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An Approach to Monitor Vaccine Quality During Distribution Using Internet of Things

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Vaccines containing living entities must be stored in a strictly controlled environment; otherwise, the vaccine would be obsolete if the criteria did not occur. Hence, the current distribution vaccine is only implemented in the local system. There is no interconnection between the temperature sensor to the command center. Only the local staff can know the status while they did not maintain it continuously. Moreover, the system relies on a paper-based report, so there is no prevention system to mitigate any potential failure. This research proposes an IoT-based vaccine monitoring system to help stakeholders maintain vaccine distribution. This research focuses on the distribution of Sinovac as the most extensive and most-ready stock. The overall system consists of devices, networks, and an application. Devices reside either in a static environment or a mobile environment. Network connectivity relies on LoRaWAN, and GSM depends on the actual availabilities. Application is responsible for displaying, track, and notifying the status of the vaccines. Furthermore, this research discusses the measurement method and testing method.

Keywords: vaccine, LoRaWAN, IoT, temperature, Covid-19

1. INTRODUCTION

Humans' population overgrows. In 1980, 2000, and 2020, the world population was 4.4 billion, 6 billion, and 7.7 billion, respectively [1]. Furthermore, more people require more living space. Such inclination has pushed humans to live on the outskirts of wild nature, and even humans are converting what was once a wildlife preservation area into a productive area. Ebola, MERS-CoV, Zika virus disease, Novel coronavirus (2019-nCoV) alias Covid-19, SARS, and other zoonoses are likely to occur in the future [2].

As such pandemics happened, vaccination is the key to suppressing the number of infections. The vaccine has become a clinically proven way to decrease the chance of having severe symptoms of viral diseases. Smallpox was the first disease treated by a vaccine. Edward Jenner was the first human who invented the vaccination during the pandemic of smallpox. In 1796, he injected the vaccinia virus (cowpox) into a 13-year-old boy and demonstrated immunity to smallpox [3, 4].

Recently, the Covid-19 outbreak has impacted the global population in terms of human interactions, way of life, economic turnover, *etc.* The impact of the Covid-19 pandemic varies by country, depending on its healthcare system, cold chain system, vaccine availability, and other factors. This research is focused on Covid-19 cases in Indonesia. Covid-19 confirmed cases are relatively common in Indonesia. At the moment, Indonesia

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is ranked 14th in terms of confirmed Covid-19 cases [5]. As a result, Indonesia is an archipelago country, with residents dispersed across its 17000 islands, not to mention the geographical challenges that each province faces. As a result, vaccine distribution is a difficult task.

The Ministry of the Health Republic of Indonesia has authorized six vaccine manufacturers in Indonesia: PT Bio Farma Tbk, Astrazeneca, Sinopharm, Moderna, Pfizer Inc & BioNTech, and Sinovac Biotech Ltd. The Sinovac vaccine is the most-ready-to-be-used vaccine in Indonesia as they have it in just several months through a bilateral relationship. As data on July 16st, 2021, Indonesia already secured 141 million Sinovac vaccines shot, while on July 31st, 2021, 47 million Indonesian already got the first vaccine shot. The majority occurred in the well-develop islands near the regional vaccine distribution center and near the regional cold chain.

The Sinovac vaccine must be stored at temperatures ranging from 2 to 8 degrees Celsius; otherwise, the vaccine is faulty. As a result, a cold chain is urgently required to keep the vaccines in good condition. The vaccine cold chain business process is as follows in terms of existing logistical distribution: (1) Vaccines produced and imported are stored in national cold chain storage; (2) vaccines are distributed to regional cold chain storage, at least one in each province; and (3) vaccines are distributed to hospitals, clinics, municipal public health offices, or service level stores; (4) finally, vaccines are given for vaccination. Under normal conditions, the cold chain can handle the vaccines' required temperature and humidity.

Although it has an end-to-end cold chain system, it relies on offline monitoring, reporting, and recapitulation. As a result, the vaccine may have become obsolete while the system failed to notify the maintainer when the non-ideal environment condition occurred. In other words, the current system does not take a preventive approach. This study attempts to improve the existing system to maintain the environment accurately and precisely, real-time alerts and notifications are generated, and digital reports will be generated to replace paper-based reports.

This paper is an extension of our work [6]. The rest of the paper is organized as follows: Section 2 describes the related work. Sections 3 and 4 explain the methodology and implementation, respectively. Section 5 describes the result. Section 6 describes the conclusion and future works.

2. RELATED WORK

Cold chain management, which refers to processes and procedures to maintain the temperature required of perishable products [7, 8] is becoming more crucial due to the overwhelming growth of logistics these years. Research [9] stated that 30% of products are defective due to improper management, while the cold chain system is only used for 15% of overall needs [10]. Thus, some studies have been done to protect the products from being damaged by the incorrect temperature. Defraeye *et al.* [11] proposed an advanced cold chain system using a unique packaging system and a quantitative analysis of the product's cooling rate and operation parameters. Badia-Melis *et al.* [12] suggested a thermal imaging technology used as a temperature sensor and sent the real-time report. This system can be applied in storehouses, cold rooms, or even in delivery vehicles. Meanwhile, wireless sensor network has been widely adopted into cold chain systems like RFID [13] and Zigbee [14] to support remote functions and data collections.

The cold chain system is an essential component of vaccine distribution. There are three outstanding cold chain system issues at the moment: (1) a lack of cold chain capacity, (2) a lack of cutting-edge technology or optimal equipment, and (3) an insufficient temperature monitoring and maintenance system [15]. With the emerging of the Internet of Things (IoT), those issues can be addressed.

As part of the extensive Essential Programme on Immunization, the World Health Organization (WHO) has defined some guidelines for handling vaccines (EPI). The EPI aims to improve vaccine programs, supply, and delivery and ensure stakeholders' transparent access to relevant vaccines.

Based on the current logistical support system, WHO requires vaccine monitoring from the production to the last facility before the vaccination injection. Fig. 1 depicts the recommended implementation of the vaccine monitoring system. Some sensors are installed in a cold/freezer room and controlled by a powerful processing unit to generate an offline alarm and send data to a server/P.C. This system must have a battery because it must be operational at all times [16]. The certified products are mostly offline-based systems.

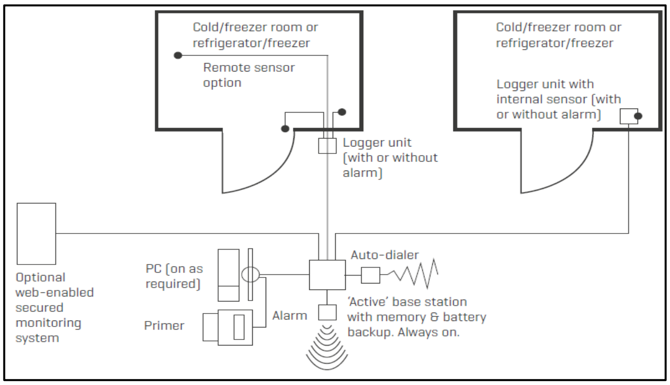


Fig. 1. WHO's recommended system architecture.

From March 2014 to September 2015, a pilot project in Uttar Pradesh, India, was carried out to enable the existing cold chain system [17] digitally. In 2012, the implemented system was tested for the first time in Karnataka, India. Mobile/web software, operating systems, browsers, transmission channels, and connectivity scenarios are all part of it. The transmission channels for this project were GPRS, SMS, and WIFI [18]. A similar approach was taken with the tracking feature's extension. The GPRS and GSM modules determine location. If an unplanned route occurs during transportation, it will notify supervisors via SMS and mobile apps [19].

LoRa is a wireless modulation for long-range, low-power, low-data-rate applications developed by Semtech. Hence, LoRa is specific to physical layer protocol only. The extensive utilization of the LoRa physical layer is LoRaWAN. A full-stack application layer protocol characterizes a Low Power and Wide Area (LPWA) networking protocol designed to wirelessly connect battery-operated 'things' to the Internet in regional, national, or global networks. It targets the key Internet of Things (IoT) requirements such as bi-directional communication, end-to-end security, mobility, and localization services [20].

Rawat *et al.* [21] suggest that the Covid-19 monitoring and tracking system's underlying protocol is LoRa and LoRaWAN. LoRa and LoRaWAN are increasing business efficiencies and improving people's lives all over the world. This research focuses on LoRa and LoRaWAN utilization for vaccine distribution.

3. METHODOLOGY

The system is divided into three layers, that is devices, networks, and an application. The architecture is shown in Fig. 2. Devices are equipped with sensors and a communication module. The module sends data through the network layer until it reaches the application layer, where various processes are done to the data.

The system groups the device and network layers into a subsystem, and there are two subsystems: at-rest and in-transit subsystems. The at-rest subsystem monitors temperature when vaccines are stored before being distributed to another place or injected into patients. Devices are installed in chillers in health facility storages, such as distribution warehouses, hospitals, and community health storages. The in-transit subsystem monitors temperature when vaccines are being transported to another place. Devices are installed in containers of trucks or motorcycles. Together, these two subsystems provide an end-to-end view of temperature when vaccines are in the distribution process, both in storage and vehicles.

The system's main objective is to monitor the temperature of vaccines. The Indonesian government has already ordered millions of CoronaVac vaccines, which Sinovac BioTech has developed. Based on WHO recommendation, the vaccine has a temperature requirement between 2-8℃ [22]. So that the system will monitor and alert if any condition outside its need occurs. The implemented system does not monitor the temperature of each vial directly. Instead, it uses an approach. For the at-rest subsystem, the device temperature probe is plugged into a glycol-filled vial, and the vial is put beside the vaccines, as shown in Fig. 3 (a). This practice is recommended by NIST [23] as the most accurate method to measure vaccine temperature. The measurement result of this method is not easily disturbed by the compressor's cooling cycle, compared to measuring air temperature inside chillers without glycol. Unfortunately, the temperature probe still measures air temperature inside the vehicles' container for the in-transit subsystem, as shown in Fig. 3 (b). The usage of the glycol-filled vial has leakage risk during distribution. Although glycol is considered safe according to the National Library of Medicine [24], based on our practical experiment, glycol may make the surface slippery.

In addition to temperature, devices also have some other sensors to provide additional features. For the at-rest subsystem, battery data is also transmitted. There are sensors to monitor engine status, container door status, GNSS location of the vehicle, and SOS button for the in-transit subsystem.

The communication protocol in the network layer is different based on the sending interval and power source type. The at-rest subsystem can use low power wide area network (LPWAN). In this research, we use LoRaWAN because the sending interval is not expected to be too frequent. To give a figure on the required interval, WHO requires that manual recording by local staff is done at least twice daily [16], and a non-opened chiller must survive the allowed temperature for at least 4 hours in the case of electricity outage [25]. We suggest using sending interval of 10 minutes. By using LoRaWAN protocol and less frequent sending intervals, the subsystem can use a battery that can survive at least two years. With the battery, the subsystem is not impacted by the electricity outage and even can monitor chillers when it experiences a blackout.

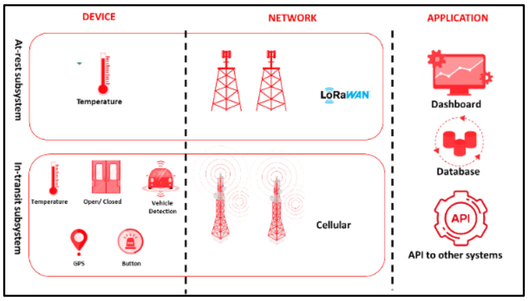


Fig. 2. Device-network-application system architecture.


(a) (b)
Fig. 3. Temperature probe installation in (a) chillers and (b) trucks.

For the in-transit subsystem, the cellular network is selected mainly due to the mature coverage. Compared to the at-rest subsystem, device sending interval is more frequent to give accurate location information of vehicles. When devices consider that cars do not move, it sends data in less regular intervals to optimize network usage.

Both subsystems send data to the application layer, which resides on cloud computing. The data meet several processes. After storing it in databases, a dashboard visualization can be made with different views for different user privileges. An alert system must notify respective personnel when the temperature data exceeds the threshold of 2-8 degrees Celsius [26]. The last feature is API exposure to integrate the system into another system.

There are some methods deployed to make the application layer robust and resilient. First, cloud servers are deployed in various locations to provide failover when a disaster happens in one area. Second, it is built using Infrastructure as Code (IaC) to maintain specification consistency between development and production environment. Third, servers are configured with an autoscaling feature to handle incoming data spikes. Fourth, data software application codes deployed on the server are also kept tracked in a source repository. Fifth, a queueing mechanism works together with auto-scaling to minimize data loss. Incoming data spikes may happen during the daytime, where distribution happens, and vehicles send data more frequently.

4. IMPLEMENTATION

4.1 At-rest Subsystem

Devices are the EM500 model from Milesight-IoT [27] with PT100 as a temperature probe. The resistance-based PT100 probe can sense temperature from –50 to 200°C, therefore can be used not only for 2-8ºC storages but also for (–15) – (–25)ºC and (–25) – (–50)ºC storages, such as ones storing Moderna and Pfizer vaccines [28, 29]. The devices are placed beside the chillers. Only the temperature probes in glycol-filled vials are in the chiller. Fig. 3 (a) shows a typical installation for this subsystem.

Although it is best to calibrate each device to a testing center, to save cost, the devices' reading is instead compared to readings from OnSet's inTemp CX402. The latter one has its calibration certification and complies with ISO 17025. The comparison and adjustment are made during installation per site. Firstly, both temperature probes are tied together and inserted into the chillers, it monitors air temperature, and data may fluctuate according to the compressor's cooling cycle. When data are between 2-8 ℃ and are considered stable, readings from both devices are logged every minute for 30 minutes, as shown in Fig. 4. When the discrepancy between EM500 and CX402 is above 0.5 ℃, the test is considered invalid; EM500 is adjusted by adding a calibration value which can be a positive or negative number. An Android application is used to adjust the temperature reading of EM500, as shown in Fig. 5. The test is restarted afterward. The following tests compare readings when the temperature is below two degrees Celcius and above eight degrees Celcius. In the first testing, temperature probes are inserted inside a freezer or two ice packs. In the latter testing, temperature probes are inserted into a regular refrigerator.

Fig. 4. The comparison of device's reading.

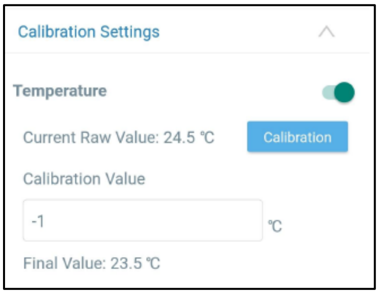


Fig. 5. The calibration of device's reading.

All devices use AS923-2 regional parameters to comply with the Indonesian regulation [30]. With Adaptive Data Rate (ADR) feature enabled, the application layer can suggest that the devices send data using DR5, the highest data rate using 125 kHz bandwidth. The temperature data is sent every 10 minutes, according to Section 3, and encoded in 4-byte data. In addition, battery data is sent once per day. When the temperature is beyond the threshold, the devices automatically send data without waiting for the following sending schedule so that the application layer can act accordingly.

An Android application is used through NFC communication to configure the devices. After the configuration, testing, and calibration are done, the devices are protected with a password from malicious users.

LoRaWAN gateways are deployed nearby the devices to provide connectivity between the device and application layers. The gateways are installed on microwave towers, with heights around 30-35 meters and distance to the devices around 1 kilometer. When there is no nearby gateway, an indoor version of gateways is installed in the health facilities. The gateways connect to the application layer using either optical fiber or cellular.

4.2 In-transit Subsystem

There are two device models used in the in-transit subsystem. One is the FMB130 model [31] for motorcycles, and another is the FMB140 model [32] for trucks. Although LTE is considered mature, 2G network provides confidence in coverage when trucks or scooters go through remote areas.

The devices are installed behind the main panel of trucks. It is connected to the engine electrical system to get power, ground, and engine status. The last one becomes a digital input of the devices. The temperature probe is connected from the container box of vehicles to the 1-wire input of the devices. Like the at-rest subsystem, the devices' readings are compared to readings from the CX402 device. The test cases also include the ones beyond the thresholds. As another digital input, the Container door sensor is installed beside the hinges of the first opened door, shown in Fig. 6 (a). When there are two doors, the first one to be opened becomes the most effective point to check. SOS button, which provides aid for drivers when threats come, is installed nearby the steering wheel, as shown in Fig. 6(b). It is also connected as a digital input. During journeys, that is when the GNSS sensor detects movement, the sending interval is 15 seconds. However, when the vehicle is stopped, the sending interval is 15 minutes. This is intended to save both vehicles and internal batteries, especially when the engine is shut off.

(a) (b)

Fig. 6. The installation of sensors in trucks.

Fig. 7. The installation of the temperature probe in motorcycles.

The installation in motorcycles is quite different than in trucks. As the container has no cooling system, the temperature probes will be inserted into a portable cool box that contains the vaccines boxes. When there is no delivery and no portable cool box, like in Fig. 7, the temperature data will be much higher than the threshold. Motorcycles also do not have SOS button and container door sensor. The first one is not required because the typical journey is within a city, and therefore not much possible threats.

4.3 Application Layer

The components inside the application layer is shown in Fig. 8. First, data from the devices layer enter queue service. There are two queues, one receives data from chillers and another one receives from vehicles. One back-end application claims data from the queue, inserts into a set of databases, and notifies notification service. Another back-end application fetches data from the database and gives to the front-end application, displaying data in a WEB dashboard. The notification service provides notification to several channels, such as Telegram, e-mail, and HTTPS notification. The last type of notification enables integration to another system. Notification can be sent when (1) there are new data, which is the case when integration to another system is needed, or (2) data exceed the thresholds, which is the case when an alert must be raised to local authority.

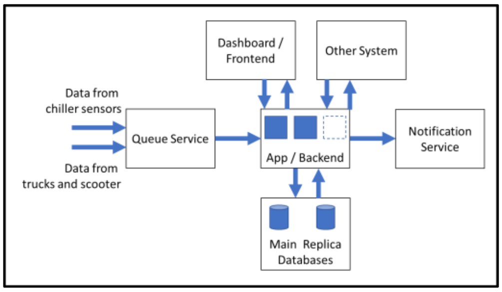


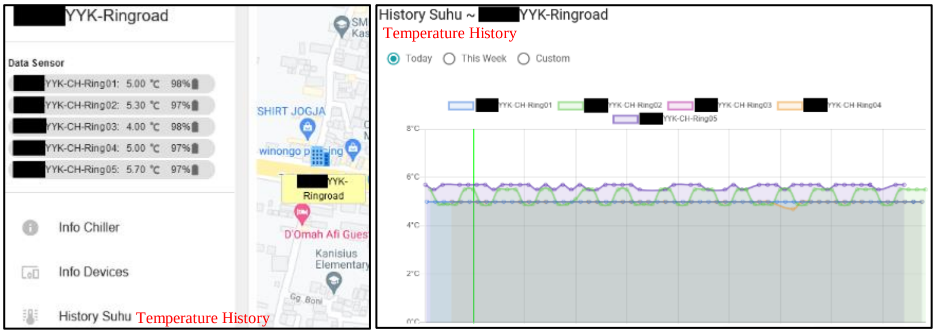
Fig. 8. The components inside the application layer.

The software used in the system are Apache Kafka as the queue application, PostgreSQL as the database, Node.js as the back-end application, Apache and PHP as the front-end application. Like the hardware, the queue has its dedicated virtual machine (VM) instance; the database uses two VM instances, one having read and write capabilities and another instance as its read replica. Both front-end and back-end services are in two VM instances. A load balancer is deployed in front of these two instances. An auto-scaling group monitors the average CPU usage of these two instances, and when it is above 70%, a new VM instance is deployed. On the other hand, when it is below 30%, the oldest VM instance will be deleted.

5. RESULT AND DISCUSSION

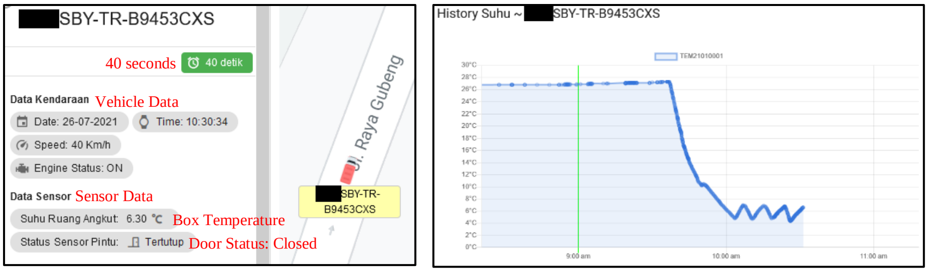
The dashboard shown in Fig. 9 is the main view when a user has logged in to the front-end. Although the number may differ based on the user's privilege, it shows all sites and vehicles. The user can filter to show: vehicles-only view, areas-only view, or both view. The dashboard automatically groups nearby devices and shows the number of group members. The user can click the group, and it automatically zooms in and shows the member of the group, that are vehicles and sites. These icons can be related as well to see detailed information and data history. For example, an area is shown in Fig. 10 (a) has five chillers with its last temperature and battery data. When the temperature data is within the threshold, it has grey shading. Otherwise, red shading covers the data. Temperature history can be seen in Fig. 10 (b). By using glycol, the data is relatively stable. Although the compressor turns on at two degrees Celcius and turns off at eight degrees Celcius, the glycol in chiller number 1 (light blue line) is relatively stable at five degrees Celcius. The glycol in chiller numbers 2 and 5 (green and purple lines, respectively) vary around 0.5℃.

Fig. 9. The distribution map of chiller and vehicles.



(a) (b)

Fig. 10. The temperature data of chillers on a site.



(a) (b)

Fig. 11. The information from a sample truck.

An example for vehicles is shown in Fig. 11. Besides temperature, there are speed, engine status, container door, and SOS button status. As can be seen in the figure, the temperature, 6.3℃, is within the threshold. As shown in Fig. 11 (b), the temperature data history is not as stable as for the chillers. Around 9 am, the engine was probably still off, and so was the air conditioner. Therefore, the temperature was about the same as the outside. After the air conditioner is turned on, the temperature drops to between 2-8℃. However, because the glycol vial is not used here, the temperature data follows the compressor's cooling cycle, as happened since 10 am. Like chillers, red shading will be used on temperature data when it exceeds the thresholds. Moreover, red shading will be used when the SOS button is pressed or the container door is opened.

Besides the sectoral view on each vehicle and chiller, the dashboard can show the vaccine distribution journey described by Distribution Order (DO) document. An example is a DO called V14072100019, as shown in Fig. 12. Users can see the truck's journey along the way. The DO document number and the vehicle's plate number, start, and end time are inserted from an external system. The external system itself probably contains the mapping between the DO number and vaccines batches. Our system matches the information with the actual vehicle location during the time range. When there are defective vaccines, users can track their batch, which vehicles were used to transport the vaccines, and which sites and chillers stored them. As a result, users can identify the point of failure causing the defective vaccines.

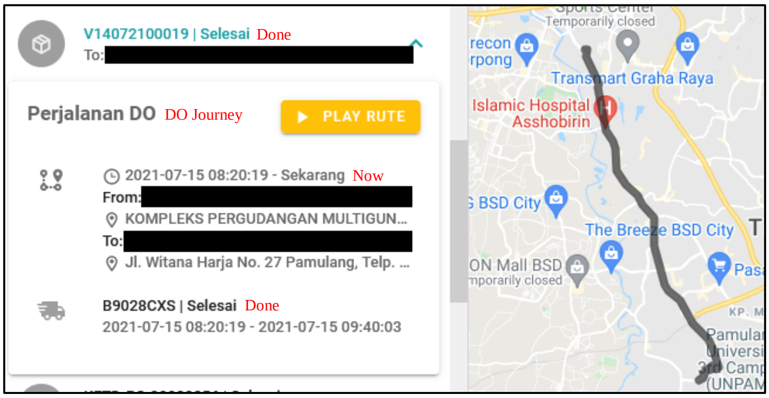


Fig. 12. The example of tracking based on distribution order.

6. CONCLUSION

An approach to monitoring vaccine distribution has been shown in this paper. The system provides temperature views of each place where vaccines are stored, both in chillers and vehicles. As the main objective, the dashboard highlights the temperature data when it exceeds the thresholds. This system assures users that vaccines stored in chillers and vehicles are not defective during the ideal time.

By the time this paper is written, data from this system must be combined with data from an external system to provide a complete view of which vehicles and chillers are used to transport and store which vaccines batches. It is best if a single system offers this view to ease the stakeholders. The notification feature currently only reaches the local person in charge. Hence, this feature has potential for further implementation, such as porting the notification to other supporting institutions like military or police offices to ensure the safety of vehicles and the vaccines.

REFERENCES

1. worldometer, “Current world population,” https://www.worldometers.info/world-population/, 2021.
2. WHO, “Pandemic and epidemic diseases,” https://www.who.int/emergencies/diseases/en/, 2021.
3. Center for Diseases Control and Prevention, “History of smallpox,” https://www.cdc.gov/smallpox/history/history.html, 2021.
4. The Immunisation Advisory Center, “A brief history of vaccination,” https://www.immune.org.nz/vaccines/vaccine-development/brief-history-vaccination, 2020.
5. WHO, “WHO Coronavirus (COVID-19) dashboard,” https://covid19.who.int/table, 2021.
6. I. K. A. Enriko, S. Pramono, D. Adrianto, and F. Alemuda, “COVID-19 vaccine distribution tracking and monitoring using IoT,” in *Proceedings of International Conference on Green Energy, Computing and Sustainable Technology*, 2021, pp. 1-5.
7. R. Badia-Melis, U. Mc Carthy, L. Ruiz-Garcia, J. Garcia-Hierro, and J. I. Robla Vil-

lalba, “New trends in cold chain monitoring applications – A review,” *Food Control*, Vol. 86, 2018, pp. 170-182.
8. I. Ali, S. Nagalingam, and B. Gurd, “A resilience model for cold chain logistics of perishable products,” *International Journal of Logistics Management*, vol. 29, 2018, pp. 922-941.
9. FAO, “Food wastage footprint: Impacts on natural resources,” http://www.fao.org/3/i3347e/i3347e.pdf, 2013.
10. J. Feng, Z. Fu, Z. Wang, M. Xu, and X. Zhang, “Development and evaluation on a RFID-based traceability system for cattle/beef quality safety in China,” *Food Control*, Vol. 31, 2013, pp. 314-325.
11. T. Defraeye *et al.*, “Towards integrated performance evaluation of future packaging for fresh produce in the cold chain,” *Trends in Food Science and Technology*, Vol. 44, 2015, pp. 201-225.
12. R. Badia-Melis, J. P. Emond, L. Ruiz-García, J. Garcia-Hierro, and J. I. Robla-Villalba, “Explorative study of using infrared imaging for temperature measurement of pallet of fresh produce,” *Food Control*, Vol. 75, 2017, pp. 211-219.
13. L. Kumari, K. Narsaiah, M. K. Grewal, and R. K. Anurag, “Application of RFID in agri-food sector,” *Trends in Food Science and Technology*, Vol. 43, 2015, pp. 144-161.
14. J. Wang *et al.*, “Wireless sensor network for real-time perishable food supply chain management,” *Computers and Electronics in Agriculture*, Vol. 110, 2015, pp. 196-207.
15. A. Ashok, M. Brison, and Y. LeTallec, “Improving cold chain systems: Challenges and solutions,” *Vaccine*, Vol. 35, 2017, pp. 2217-2223.
16. WHO, “How to monitor temperatures in the vaccine supply chain, WHO/IVB/15.04,” *WHO Vaccine Management Handbook*, Modul. VMH-E2-01.1, 2015, pp. 1-44.
17. S. S. Gilbert, N. Thakare, A. Ramanujapuram, and A. Akkihal, “Assessing stability and performance of a digitally enabled supply chain: Retrospective of a pilot in Uttar Pradesh, India,” *Vaccine*, Vol. 35, 2017, pp. 2203-2208.
18. A. Ramanujapuram and A. Akkihal, “Improving performance of rural supply chains using mobile phones: Reducing information asymmetry to improve stock availability in low-resource environments,” in *Proceedings of the 5th ACM Symposium on Computing for Development*, 2014, pp. 11-20.
19. R. T. Hasanat and N. Mohammed, “An IoT based real-time data-centric monitoring system for vaccine cold chain,” in *Proceedings of IEEE East-West Design Test Symposium*, 2020, pp. 1-5.
20. LoRa Alliance, “What is LoRaWAN specification,” https://lora-alliance.org/about-lorawan/, 2021.
21. A. S. Rawat, J. Rajendran, H. Ramiah, and A. Rana, “LoRa (Long Range) and LoRaWAN technology for IoT applications in COVID-19 pandemic,” in *Proceedings of International Conference on Advances in Computing, Communication and Materials*, 2020, pp. 419-422.
22. WHO, “WHO recommendation of Sinovac COVID-19 vaccine (Vero Cell [Inactivated]) – CoronaVac,” Sinovac Life Sciences Co., Ltd.
23. M. J. Chojnacky, W. M. Miller, and G. F. Strouse, “Methods for accurate cold-chain temperature monitoring using digital data-logger thermometers,” in *Proceedings American Institute of Physics: Conference Series*, Vol. 1552, 2013, pp. 1014-1019.
24. National Library of Medicine, “Ethylene glycol – NFPA hazard classification,” http:

//webwiser.nlm.nih.gov/substance?substanceId=147&catId=56, 2010, pp. 1-11.
25. WHO, "Refrigerator or combined refrigerator water-pack freezer: compression cycle," 2010, pp. 1-11, https://www.who.int/immunization_standards/vaccine_quality/pqs_e03_rf1.2.pdf.
26. Ministry of Health Republic of Indonesia, "COVID-19 vaccine arrives in Indonesia," https://www.kemkes.go.id/article/view/20120700001/covid-19-vaccine-arrives-in-indonesia.html, 2020.
27. Milesight-IoT, "EM500 PT100," https://www.milesight-iot.com/lorawan/sensor/em500-pt100/, 2021.
28. Center for Diseases Control and Prevention, "Pfizer-BioNTech COVID-19 vaccine storage," https://www.cdc.gov/vaccines/covid-19/info-by-product/pfizer/downloads/storage-summary.pdf, 2021.
29. Center for Diseases Control and Prevention, "Moderna COVID-19 vaccine storage," https://www.cdc.gov/vaccines/covid-19/info-by-product/moderna/downloads/storage-summary.pdf, 2021.
30. LoRa Alliance, "RP002-1.0.3 LoRaWAN® regional parameters," http: //lora-alliance.org/wp-content/uploads/2021/05/RP-2-1.0.3.pdf, 2021, pp. 1-94,
31. Teltonika, "FMB130," https://teltonika-gps.com/product/fmb130/, 2021.
32. Teltonika, "FMB140," https://teltonika-gps.com/product/fmb140/, 2021.

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