An IoT-Based Logistics and Inventory Monitoring System

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Abstract: The Internet of Things (IoT) allowed physical things to communicate with information to the cloud using various technologies. One industry area that can benefit from IoT is logistic operation. This study is a development of an IoT-based logistics system that allows a company to create a sales order, use the sales order to create a delivery schedule and then track the location of the truck for the delivery. The IoT system also monitors the loading, unloading and order completion of the delivered items. The system was validated by testing its functionality and a user acceptance test in a sample company.

Key Words: Internet of things; IoT Logistics; Embedded Systems

1. INTRODUCTION

Internet of Things (IoT) refers to the network of physical objects that are embedded with sensors, software, and various technologies and allows all devices to communicate with one another. IoT-enabled devices communicate with each other by being connected to a wireless network. Ranger (Ranger, 2024) states that due to the "arrival of super-cheap computer chips and the ubiquity of wireless networks, it is possible to turn anything, from something as small as a pill to something as big as an airplane, into a part of the IoT". IoT enables physical objects to communicate real-time data, making our society much smarter and more responsive to social changes. In recent years, IoT has been becoming prevalent in various business industries, such as manufacturing, retail, logistics, and services, with the main goal of increasing agility and efficiency. Due to the growing demand for efficiency and agility of transportation of goods, IoT in the logistics industry has been growing rapidly. (Meshawari, 2024) (Samsukha, 2024)

IoT in logistics uses several input technologies such as Radio-Frequency Identification (RFID), Global Positioning System (GPS), and Global System for Mobile Communication (GSM) to collect data within a company's logistical operations. The data gathered are then transmitted to a cloud database such as Amazon Web Services (Amazon, 2024), IBM Cloud (IBM, 2024), and Cloud SQL (Google, 2024). The various technologies utilized in logistics allow it to generate important data such as real-time location of vehicles, status of deliveries, and an overview of each item during the delivery which could be used by companies to gain more control over the status and operations of their logistics. IoT in logistics allows organizations to create data-driven decisions gathered by these devices. The IoT in logistics can greatly contribute and enhance the various processes of logistics companies, and boosts productivity within organizations.

There are companies in the Philippines that handles its own logistics internally. These types of companies have their fleet of trucks and logistics staff to handle delivery to stores. Most of the companies' experiences problems in the number of deliveries that can be made, and inventory inconsistencies from warehouses. These problems have led to a reduction in the organization's overall efficiency, resulting in increased costs, as well as a drop in customer satisfaction.

1.1 Limited deliveries

There are times when employees have served their own agendas, resulting in the increase of delivery time. One example of this is when drivers take detours from the intended route. Most companies have no method of accountability towards the driver as they cannot track the exact whereabouts of the truck. Instead, they rely on phone calls to the truck driver to gain information of the location of the truck.

Another factor that causes the increased amount of time to fulfill a delivery order is the method of counting items being loaded into the truck. Employees normally manually check and count every item inside the truck and this process takes up a large portion of the time.

1.2 Inconsistent inventory

Another problem with logistics is inventory inconsistencies in deliveries. A simple explanation as to why there are inconsistencies in the number of items being delivered is that a company does not have an efficient method of counting the number of items being loaded or unloaded into the truck, thus relying solely on the counting of their own employees. There have been multiple instances that human error in counting has occurred, resulting in an inconsistent count of items.

Another explanation is there are cases where employees have stolen items during the delivery process, leading to the inconsistent amount of delivered items. Once the truck leaves the warehouse the company has no control over the delivery in transit.

1.3 Proposed IoT solution

As a company continues to operate with manual and tedious methods, the company's overall productivity decreases. Developing a system that allows the company to have information about their assets during the delivery process is beneficial.

The solution is to create an IoT based system that can monitor trucks and items being delivered using Radio Frequency Identification (RFID) technology and global positioning system (GPS) communicating to a server in the cloud. RFID technology is used to track items being delivered as it is the main technology used for asset tracking (Casella, Bigliardi, & Bottani, 2022). While GPS technology is used to locate the delivery truck on the road. Combining the two mentioned technology into the IoT system allows the company to gain information of the delivery process, ensuring accountability and monitoring of employees' action. Fig. 1 shows the conceptual framework of the solution.

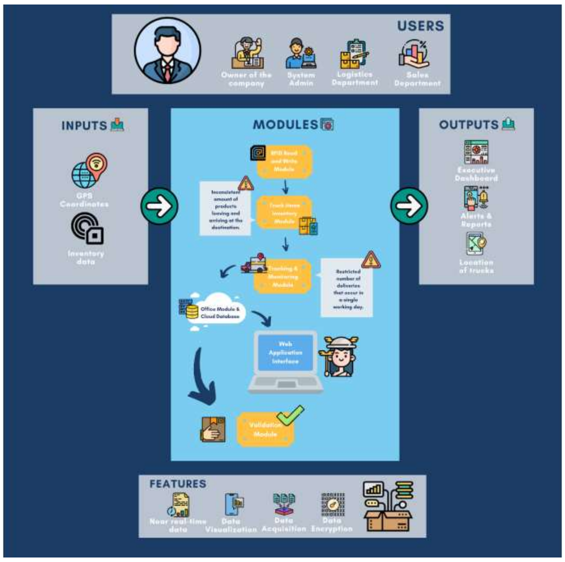

Fig. 1. Conceptual Framework of the IoT solution

2. SYSTEM ARCHITECTURE

The developed IoT system aids in keeping track and monitoring the whole delivery process of each truck in the company, such as inputting information of RFID tags, truck location, loaded items, and unloaded items. This allows management to remotely track delivery trucks in near real-time. With this, management can use features such as retrieving information regarding each scheduled truck delivery, creating delivery orders, viewing delivery orders, and adding a pending status to orders if there are issues. Consequently, they can efficiently manage and track deliveries whenever and wherever they are and do all the mentioned features through accessing the web application. The system architecture of the IoT application is shown in Fig. 2.

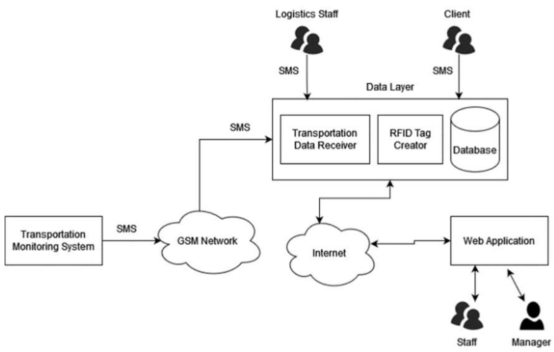

Fig. 2. System architecture of the system

The system tracks the truck thru the transportation monitoring system which sends SMS messages to the data layer module and stores the information in a database. Items for delivery are given an RFID tag from the data layer so that it can be identified uniquely by the application when loaded or unloaded from the truck.

The web application can be used by the users of the logistics department to view each delivery truck and the items inside. The users can track and monitor information regarding how items are handled and transported from the company warehouse to the client's destination. Consequently, each item inside the delivery truck has loaded and unloaded status to ensure that all items are complete and properly delivered once every item has been unloaded. Specific information regarding each order can also be seen through viewing the order details which show the route, loaded, and unloaded items in each truck.

Lastly, the sales department users of the company can monitor, track, and create orders for delivery. They can view the status of delivery trucks from being approved, in transit, and delivered through the web application.

2.1 Transportation monitoring system

The transportation monitoring system tracks all items loaded and unloaded in a specific truck. It will also ensure that the recipient of the delivery receives all products indicated in their orders. The system will allow the tracking and visualization of the current and past locations of the truck. The truck is equipped with an embedded device composed of an RFID reader, GPS module and GSM communication module as shown in Fig. 3. The transportation monitoring system sends its GPS location back to the data layer module every five minutes. The location data is recorded into the database. The RFID tags are created for the items using the RFID tag creator in the data layer. The microcontroller used is the ESP32 (Espressif, 2024) microcontroller.

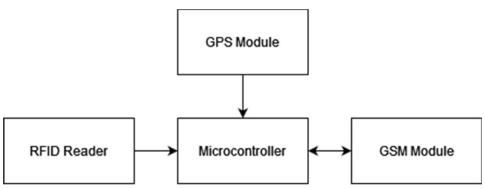

Fig. 3. Transportation monitoring system hardware

2.2 Data Layer

The Data Layer module is composed of three submodules: transportation data receiver, RFID tag creator and database which are software components (Fig. 2). The hardware component of the data layer module is composed of a server, and RFID tag writer, GSM module and connection to the database, as shown in Fig. 4. The transportation data receiver receives location data from the transportation monitoring module and then records it to the database.

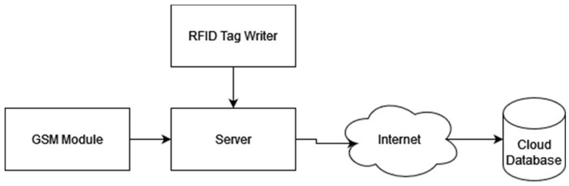

Fig. 4. Data layer hardware components

Every item loaded into the truck receives an RFID tag. The RFID tag writer module is used to ensure that each RFID tag will have its own unique code that comprises 3 randomly unique characters, with an additional 12 characters, indicating its product code.

The database in the data layer use the AWS RDS MySQL instance. A subscription plan is required for the database to function.

2.3 Web Application

The web application supports the business process of the logistics system. The web application is composed of the user management, logistics system and order information system. The user management module is used to authenticate users during login to the web application, user account creation and deletion, and assign user roles. Upon user login, the dashboard content varies depending on the user role. There are four different user roles: president, sales, logistics and admin. Fig. 5 shows a screenshot of the dashboard of the company president account page.

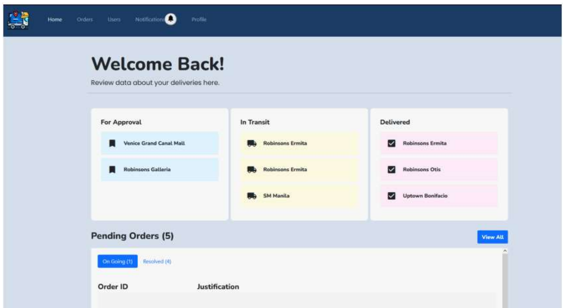

Fig. 5. A screenshot of a user's dashboard of the system

The order information system allows the sales employee to create orders from their clients. This information is used by logistics to schedule delivery to the client's store. Sales is not able to see the logistics detail of the orders but can see the status of the delivery.

The logistics system can monitor the pending orders and delivery status. This is where the logistics group can input resolutions for pending orders. The logistics group can also see the delivery in semi-real time and the average delivery time per branch. In contrast to the sales account, the logistics group is not able to create orders but see order details. Fig. 6 shows a screenshot of the logistics system.

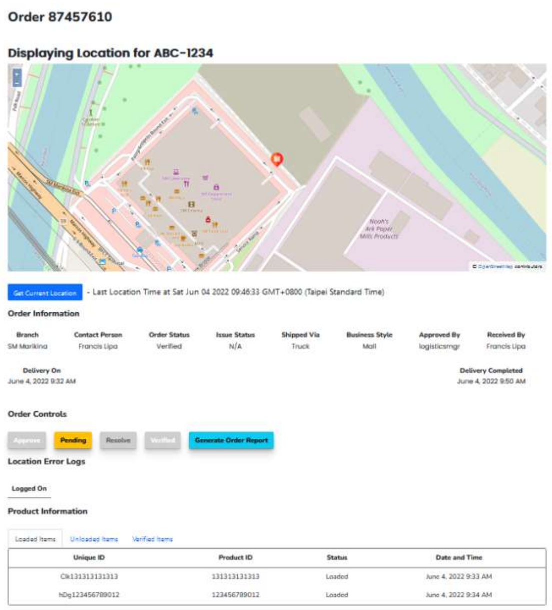

Fig. 6. Screenshot of the logistics dashboard

3. BUSINESS PROCESSES

The system is only effective if it follows a business process of a company for delivering its own product. For this study, a sample company is used as the model for the system's business processes. The business process also validates the function and effectiveness of the system.

3.1 Overall Process

The overall business process of the systems starts with the client, as shown in Fig. 7. After the client sends the order, sales create a purchase on the system and sends the delivery receipt to logistics. The sales order and delivery are created on the web application. Logistics can see the delivery receipt on system and schedules the delivery. During this time, logistics should ensure that the items for delivery has been tagged with the unique RFID sticker. On the day of delivery schedule, the truck driver scans the RFID tag before loading on truck before travelling to the client. During unloading of products in the client location, the truck driver has to scan the RFID tags of the unloaded items. Client accepts the delivery of the items and sends the unique RFID tags of each item received thru SMS. The RFID tags that were received by the client is verified thru the web application.

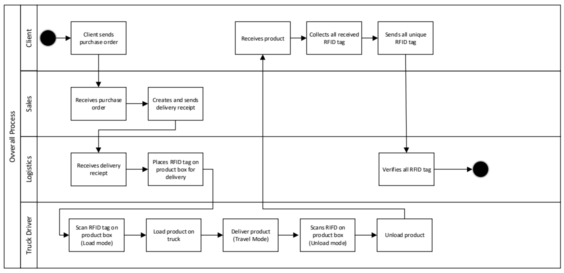

Fig. 7. Overall business process of the IoT logistics system

3.2 Delivery Process

The delivery process which is also called the truck module process, involves 3 different processes; the load procedure, travel module, and unload procedure.

The first process is the loading procedure (Fig. 8), which will involve the truck driver, truck module program, and the office module program. The truck module will be powered up. The "Load" mode button / "A" button will be pressed in the keypad. The driver will then scan the product box's RFID tag. As the RFID tags are scanned, the truck module and office module programs will simultaneously read the product details and send the product details to the office module. The office module will then receive the product details sent through SMS and input the data onto the database. Lastly, the truck driver will load the product into the truck. This process will be repeated for all the orders to be put in the truck for the delivery.

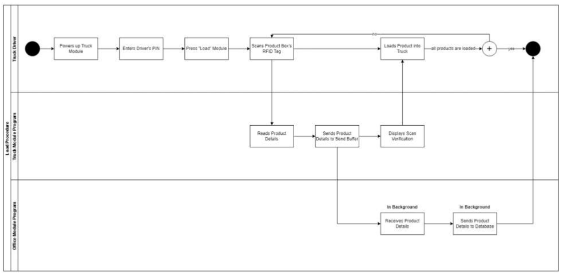

Fig. 8. Loading business process of the truck delivery module of the IoT logistics systems

The second process within the truck module is the "Travel" mode (Fig. 9), which will involve the driver, truck module program, and the office module program. The process will start by the driver pressing the "Travel" mode button on the keypad. The truck module program will then automatically transmit its GPS location to the office module every five minutes. The office module then receives the text and stores the data in the database. This will repeat every five minutes as the truck driver travels to the destination.

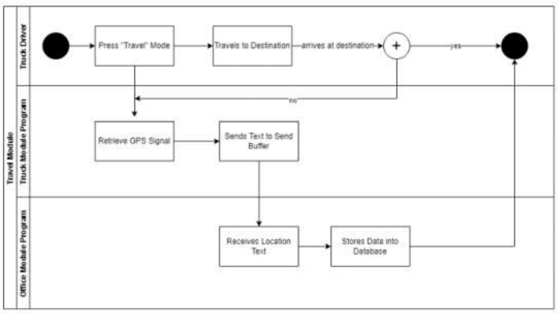

Fig. 9. On the road delivery (travel mode) business process of the IoT logistics systems

The third process within the truck module is the "Unload" mode (Fig. 10). This mode is highly similar to the "Load" mode. The driver can activate the "Unload" mode upon pressing the "Unload" button. Just like the "Load" mode, the driver would have to scan each product's RFID tag as they are bringing the box out of the truck. Each scan will allow the truck module to process the data on the RFID tag and transmit it to the office module which will then store the data on the database.

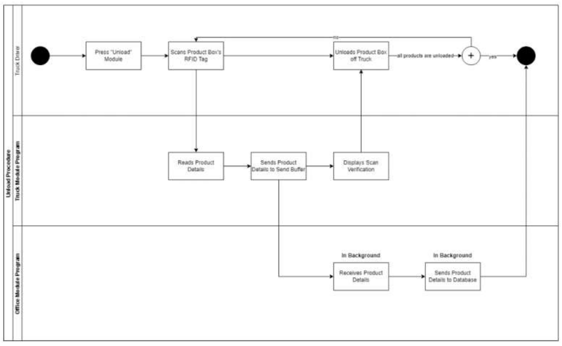

Fig. 10. Unloading business process of the truck module of the IoT logistics system

3.3 Client Verification

The client will begin the process upon inspection of the product boxes after the unload procedure has been completed as shown in Fig. 11. For each product that the client will approve, they will need to tear the removable tag from the product box, which contains the unique code of the product. After the clients sign the physical delivery receipt, they will then proceed to send SMS messages towards the office module in a prescribed format. These SMS messages will be received by the office module and will be sent to the database. The website application will then be able to display the items that have been verified received by the client, ending the process.

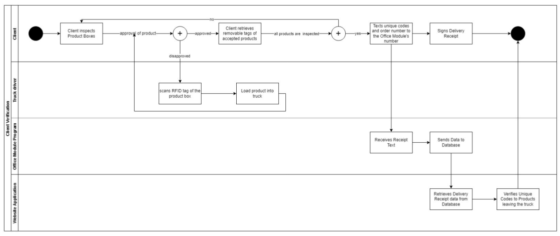

Fig. 11. Client verification process

4. VALIDATION RESULTS

The testing of the various modules within the system was conducted to verify that the hardware, as well as the software works as intended based on the business processes identified for the system.

When the sales team creates an order in the web application, this has to be approved so that a delivery schedule can be made. Table 1 shows that order creation is successful in the web application while Table 2 shows the orders were approved. This shows the creating orders and delivery schedule is functionally correct on the web application.

Table 1. Result of creating orders in the web application functionality

Module	Test Case ID	User	Test Case Scenario	Action / Steps	Expected Results	Pass / Fail
Website Application	CO1	Sales Employee	Navigating to Orders Page	Click [Orders] on Navigation Bar	Orders Page is displayed	Pass
	CO2	Sales Employee	Navigating to Create Orders Form	Click on [Create Order] button	Create Order Form is displayed	Pass
	CO3	Sales Employee	Creation of new order for delivery	Input order details found on physical Purchase Order	Form should accept inputs and redirect back to orders page upon submission	Pass

Table 2. Result of approving orders in the web application functionality

Module	Test Case ID	User	Test Case Scenario	Action / Steps	Expected Results	Pass / Fail
Website Application	FA1	Logistics Employee	Navigating to Orders Page	Click [Orders] on Navigation Bar	Orders Page is displayed	Pass
	FA2	Logistics Employee	Searching for a specific order	Enter order ID on search bar	Orders will be filtered as user inputs order ID	Pass
	FA3	Logistics Employee	Filtering through orders by status	Selects 'For Approval' in dropdown menu	All 'For Approval' orders will be filtered and shown	Pass
	FA4	Logistics Employee	Navigating to Order Details Page	Clicks on the highlighted order row	Order Details Page is displayed	Pass
	FA5	Logistics Employee	Approve order for delivery	Click on [Approve] Button	Order status will change to 'In Transit'	Pass

During the delivery process, items are scanned and loaded into the truck using the "load" mode, then delivery staff must put the truck hardware into "travel" mode going the client. Upon reaching destination, "unload" mode is pressed, unloads, and scans the item. The "order complete" button is pressed when all items are unloaded for the client. This process of unloading and completing orders can be repeated several times for every client that has delivery on the day. Table 3, Table 4, Table 5, and Table 6 shows the correctness of the delivery process functionality.

Table 3. Results of the loading items into the truck for the truck software module

Module	Test Case ID	User	Test Case Scenario	Action / Steps	Expected Results	Pass / Fail
Truck Module	LM1	Truck Driver	Loading items to the truck	Place RFID scanner on the item's RFID sticker and click on the [A] button in the keypad	LED will blink once for two seconds in each scan	Pass

Table 4. Result of tracking the location of the truck using GPS for the truck software module

Module	Test Case ID	User	Test Case Scenario	Action / Steps	Expected Results	Pass / Fail
Truck Module	TM1	Truck Driver	Start Travel Mode	Click on the [B] button in the keypad	Office module receives the truck's GPS coordinates every 5 minutes	Pass

Table 5. Result of the unloading of items from the truck for the truck software module

Module	Test Case ID	User	Test Case Scenario	Action / Steps	Expected Results	Pass / Fail
Truck Module	UM1	Truck Driver	Unloading items to the truck	Place RFID scanner on the item's RFID sticker and click on the [C] button in the keypad	LED will blink once for two seconds in each scan	Pass

Table 6. Result of the order completion phase for the truck software module

Module	Test Case ID	User	Test Case Scenario	Action / Steps	Expected Results	Pass / Fail
Truck Module	VE1	Truck Driver	Verification of Completed Order	Click on the [D] button in the keypad	LED will blink once	Pass

After the delivery is made, logistics can check the status of the orders if it is pending or is resolved properly in the web application as shown in Table 7.

Table 7. Result of the order resolution functionality of the web application

Module	Test Case ID	User	Test Case Scenario	Action / Steps	Expected Results	Pass / Fail
Website Application	PR1	Executive, Logistics Employee	Navigating to Orders Page	Click [Orders] on Navigation Bar	Orders Page is displayed	Pass
	PR2	Executive, Logistics Employee	Navigating to Order Details Page	Clicks on the highlighted order row	Order Details Page is displayed	Pass
	PR3	Executive, Logistics Employee	Tagging Order as Pended	Clicking on [Pending] Button and enter justification	Pending Modal will show and accept inputs. Order status will be changed to Pending	Pass
	PR4	Executive, Logistics Employee	Resolving a Pended Order	Clicking on [Resolve] Button and enter resolution	Resolution Modal will show and accept inputs. Order status will change to Resolved and back to original status	Pass

4.1 User Acceptance Test (UAT)

Asides from conducting an internal systems test, the study conducted a UAT in an actual company to gauge the system's effectivity in solving logistics transportation problems.

The UAT was conducted in two phases. The first phase featured the users of the website, namely the sales, logistics, and executive employees, with one representative each. The test conducted was to simulate a delivery that started when the sales employee would receive the item, which would then make its way to the logistics department, and the truck driver. The Executive employee oversaw the entire process through the website. Tasks such as creating an order, approving an order, and pending and resolving an order was done.

For the second phase of the UAT, the delivery process was tested by the truck drivers, as they are the primary users of the truck module. Major task categories such as Load, Travel, and Unload Mode were conducted.

Results from the User Acceptance Test showed that all users were able to accomplish their tasks with no errors. Problems such as confusion in operating the website and hardware were resolved immediately once it was clarified to the testers the functionality of a certain feature. An example of this would be the handling of the truck module hardware, as the truck drivers found it difficult at first to operate the Truck Module.

5. CONCLUSION

The system in the study was able to create an IoT-based system that follows a business process of creating orders, scheduling deliveries, tracking truck location, loading, and unloading items, and resolving pending issues in orders and deliveries.

The study has shown that being able to view a company's truck' current location, as well as keeping eyes on their products is a vital process in the distribution industry. As distribution companies rely heavily on their service of transporting goods from one point to another, being able to properly monitor the status, and location of their deliveries is a needed to ensure that processes move smoothly.

Aside from monitoring a truck's location, the system shows that a company can monitor the deliveries which prevents cases of employee mishandling, and misconduct. The system also optimizes their delivery time, as well as make sure that the truck's contents are not breached.

6. REFERENCES

Amazon. (2024, April 22). *Amazon Relational Database Service*. Retrieved from AWS: https://aws.amazon.com/rds/

Casella, G., Bigliardi, B., & Bottani, E. (2022). The evolution of RFID technology in the logistics field: a review. *3rd International Conference on Industry 4.0 and Smart Manufacturing* (pp. 1582-1592). Procedia Computer Science.

Espressif. (2024, May 2). *ESP32 Devkit-C*. Retrieved from Espressif: https://www.espressif.com/en/products/devkits/esp32-devkitc

Google. (2024, April 22). *CloudSQL*. Retrieved from Google Cloud: https://cloud.google.com/sql/

IBM. (2024, April 22). *IBM Cloud Databases for MySQL*. Retrieved from IBM Cloud: https://www.ibm.com/products/databases-for-mysql

Meshawari, A. (2024, April 22). *Transforming the PH Logistics Landscape : The Rise of IoT in Shipping*. Retrieved from PortCalls: https://www.portcalls.com/transforming-the-ph-logistics-landscape-the-rise-of-iot-in-shipping/

Ranger, S. (2024, April 22). *What is the IoT? Everything you need to know about the Internet of Things right now*. Retrieved from ZDNet: https://www.zdnet.com/article/what-is-the-internet-of-things-everything-you-need-to-know-about-the-iot-right-now/

Samsukha, A. (2024, April 22). *The IoT-Powered Logistics Industry: Use Cases, Benefits And Challenges*. Retrieved from Forbes: https://www.forbes.com/sites/forbestechcouncil/2023/02/21/the-iot-powered-logistics-industry-use-cases-benefits-and-challenges/?sh=2927d3226622