllers and controllers to the main power source are secured using a small cable duct to prevent being pulled by the user. However, on the hinge area, some cable needs to be freed up to allow the hinge movement as could be seen at the right side of the Figure 4.5. The right side of the Figure 4.5 above also shows four M3 screws that are being used to secure the 3D printed enclosure.



Figure 4.6 Overall Assembly

The Figure 4.6 above shows the overall assembly of the locker being used in this research. There are three doors in total with three controllers mounted on each door as could be seen in the left side of the Figure 4.6. The right side of the Figure 4.6 shows

the situation when the specific locker door activated. The indicator lamp is turning on and the OLED screen showing a QR code for the user to open the door. Overall, the locker assembly could serve all the requirements needed for the smart locker system to operate.



Figure 4.7 Labelled Locker for Testing

The Figure 4.7 shows the labelled locker sample for the research testing process. The left side of the figure shows the front side of the lockers. Each locker front side having an identifier label indicating the locker name and the box name with the template of “[locker_name]/[door_name]”. For this research, the locker name is set to be “AAA” and the box names are “001”, “002”, and “003”. The box name will be called as sample 1, 2, and 3 accordingly. The right side of the figure shows the back side of the smart locker prototype. As could be seen, each box has the identifier label as in the front side of each box. Furthermore, each box has dedicated QR code containing the same value as the unique identifier of each box to be scanned by the warehouse operator eliminating the needs of them to type the locker unique identifier to assign the locker with specific package.

4.3 Locking Mechanism Actuation Test

The robustness of the locking mechanism is being done by triggering the lock open mechanism. There are only two result categories for the test which are success and failed. The trigger is being done by manual and electrical actuation. Where the mechanical actuation is done by actuating the lever until its end of motion range and the electrical method is being done by energize the titanium wire inside the lock for approximately one second by pushing a button.

Table 4.2 Locking Mechanism Actuation Test

Sample Number	Method	Number of Success	Number of Trial
1	Electrical	500	500
	Manual	500	500
2	Electrical	500	500
	Manual	500	500
3	Electrical	500	500
	Manual	500	500
Grand Total		3000	3000
Success Rate		100%	

The Table 4.2 above shows the locking mechanism actuation test. The test is being done to three locking mechanism sample attached in the locker. The success criteria are defined as the door could be open from the front side of the locker by pulling the door leaf. The test is being done in separate 8 days. As could be seen in the Table 4.2 above, the locking mechanism is robust enough to serve the users. The number is getting higher through the lockers is being tested more up until the moment this research book is written.

4.4 QR Code Display Accuracy

The QR Code display accuracy and robustness is being tested to ensure that the OLED screen on each door displaying the correct key code to open the locker door. The test is being conducted by randomly show a combination of 6 digit alphanumeric that are going to be used also in the production. The code then being verified by standard mobile phone QR Code scanner.

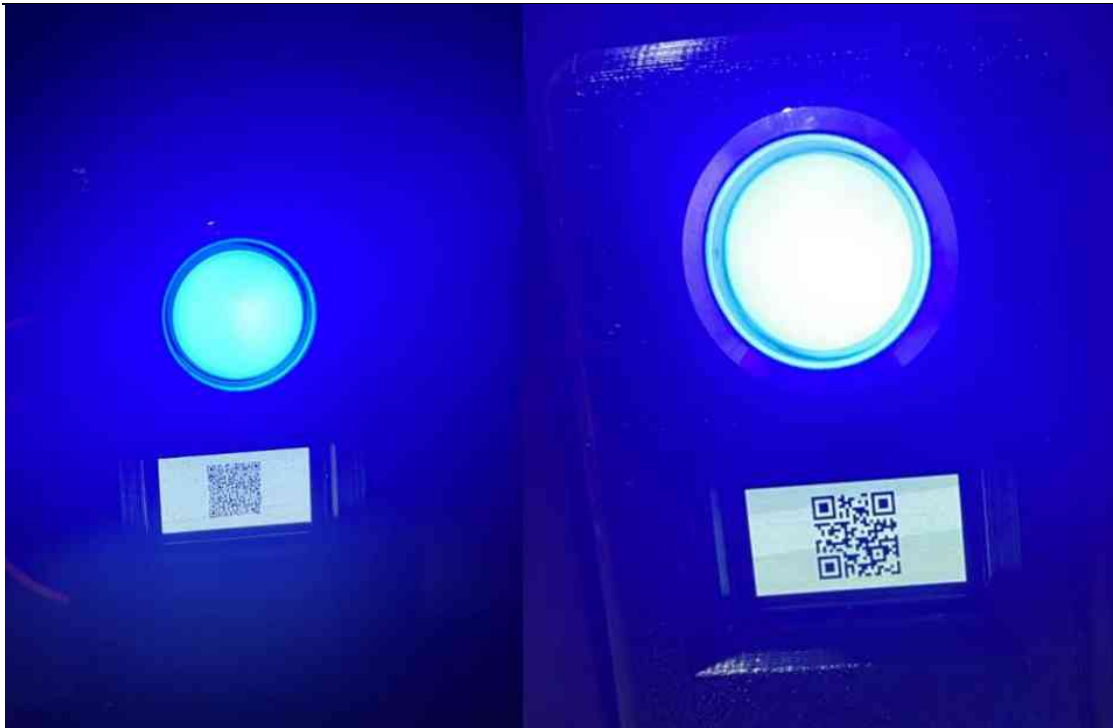


Figure 4.8 QR Code Readings Issue (Before vs After)

During the test, an issue with the QR Code scanning occurs. As could be seen at the right side of Figure 4.6 and Figure 4.8 above, the QR Code displayed on the OLED screen is small and blurry. The blur is mainly caused by the native of OLED display to be very bright to achieve wide viewing angel. It could be seen by comparing the brightness of the right and left side indicator lamp. It could be clearly seen that the OLED screen at the right side of the figure is much dimmer compared to the indicator lamp meanwhile the OLED screen at the left side of the figure outshine the indicator lamp. In reality, the indicator lamp always has the same brightness. Furthermore, the small size of the QR Code module also making it harder for the QR Code scanner to read it.

The high brightness might be beneficial for human eyes to easily look at the content. However, mobile phone camera might need additional time to re-adjust the camera exposure and zoom. These issues could cause in comfortability for the user due to longer scanning time and the auto exposure and zoom adjustment feature might be failed. Due to those reasons, as could be seen at the right part of the Figure 4.8 the solution could be done by reducing the brightness of the OLED screen and using

simpler QR Code encoding from version 7 (default from the QR Code Display library) to version 3.

The QR Code version determines the format of the QR Code being used. Higher number of QR Code has more capabilities to contain more information. The QR Code version 7 could contains up to 224 alphanumeric characters which is too large for the smart locker use cases. The version 3 QR Code has the capacity of 77 alphanumeric characters which are just enough for high level security UUID V4 payload with JSON format which usually preferred. The higher the number of the version and data capacity, the smaller also the modules. Which could make it harder to be scanned especially with limited screen size that screen resolutions also need to be considered.

Table 4.3 QR Code Display Accuracy Test

Sample Number	Number of Success	Number of Trial
1	40	40
2	40	40
3	40	40
Grand Total	120	120
Success Rate	100%	

The Table 4.3 above shows the QR Code display accuracy test results. There are only two success criteria in the test which are success and failed. The success is defined as the scanned QR Code show exactly the same alphanumeric combination as being given to the OLED display. The test was conducted by using the three OLED screens attached to the door during eight days period. As could be seen from the Table 4.3 above the QR Code display could reliably and accurately display the QR Code to the user.

The implementation of dynamically updated QR code increase the level of security of the system. It could prevent the issues where the user could easily take a picture of the QR code and open it remotely. The dynamically change QR code forces the user to be able to open the locker only when he / she presents in front of the door. The 77 alphanumeric character capacity of the class 3 QR code also supports the UUID version 4 data type that are commonly being used as an unpredictable id of a system.

Furthermore, the QR code could also be updated periodically every several minutes as an additional security measure.

4.5 Ping Test

Table 4.4 Smart Locker System Ping Test

N-Test	Sample 1	Sample 2	Sample 3
1	Success	Success	Success
2	Success	Success	Success
3	Success	Success	Success
4	Success	Success	Success
5	Success	Success	Success
6	Success	Success	Success
7	Success	Success	Success
8	Success	Success	Success
9	Success	Success	Success
10	Success	Success	Success
11	Success	Success	Success
12	Success	Success	Success
13	Success	Success	Success
14	Success	Success	Success
15	Success	Success	Success

The Table 4.4 above shows the test result of the ping system to the smart locker system where the ping system was made to help the user ensure that they are in front of the correct locker door. The test was being conducted together with the user test in chapter 0. Out of total 45 trials with 3 different locker doors, the reliability and repeatability of the ping system is 100% without any failure. In terms of responses, there were no significant delay between the moment the ping button pressed and the indicator lamp is changing state. However, the latency to the ping action might occurs in the production where the server and lockers is not in the same local network.

4.6 Signal Strength

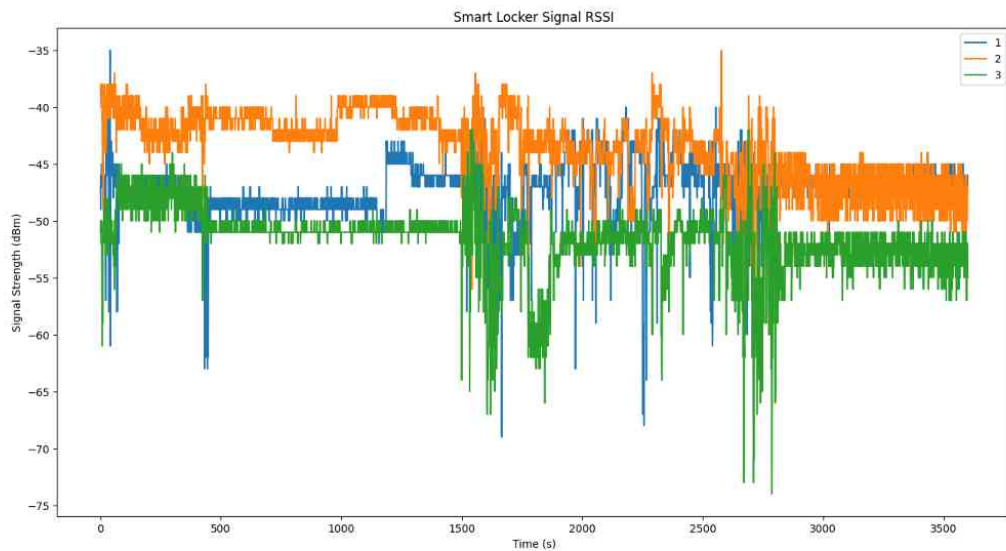


Figure 4.9 Smart Locker System User Test RSSI Plot

The Figure 4.9 above shows the RSSI plot of the three sample being used for the user test. As could be seen in the one hour or 3600 seconds logging time period the signals fluctuate. However, no disconnections occurs and the minimum RSSI value still much higher than the minimum -80 dBm required for basic connectivity. In majority, all signals have a very good connectivity over -67 dBm very good category. The RSSI fluctuation might be caused by the movement of the door handle that contains the microcontrollers when the door is opened and the presence of other devices that might causes disturbances. Overall, the current enclosure and component placement reliably serves the function to operates and protect the electronics inside with good signal capture (Metageek 2023).

4.7 User Test

Table 4.5 Smart Locker User Test Time Result

N-Test	Sample 1 (s)	Sample 2 (s)	Sample 3 (s)
1	19.94	33.82	22.03
2	18.96	15.33	14.50
3	20.56	21.81	17.12
4	18.75	23.60	18.04
5	17.69	17.05	29.29
6	18.83	19.27	16.71
7	16.27	17.78	19.82
8	23.37	17.22	16.26
9	16.97	16.44	13.61
10	14.33	13.52	16.32
11	21.05	15.61	16.86
12	27.72	15.01	17.46
13	13.65	14.79	17.00
14	16.11	16.51	15.79
15	14.27	16.84	14.21
Min	13.65	13.52	13.61
Q1	16.11	15.33	15.79
Median	18.75	16.84	16.86
Q3	20.56	19.27	18.04
Max	23.37	23.60	19.82
Mean	18.56	18.31	17.67
Inter Quartile Range	4.45	3.94	2.25
Lower Limit	9.44	9.42	12.42
Upper Limit	27.24	25.18	21.42
ST. Dev	3.73	5.04	3.85

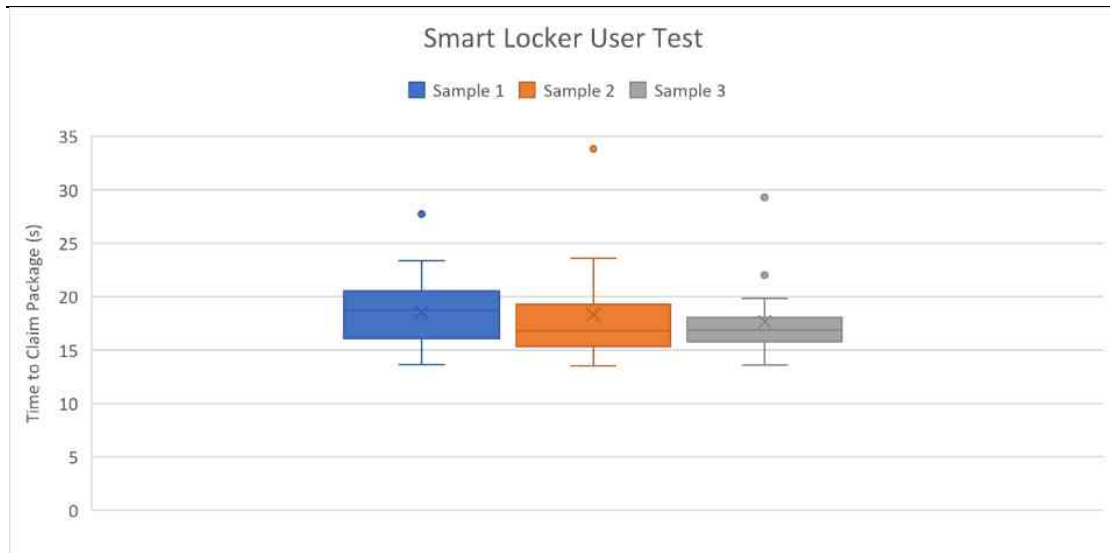


Figure 4.10 Smart Locker User Test Time Result

The Figure 4.10 above visualize Table 4.5 above in form of the box and whisker plot of the user test time results. The test was conducted by measuring the time needed for the user to claim their package starting from inputting the tracking number on the web-app up until to close the door after claim the package. The test was being done by using the three doors locker prototype made for this research with random users using different kind of both Android and iOS mobile phone. As could be seen clearly, all of the sample have similar mean time of around 17 to 18 seconds indicated by the cross mark in the box. Other than that, the minimum value of each plot also quite consistent at around 13 seconds indicated by the lowest horizontal line.

Out of the 45 data taken during the test. There are 4 outliers in total indicated by the separated dot in each plot. Whereas could be seen 2 of the total 4 outliers lies in the third sample. The outliers in the chart and table defined by shifting the first and third quartile by 1.5 times of the interquartile range. Where the interquartile range is the difference between the first and third quartile. The lower limit for the outliers defined as the first quartile shifted down by 1.5 of the interquartile range and the upper limit for the outliers defined as the third quartile shifted up by 1.5 of the interquartile range. As clearly shown in the Figure 4.10, there are only outliers in the upper section of the data.

The outliers occur in the test could mainly cause by technical issues that being found during the test. One of the most common technical issues found is the web-app

accidentally restarted by the user or the user was accidentally disconnected from the local network where the local server is deployed. Modern days mobile phone could automatically switchover to other network that have better internet connections. Due to the local network for the smart locker system deployment is not connected to the internet, the mobile phone might sometimes automatically switch to other available network including mobile data and other registered Wi-Fi.

In general, the test shown that the smart locker system could fulfil the needs of PT. XYZ warehouse to achieve 5 minutes total handover time by achieving less than 30 seconds package claim process. Only one single data point in sample 2 that exceeds the 30 seconds cutoff time and also defined as an outlier by the statistical analysis. Both of the mean and median of each sample test lies below 20 seconds which is much lower than the expected 30 seconds.

Table 4.6 Overall Standard Deviation Value of the User Test Time Result

Properties	Value (s)
Average	18.18
σ	4.12
-1σ	14.06
-2σ	9.94
$+1\sigma$	22.30
$+2\sigma$	26.42
$+3\sigma$	30.54

The Table 4.6 above shows the summary of the overall average and standard deviation value of the user test time result. Overall, only the value with positive offset standard deviation interests due to the time limit. As could be seen the plus two standard deviation that could represent 95.4% of the entire population is 26.42 seconds which are lower than the expected 30 seconds target time. Furthermore, the three-sigma value that covers 99.7% of the entire populations is slightly higher by 0.54 seconds at 30.54 seconds from the 30 seconds' target. Note that this average and standard deviation still could be improved by removing the outliers occurs during the test such as deploying the server with a public access from internet in cloud so that the user could always access the web apps via internet without getting interrupted by the suddenly network changed by the smart phone.

4.8 Power Failure Situation

Table 4.7 Power Failure Reconnection Time

Experiment Number	Sample 1 (s)	Sample 2 (s)	Sample 3 (s)
1	3.26	1.94	2.85
2	3.45	2.67	2.49
3	3.24	1.99	2.06
4	3.19	2.40	2.00
5	3.84	2.65	2.50
Average (s)	3.40	2.33	2.38
Standard Deviation (s)	0.27	0.35	0.35
Overall Average (s)	2.70		
Overall Standard Deviation (s)	0.59		

The Table 4.7 above shows the reconnection time needed on power failure occurrences. The test is being conducted by assigning a package to each locker so that the locker doors are all in active state showing QR code. Only after that, the power source then removed. The timer is started once the power source is re-connected and stopped when the display showing the QR code indicating the door is active. The test samples are being taken randomly during the user test experiment to reduce the effect of temporary caching in the broker side.

As could be seen in the Table 4.7, all three sample requires different time for the reconnection time. The first sample shows the most consistent reconnection time among the other sample with smaller standard deviation of 0.27 seconds with longer average reconnection time of 3.4 seconds. Overall, the reconnection time of the lockers took only average of 2.7 seconds with standard deviation of 0.59 seconds that are unnoticeable without any reconnection issues during the test.