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Development of Smart Locker System with Simultaneous User Access Capabilities for Warehouse Package Handovers

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ABSTRACT – The burgeoning of e-commerce industry especially instant delivery service provides new opportunities for warehousing companies such as PT. XYZ. However, demand for short time window in the handover process given to the warehouses is essential in the business. Piling carry-over order from previous day in combination with large incoming orders with uncontrollable user arrival time creates queues especially in the early opening hours with significant amount of the overall handover time. This research aims to develop a smart locker system tailor made for the handover purposes with fast access by the warehouse worker and simultaneous user access by scanning a dynamically generated QR Codes on each locker door. The Organic Light Emitting Diode (OLED) display could accurately show the QR Code and the locker doors could successfully open when the user scan the QR Code using the web apps. It is proven that the smart locker system could reduce the handover time with average of the package claiming time of 18.18 seconds reducing the overall handover time to below the desired 5 minutes by PT. XYZ warehouse management team.

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Introduction

Smart locker system as one form of Internet of Things (IoT) technology implementation are temporary storage areas to store various packages with additional features compared to traditional locker system [1]. It uses digital code provided by the service provider to replace the traditional key [2]. Radio frequency identification (RFID) [3, 4], one-time password (OTP) system [5], Bluetooth [6], multi-factor authentication (MFA) [4], QR Code [7] and even biometrics [8] are some common examples of the digital code that are commonly used in Smart locker applications. Public area such as entertainment and residential areas are common places where locker systems are commonly presence [9, 10].

The COVID-19 pandemic causes a significant rise for both smart lockers and e-commerce industry, contradictory with other sectors that face lowest point in history ever. The significant growth of e-commerce industry is closely related with government rule to force Offline to Online (O2O) regulations [11]. Work From Home (WFH) and study from home system are globally implemented since then. As a result, the number of online transactions rise significantly covering groceries, daily needs, as well as window shopping [12].

PT. XYZ, an Indonesian based e-commerce and warehousing company is also benefit from the burgeoning of e-commerce industry during COVID-19. As an effect, the variant of product increases following the increase in demands. The comfort and flexibility of online shopping affect the grocery sectors the most [13]. In general, most of the PT. XYZ customers order groceries for morning delivery with online delivery courier services for direct delivery from PT. XYZ warehouses to customer home due to some special treatment needs for the food items such as controlled temperature. The delivery duration consists of instant delivery (2 hours direct delivery) and same day delivery (single source multiple destination 8-hour delivery). The incoming order for morning delivery might come from the previous day's evening and could only be handed over for delivery in the morning. As a result, the number of packages need to be handed over in the morning spikes resulting in queueing problems in the handover area that sometimes could leads into late delivery.

The main root cause of the queueing problem in the warehouse is that the warehouse team is forced to follow courier arrival orders instead of package orders resulting in waste of time in finding the required package in piles of packages that can be solved by the implementations of the smart locker system as ddditional resources and digitalization of the queue. This approach aligns with existing studies that demonstate the effectiveness of resource allocation optimization through simulation and analysis [14], and the benefit of digital queue management to reduce waiting time [15].

To solve the queueing problem in PT. XYZ warehouse that consists of long queue and waiting time, this research

goal is to develop a smart locker system to effectively solve the issues. The smart locker system will utilize an OLED display on each door to be scanned by the users using dedicated web applications to open the door. By using this approach, the smart locker system does not require any form of physical assets to be held by the user and able to serve multiple users at a time. Due to the similar workflow of warehouse handover process, this smart locker system is applicable for any other warehouse.

Literature Review

As one form of IoT implementation in storage applications, Smart Locker system utilizes digital key to provide the best service for both users and providers with hassle free operations while maintaining high security standard. There is vast amount of research around smart locker system being done focusing on the most suitable form of digital keys being used to ensure the best user experience and security.

During development, online IoT platform was used in 2021 [1]. RFID based card was used in 2019 [3] and in 2023 [4]. One time password (OTP) was used in 2023 [4, 5]. Bluetooth based technology was used in 2023 [6]. Multi Factor Authentication (MFA) was used in 2023 [4]. Biometrics data such as fingerprint was used in 2018 [8]. QR Code pointed by user to the locker was used in 2023 [7].

Based on PT. XYZ needs, this research utilizes QR Code used in the locker's method [16]. Users will be guided and given access to open the door by scanning the QR Code using a mobile App. The smart locker system will be developed using ESP32 based micro-controllers, OLED Screen, Vue.js web applications, Python backend, and PostgreSQL database.

Research Methods

Root cause analysis was being done to find the cause behind long queueing process in PT. XYZ outbound area. Fig.1 shows the fishbone diagram for the root cause analysis. The People and Method factors become the main factors of the queuing problem since the orders incoming package to be handed over and the driver arrival does not match. The warehouse team is forced to follow the driver arrival due to the low driver's patient resulting in additional time to find specific package in piles of packages. Furthermore, the short Service Level Agreement (SLA) time is the most critical factor for the user since late package shipment could lead to real financial and business loss for PT. XYZ.

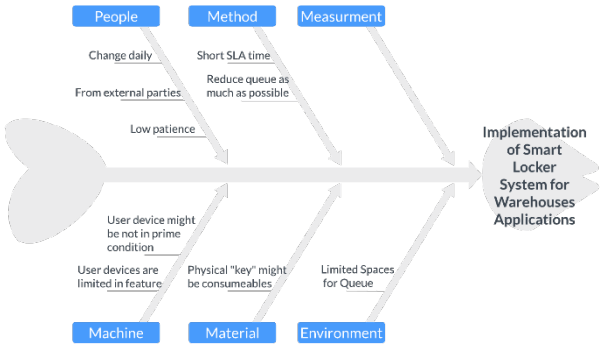

Figure 1. Fishbone diagram of the long queueing problem

Based on the user requirement and the fish bone analysis, this research aims to solve the queueing and waiting issues by forcing the drivers to follow the incoming package orders by implementing the Smart Locker system for the handover process. At the same time, PT. XYZ could also reduce manpower needed since the system can automate handover process with minimum human intervention.

A. Simulation and Validation

Fig.2 shows simulation result of the number of people in the queue as a function of waiting time for each driver based on PT. XYZ current situation. In this simulation, there are 350 drivers at the opening time and new driver is coming every 5 minutes. There are total of 12 counters for handovers with average processing time of 2 minutes. There are total of 7000 packages to be handed over to 7000 drivers in one day. The simulation shows that the peak of queue number is 29 people at the opening time and the longest waiting time is 60 minutes for the 400th person in the queue.

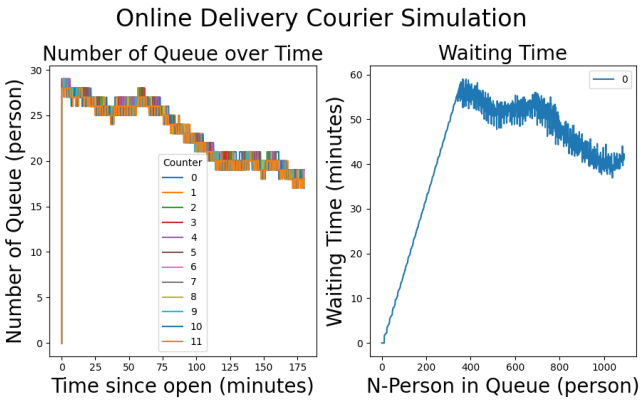

Figure 2. Simulation result for initial situation

Fig.3 shows the simulation result for new situation with the assumption of 1 minute for new processing time and the number of useable lockers door for handover is 88 doors. It shows that the queue only occurs in the beginning with maximum number of queues of 4 people which significantly drops from 29 people. It also shows that the maximum waiting time is 3.4 minutes which significantly drops from 60 minutes.

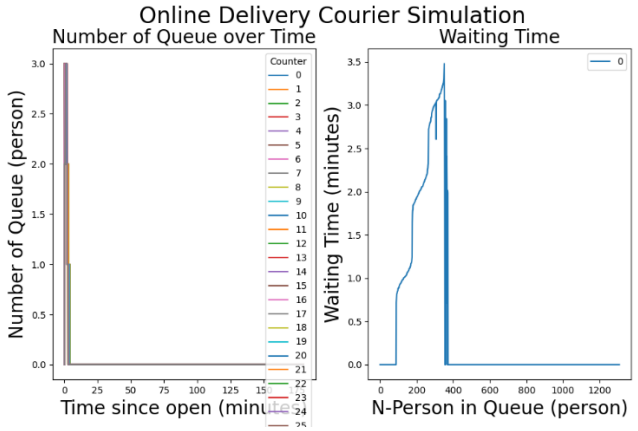

Figure 3. Simulation result for after Smart Locker System implementation

B. System Block Diagram

Fig.4 shows the overall block diagram of the Smart Locker System design with multiple boxes. Each locker box has its own microcontroller to communicate with main server. It receives QR Codes to be displayed in its Screen, responds to the door open request, responds to lamp ping request, and reports the actual conditions of the door to the server. Separated web-based applications are used for the users to claim the packages after the warehouse team placed the package in the box and assigned using warehouse staff web app.

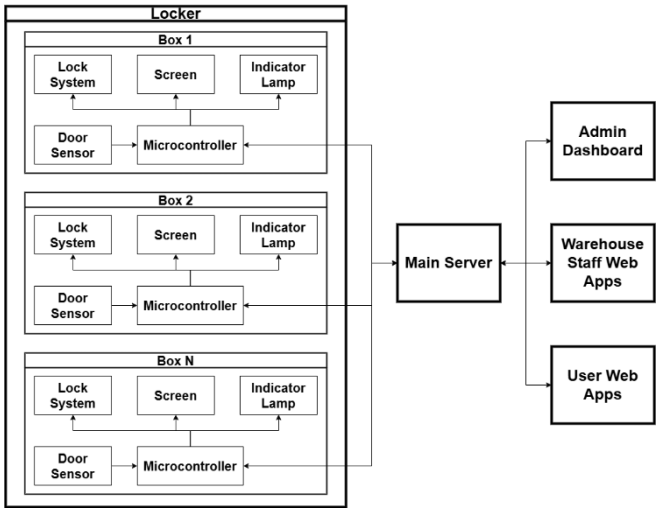

Figure 4. Overall system block diagram

C. Mechanical Design

Fig.5 shows the locking mechanism used for the lockers. This safety mechanism, triggered automatically or manually in case of mechanical failure, releases a buckle. Automatic activation relies on a memory wire that contracts when current is applied, generating a compressive force. The system includes: a spring-loaded main lever that secures the buckle, a locking lever that retains the main lever, a manual release lever, and the memory wire that actuates the manual release. When the manual release lever is engaged (either manually or by the memory wire), it lifts the locking lever, allowing the main lever to rotate counter-clockwise and release the buckle. When the buckle is inserted, it's captured by the main lever and secured by the locking lever. An electrical circuit, including a current-limiting resistor and a limit switch monitoring the main lever's position, ensures proper operation.

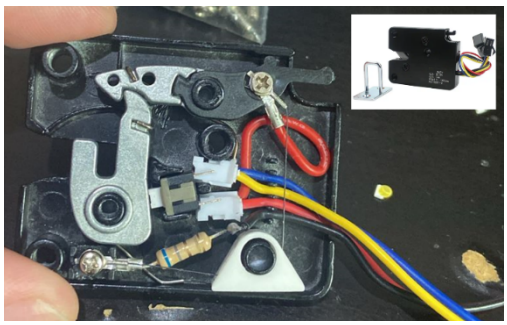

Figure 5. Locking Mechanism

D. System Flow Diagram Design

Fig.6 shows the overall system flow diagram for the handover process in the smart locker system design.

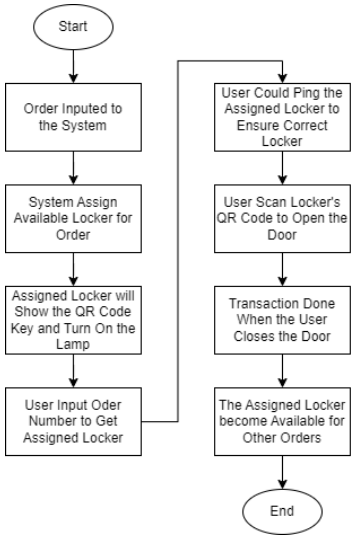

Figure 6. Overall system flow diagram

Fig. 7 shows the overall micro-controller software flow diagram for the handover process in the smart locker system.

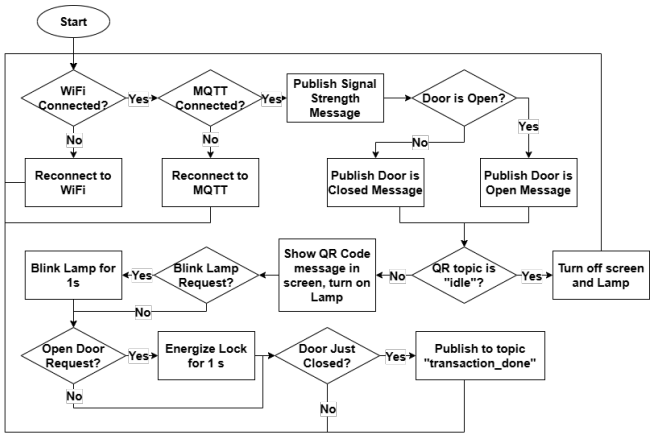

Figure 7. Micro-controllers software flow diagram

E. Web Applications for Staffs and Users

Fig.8 shows the warehouse staff web application used to input the package information, order number and locker location to the system.

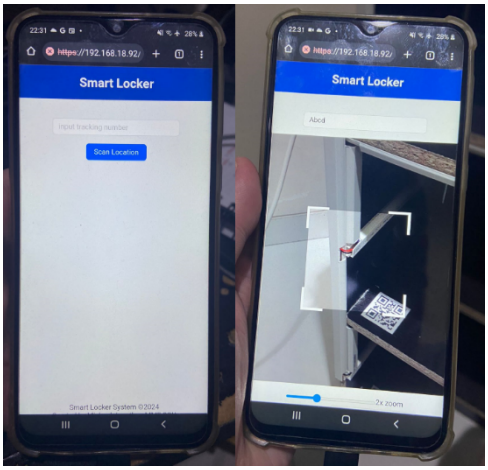

Figure 8. Warehouse staff web application

Fig. 9 shows the User Web Application used to track users packages inside the smart locker system, ping the assigned locker and scan the QR Code displayed on the OLED to open the door.

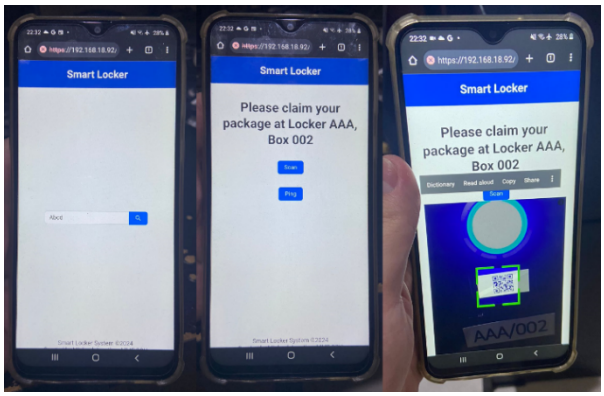

Figure 9. User web application

F. Performance Test and Data Taking

To ensure that the developed Smart Locker system is robust and able to meet the requirements, the following tests were done.

- Preliminary data taking of the actual situation test
- System assembly test
- Locking mechanism actuation test
- QR Code Display Accuracy test
- Ping test
- Signal strength test
- User test
- Power failure simulation test

Results and Discussions

A. Preliminary Data Taking

Table 1 shows previous data sample taken in PT. XYZ during the "double date" peak season. The number of maximum queues in a counter surpass the simulation data due to unpredictable issue caused by different queueing distances between each person that makes some queues seems to be longer. From the onsite observation, most of processing time is used for package searching process by the warehouse team. This data shows that the maximum number of people in the queue is more than 29 as in the simulation and maximum waiting time is more than 60 minutes as in the simulation.

Table 1: Warehouse Queue Data

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 Times (Minutes)	80	72	90
Average Processing Time (Minutes)	2.2	2.1	1.9
Max Waiting Time (Minutes)	82.2	74.1	91.9

B. System Assembly and Fittings



Figure 10. Prototype of Smart Locker System

Fig.10 shows the prototype unit made for the testing purposes. The back side of the lockers are open to ease the warehouse team to put the packages and to actuate the locking lever in case of emergency. In the real applications, the back side of the lockers will not be accessible to the users. Only the front part of the box is accessible to the users. Additional locker name and QR Code are placed to help the warehouse team to locate the lockers and to input the package location information into the system.

C. Locking Mechanism Actuation Test

The test was done for both manual and electrical actuation in fully assembled conditions. Both were tested for 500 times for each door prototype. The results from the test showed that all locking mechanism using 500 electrical actuations and 500 manual actuations were 100% successful without any failure.

D. QR Code Display Accuracy

The test was done for 40 repetitions on the OLED display by comparing the injected QR Code value to the QR Code reading using various mobile phone devices. Based on this

test, the QR Code display accuracy is 100% without any errors.

During the test, some mobile phones especially IOS devices needed some position adjustments or tweaks to be able to scan the QR Code. This issue was caused by the auto focus and brightness adjustment features were unable to run well in IOS based device browsers. To solve the brightness issue, reducing the OLED display brightness successfully eliminated the issue. For the auto focus feature issue, IOS device user needed to manually move the phone closer to be able to scan the QR Code properly.

E. Ping Test

The ping test was done by giving the access to random people as users to ping the locker without knowing which locker was assigned to them. Out of 15 trials done for all 3 doors prototype, the users could immediately recognize which locker was assigned to them. In cases when 3 users simultaneously tried to identify their assigned lockers at the same time, the identification process was still success without any problem.

F. Signal Strength

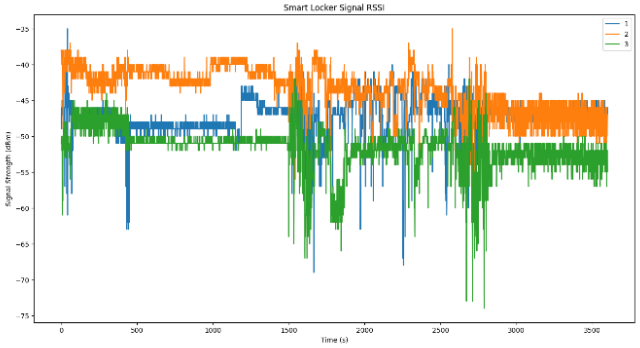

Figure 11. Smart locker system signal strength (RSSI) variations

The WIFI signal strength value was recorded during the ping and user tests. As shown in Fig. 11 there were some differences in the average signal strength for all 3 doors that might due to different distance to the WIFI router or different antenna conditions. Overall, all three lockers signal strength values are still in the very good category of over -67 dBm. Only few times the signal strength values dropped below -70 dBm which were still higher than the minimum of -80 dBm required for basic connectivity [17]. In the real situation, there were no noticeable performance differences among all the locker doors during the test.

G. User Test

The user test was conducted by asking 15 random persons for each door to act as the user. Each person only could participate once to ensure that the data gathered were applicable in real situations where most of the user will be a first timer. According to the statistical data analysis on the Table 2 shown, the average time needed for each user to claim their package from the moment they knew the assigned locker is 18.18 seconds with a standard deviation of 4.12 seconds.

Table 2: User Test Data

N	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

During the test period, all users were initially required to use their own mobile phone devices. They needed to connect to a dedicated access point so that they could access the dashboard within the dedicated network. In some cases, some mobile phone rejected to connect to the access point due to the presence of alternative network with better signal. In some cases, users needed to turn off their mobile data first to be able to connect.

H. Power Failure Simulation

The power failure test was conducted by removing the power source of all 3 sample doors 5 times each. According to the statistical data analysis on the Table 3 shown, the average recovery time was 2.7 seconds with standard deviation of 0.59s.

Table 3: Power Failure Test Data

N	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

Conclusions

- Smart Locker system can solve high queueing problem in early morning and it is more preferable compared to additional manpower that could leads to low manpower utilization on the rest of the day.
- Theoretically, the number of maximum queues could be reduced from 29 to 3 person per counter and maximum waiting time from around 60 to 4.5 minutes by implementing 88 doors of smart locker system replacing 12 human-based counters and reducing the handover processing time from 2 to 1 minutes.

- The smart locker system can achieve the 1-minute processing time target from 2 minutes where the package claiming process can take only in average 18.18 seconds giving more times for the driver to find the assigned locker and warehouse operator to load the package in the 1-minute time window.
- The smart locker system has passed the repeatability, robustness, accuracy and power failure tests.
- The unique QR Codes in the smart locker system is generated by the backend system that could be updated periodically to provide high level of securities to the system.

References

[1] S. E. Prasetyo and J. F. Andrianto, "Smart Key Based Locker Desıgn Wıth Arduıno", Conference on Management, Business, Innovation, Education and Social Science, Vol. 1 No. 1, 2021

[2] L. Faugere and B. Montreuil, "Hyperconnected City Logistics: Smart Lockers Terminals & Last Mile Delivery Networks", 3rd International Physical Internet Conference, Atlanta, United States, 2016.

[3] V. R. Hananto, I. Gusti, N. Alit, W. Putra, and N. Ningsih, "Design of RFID Smart Locker for Marketplace Systems," International Journal of Latest Engineering and Management Research (IJLEMR), vol. 04, no. 08, pp. 79–86, 2019

[4] I. Hermawan, D. Arnaldy, P. Oktivasari, D. A. Fachrudin, R. Nuraini, and N. T. Sulthanah, "Development of Intelligent Door Lock System for Room Management Using Multi Factor Authentication," Jurnal Teknik Informatika, vol. 16, no. 1, pp. 1–14, May 2023, doi: 10.15408/jti.v16i1.29045.

[5] PopBox, "PopBox PH Collect." Accessed: Jul. 01, 2023. [Online]. Available: https://www.popbox.asia/service/collect

[6] Amazon, "Collect a Package at an Amazon Hub Locker." Accessed: Jul. 01, 2023. [Online]. Available: https://www.amazon.com/gp/help/customer/display.html?nodeId=GRQMENKQV9RQ6BWF

[7] Paxel, "What is PaxelBox." Accessed: Jul. 23, 2023. [Online]. Available: https://paxel.co/id/detail-layanan-dan-bantuan/apa-itu-paxelbox

[8] S. P. Chavan, T. G. Pagare, S. K. Sapkal, and G. S. Shimpi, "Smart Locker System Using Biometrics Authentication", International Journal of Innovative Research in Technology, vol. 4, no. 12, pp. 486-489, 2022

[9] PopBox, "Lokasi PopBox." Accessed: Jul. 01, 2023. [Online]. Available: https://www.popbox.asia/locations

[10] Paxel, "Paxel Box Location." Accessed: Jul. 01, 2023. [Online]. Available: https://paxelbox.paxel.co/#location

[11] C. Ricky, A.A.A.P. Ardyanti, and K. Govinda, "An unexpected surge in e-commerce and accelerated digital transformation: A blessing in disguise from COVID-19", in Indonesia Post-Pandemic Outlook: Rethinking Health and Economics Post-COVID-19, Penerbit BRIN, 2022. doi: 10.55981/brin.537.c517.

[12] L. R. Chandra, F. Ferdyansyah, M. Denisha, W. P. Bachtiar, and H. K. Tanjungsari, "Analysis of Increasing Online Business in Indonesia during the COVID-19 Pandemic", Advances in Social Science, Education and Humanities Research, vol. 655, Dec. 2022, doi: 10.15294/sji.v7i2.26056.

[13] D. L. Warganegara and R. B. Hendijani, "Factors That Drive Actual Purchasing of Groceries through E-Commerce Platforms during COVID-19 in Indonesia", Sustainability, vol. 14, no. 6, Mar. 2022, doi: 10.3390/su14063235.

[14] P. Amalia and N. Cahyati, "Queue analysis of public healthcare system to reduce waiting time using flexsim 6.0", International Journal of Industrial Optimization, vol. 1, pp. 101, Aug. 2020, doi: 10.12928/ijio.v1i2.2428.

[15] Y. Kusuma and D. Avianto, "Enhancing Hospital Efficiency with Healthyline: A Digital Solution for Registration, Appointment Reminders, and Queue Management", Asian Journal of Research in Computer Science, vol. 17, pp. 252-271, Dec. 2024, doi: 10.9734/ajrcos/2024/v17i12542.

[16] A. F. S. Luís, G. M. C. Martins, J. M. L. P. Caldeira, and V. N. G. J. Soares, "Smart Lockers: Approaches, Challenges and Opportunities", International Journal of Engineering and Advanced Technology, vol. 11, no. 3, pp. 141–149, Feb. 2022, doi: 10.35940/ijeat.C3374.0211322.

[17] Metageek, "Undeerstanding RSSI," Metageek. Accessed: Dec. 23, 2023. [Online]. Available: https://www.metageek.com/training/resources/understanding-rssi/