SE4IOT - SOFTWARE ENGINEERING FOR INTERNET OF THINGS

Name of the Study:
Erasmus Mundus M.Sc. Programme
Software Engineers For Green Deal (SE4GD)

COLD CHAIN SOLUTION FOR TRANSPORTING VACCINES

Github Repository
https://github.com/Apoorvanp/IoT-Coldchain/tree/demo

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INTRODUCTION:

Cold chain refers to the controlled logistics system utilised for the transportation of vaccines and medicines from the manufacturer to the end recipient. Ensuring the appropriate atmospheric parameters range during the entire supply chain is critical for preserving the efficacy and safety of these sensitive products.

The importance of a well-functioning cold chain lies in the fact that vaccines and many life-saving medicines can be compromised if exposed to temperature, humidity or pressure outside of the recommended range. This can result in degradation and reduced potency, potentially jeopardising their effectiveness in preventing diseases. The cold chain is therefore essential in guaranteeing the delivery of high-quality vaccines and medicines to those who require them.

Key components of the cold chain include suitable packaging, monitoring equipment, insulated containers, specially designed vehicles, and refrigeration units at storage and transit locations. Training of personnel involved in handling and transporting these products is also crucial to ensure proper handling and maintenance of the cold chain. Personnel must be instructed on the handling, storage, and transportation of sensitive products, and the proper use of the monitoring devices.

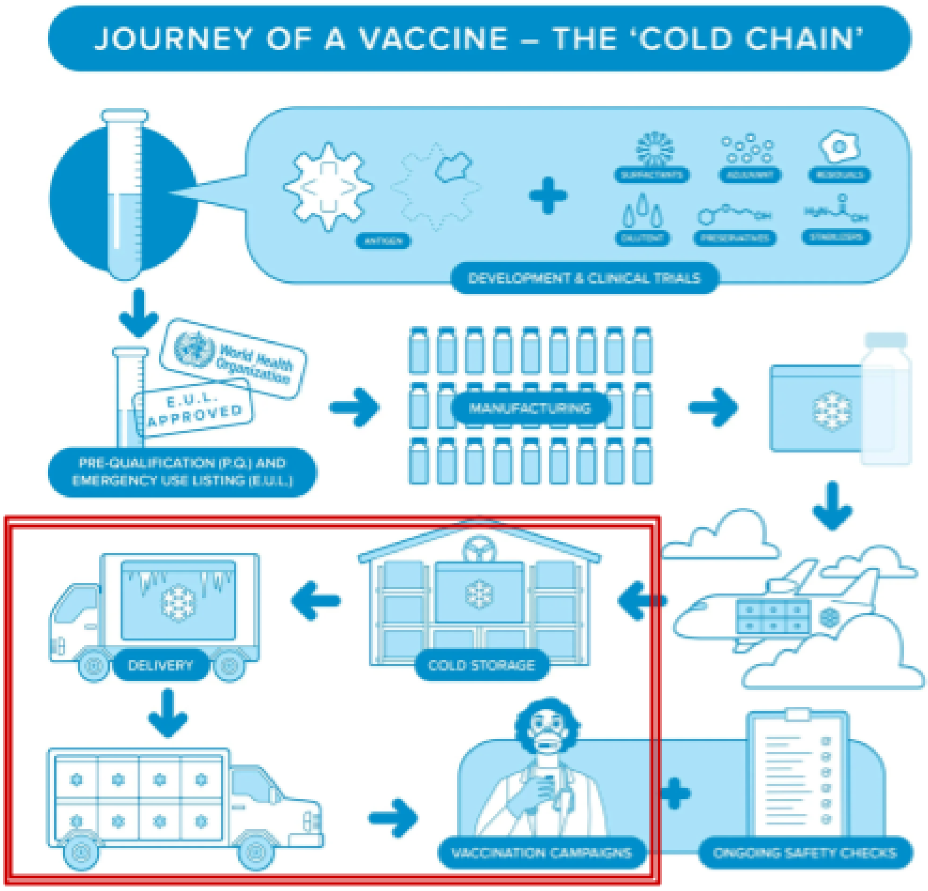
A reliable cold chain offers numerous benefits, including increased access to life-saving vaccines and medicines, particularly in remote or underdeveloped regions with limited healthcare resources. Maintaining the correct atmospheric specification range throughout the supply chain also ensures the preservation of product potency and efficacy, resulting in better health outcomes for patients and reduced waste and costs. Furthermore, a strong cold chain can prevent the spread of vaccine-preventable illnesses, decrease disease outbreaks and lower mortality rates in populations.

In conclusion, the cold chain plays a pivotal role in ensuring the safe and effective delivery of vaccines and medicines to those in need. Investment in the improvement and maintenance of a dependable cold chain infrastructure is essential to guarantee the delivery of high-quality vaccines and medicines. This leads to improved health outcomes, reduced waste and costs, and a safer and healthier world for all.

IOT IN COLDCHAIN:

An IoT based solution for a cold chain offers several advantages over traditional measures. Firstly, it provides real-time monitoring of temperature and other relevant parameters, ensuring that vaccines and medicines are stored and transported at optimal conditions. This helps to avoid spoilage and wastage, which can have a significant impact on public health.
Secondly, the use of IoT devices and sensors enables remote monitoring and control, eliminating the need for manual checks and increasing efficiency. Additionally, the data collected by these devices can be analysed to identify patterns and areas for improvement, leading to more effective and efficient supply chain management.
Furthermore, the use of IoT technology provides an increased level of transparency and accountability, as all parties involved in the supply chain have access to real-time data. This can help to minimise the risk of counterfeiting and other forms of fraud, further ensuring the quality and safety of vaccines and medicines. In conclusion, the use of an IoT based solution for a cold chain provides significant benefits over traditional measures, including improved efficiency, increased transparency, and enhanced quality control.

PROJECT SPECIFICATION:



The above figure [1] illustrates the journey of a vaccine right from its development in a laboratory to a location where vaccination campaigns take place. In this map, the part highlighted by the red box represents the most crucial step where the chances for complications to arise are great - transportation(last-mile delivery). To counter this, we propose an IoT based monitoring, alert and actuation system which constantly monitors the vials of vaccines in the containers of the delivery trucks in order to analyse the monitored data. It also alerts the administrator of the transportation system in case of any anomaly in the parameters recorded and also acts autonomously in order to enable or disable solutions (cooling system, dehumidifying system and pressure valves).

VACCINE STORAGE AND TRANSPORT PARAMETERS:

Temperature:

During storage and transport, vaccines need to be under an optimum temperature range so that its efficacy is not affected. According to WHO, the optimum temperature during transport in cooler boxes is +2 ° C to +8° C. [2]

Humidity:

The humidity of the vaccine containers also need to be maintained within a particular range in order to avoid spoilage. According to WHO, the optimum humidity range to be maintained during transportation is 55% to 75% relative humidity. [3]

Pressure:

Pressure of the vaccine containers is also an important parameter to be maintained with caution. Pressure changes occur when there is a change in temperature and humidity. Since we want to maintain the pressure of the vaccine vials at the regular atmospheric pressure (1 atm), the chosen optimum pressure range is 1000 to 1100 hPa (~between 1 to 1.1 atm).

FUNCTIONAL & NON FUNCTIONAL REQUIREMENTS:

Functional Requirements:

It is necessary for the Cold chain solution to perform the following functions:

Monitor and aggregate data from the sensors in the medicine storage containers:

Collecting real-time data from various sensors and devices in the supply chain is crucial for effective cold chain management. By monitoring and aggregating this data, it is possible to get a comprehensive overview of the entire supply chain and identify areas for improvement.

Transform and store data received from the sensors:
The data collected from the supply chain must be transformed into a format that can be easily analysed and stored. This will enable more effective decision-making and ensure that the data is available for future reference.

Visualise data from each container:
Visualising the data collected from the supply chain can help to identify trends, patterns and areas for improvement. By presenting the data in an intuitive and accessible format, it is easier to make informed decisions and take appropriate actions.

Send alerts to the administrator of the cold chain system:
A key aspect of an IoT-based cold chain solution is the ability to send alerts in real-time. This can include alerts related to temperature fluctuations and other relevant parameters. This helps to ensure that issues are addressed promptly, avoiding spoilage and wastage of vaccines and medicines.

Control the actuators in different containers and also conserving energy:
The ability to control the cooling system, dehumidifying solution and the pressure valves autonomously and remotely is crucial for effective cold chain management. This is especially necessary while transporting vaccines or medicines to remote areas. This makes it possible to optimise energy consumption while also ensuring that vaccines and medicines are stored at the appropriate conditions.

Non-Functional Requirements:

Usability: The system should be configurable to be easy to use and monitor.

Reliability: The system should always provide reliable, complete and accurate data.

Transparency: The system should be understandable and accountable so that it is easier to adhere to relevant regulations and standards, such as Good Distribution Practices (GDP) for pharmaceuticals.

TECHNOLOGIES:

We have used the following technologies to implement our system according to the project specifications.

IoT Sensors:

Data from sensors for parameters - temperature, humidity and pressure are simulated using Kotlin programs.

Mosquitto MQTT Broker:

Mosquitto is an open-source message broker that implements the MQTT protocol. It acts as a central hub, facilitating communication between connected devices. With its ability to handle large numbers of simultaneous connections, Mosquitto is ideal for IoT and M2M communication.
For our solution, we require a component which is able to provide a pub-sub mechanism that is also lightweight and integrable with other technologies for flexibility if necessary in the future. Thus, Mosquitto MQTT was a viable option. The MQTT protocol is used to get the data from the sensors (simulated) and to publish the data to the broker.

Published topics in MQTT include:
- /temperature
- /pressure
- /humidity

Telegraf:

Telegraf is an open-source agent for collecting, processing, and aggregating metrics. It can gather data from a variety of sources, including systems, databases, and IoT devices, and send it to a destination of our choice.

For the cold chain solution, Telegraf is utilised as a subscriber to subscribe the topics listed above and ingest it to a bucket in InfluxDB.

InfluxDB:

InfluxDB is a high-performance time-series database designed to handle large amounts of time-stamped data. It provides real-time analysis and is optimised for handling metric and event data.
Since data being simulated by the different sensors in our solution needs to be stored in a highly scalable, time-series database with provisions for a variety of plugins, InfluxDB is a good choice. The data being subscribed by Telegraf is ingested into a Bucket in InfluxDB for storage. For our solution, we use the interactive UI of Influx which provides us with easy querying capabilities across specific timeframes.

Grafana:

Grafana is an open-source platform for visualising and analysing data. It provides a user-friendly interface for creating dynamic dashboards, allowing users to easily interact with their data. Grafana supports a range of data sources, including InfluxDB, and can visualise data in a variety of formats.
We use Grafana to visualise and analyse the data obtained from the InfluxDB Bucket. We have utilised Grafana to create tailor-made dashboards of the sensor data received to provide better visualisation capability for the admin. We have also made use of the alerting features in Grafana to send alerts through Telegram in case of any abnormalities in the parameter readings (temperature, pressure, humidity).

Telegram:

Telegram is a popular messaging app that offers a range of features, including the ability to create bots for various purposes. Telegram bots can automate tasks, provide information, and interact with users in a variety of ways.
For our solution, we have created a contact endpoint on Grafana which will enable us to receive notification on Telegram. We made use of the Telegram Bot functionality to create a bot which will fire alerts to a Telegram group upon receiving an alert on Grafana in case of abnormalities in the data received from the sensors.

OpenHAB:

OpenHAB is an open-source home automation platform that enables users to connect and control various smart devices and sensors. It offers a flexible and modular architecture that supports multiple protocols and technologies, making it compatible with a wide range of devices and systems.
In our IoT system, OpenHAB is used mainly to automate the activation of different actuators when abnormalities occur in temperature, pressure or humidity of vaccines in containers in different transportation trucks. We also use it to visualise the switches of the actuators virtually in the OpenHAB dashboard.

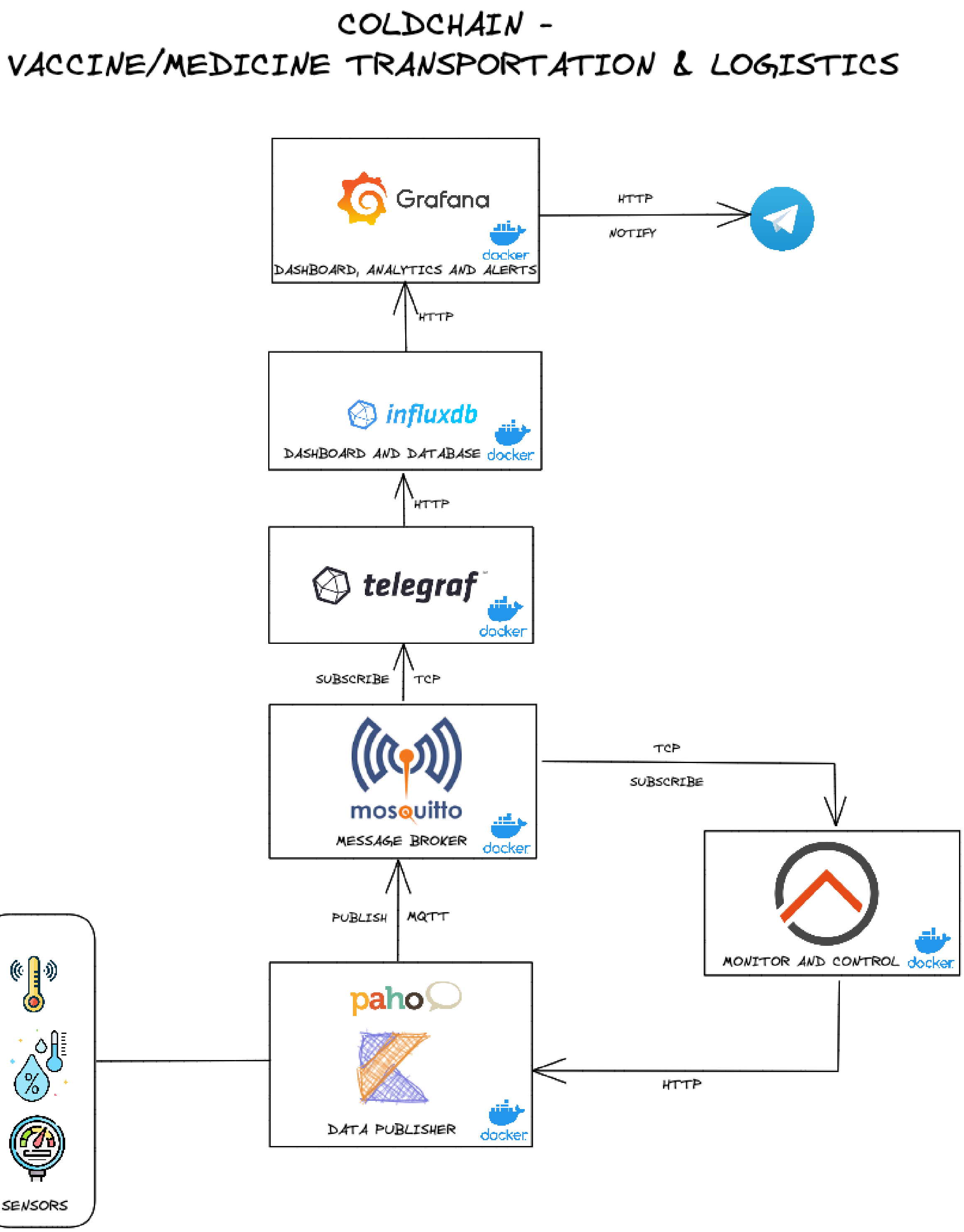
Docker:

Docker is a platform that enables the deployment of applications in containers. Containers provide isolation and reproducibility, allowing developers to build and deploy applications with confidence.

The various components of our Cold chain solution are containerized using Docker and thus can be composed, replicated and deployed easily.

SYSTEM ARCHITECTURE:

The following diagram shows our cold chain vaccine transportation IoT system architecture and the technologies used.

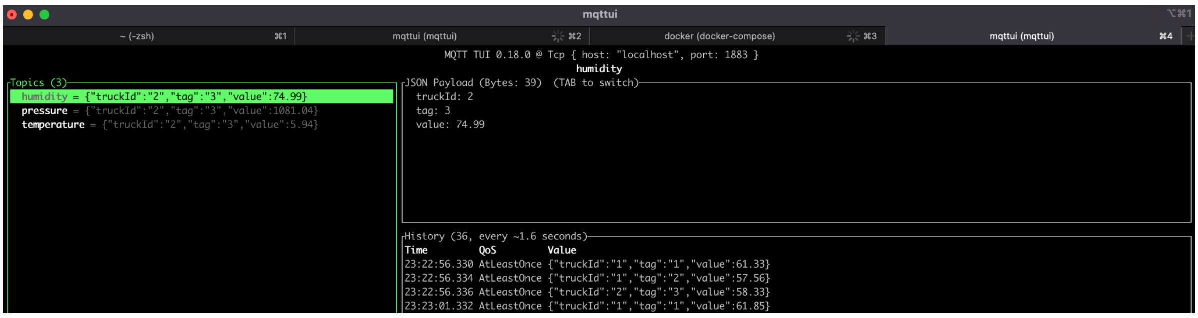


ADDRESSING REQUIREMENTS:

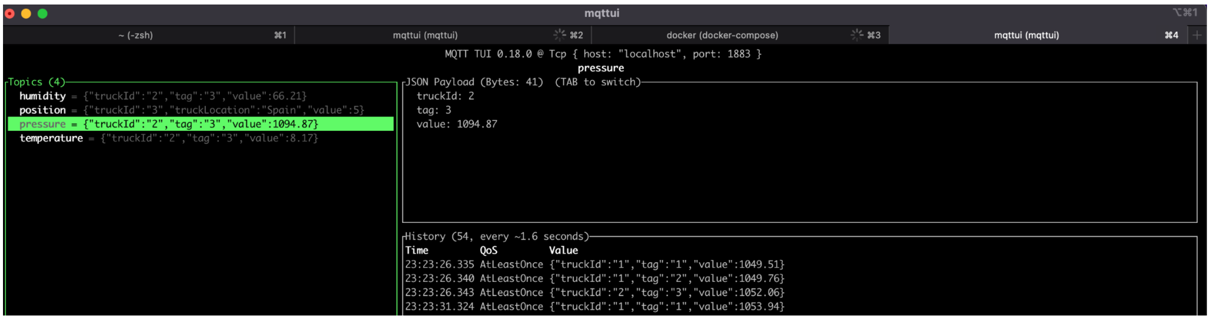
To illustrate how our solution addresses the functional requirements, the data from the temperature, pressure and humidity sensors attached to three different vaccine containers in two different trucks are considered.

Monitor and aggregate data from the sensors in the medicine storage containers:

The figure below depicts the values of humidity(percentage) in each vaccine container which have been published by the sensor to the Mosquitto MQTT Broker.



The figure below depicts the values of pressure(hPa) in each vaccine container which have been published by the sensor to the Mosquitto MQTT Broker.

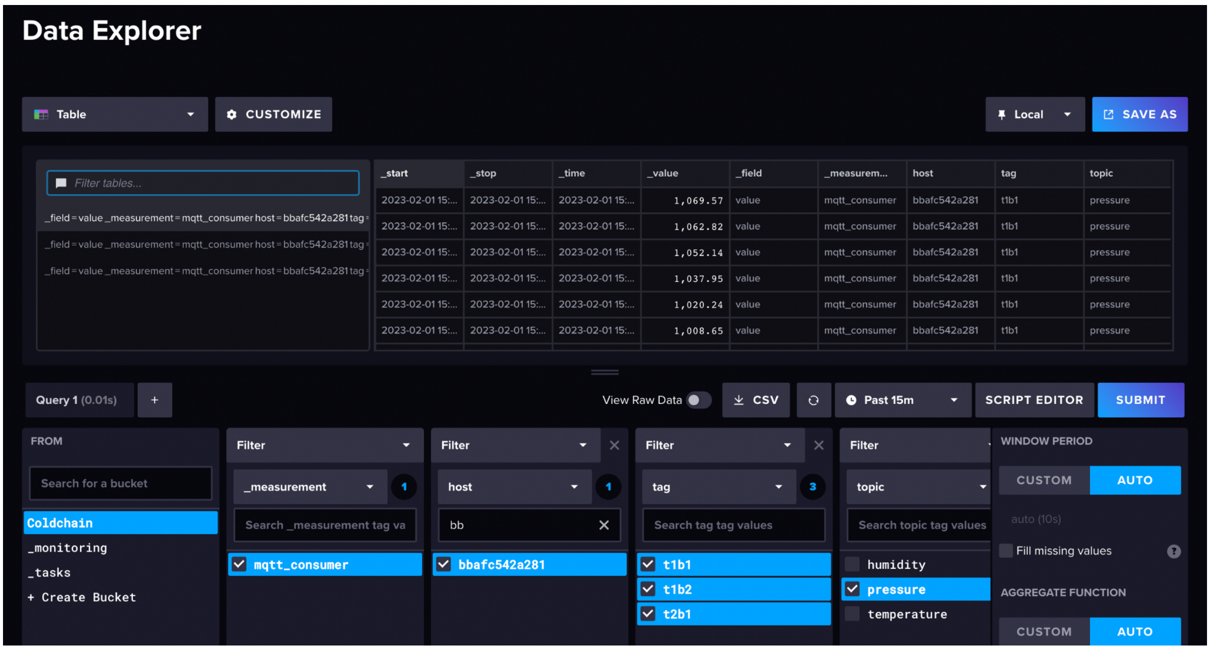


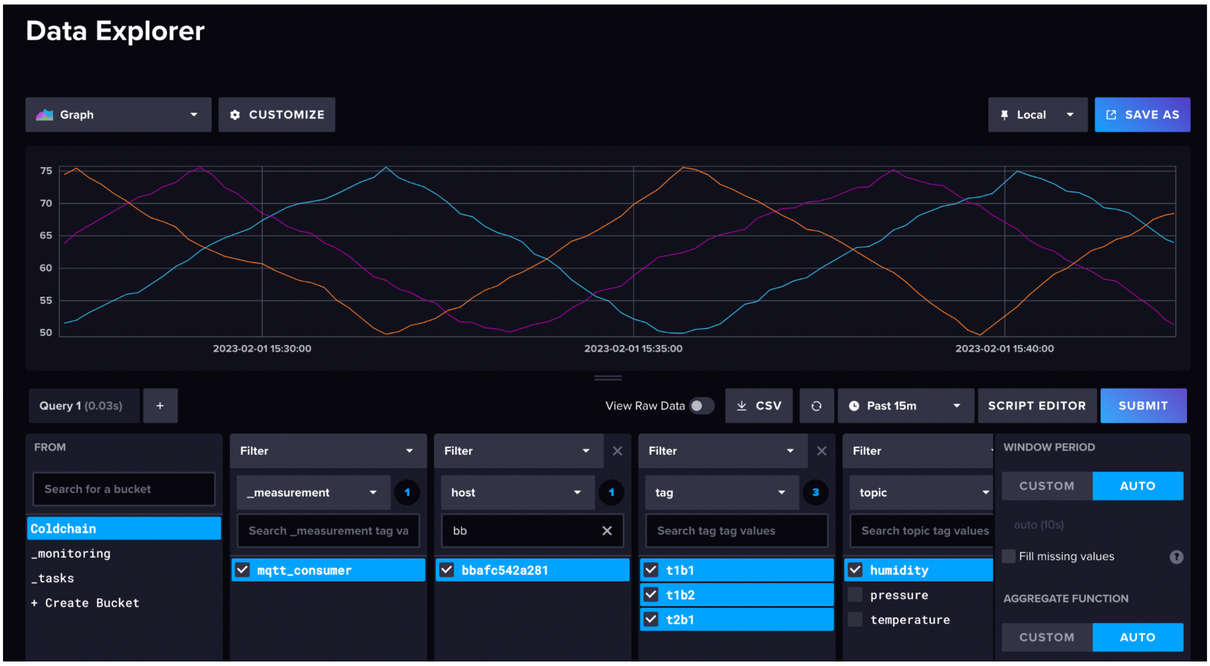
The figure below depicts the values of temperature(°C) in each vaccine container which have been published by the sensor to the Mosquitto MQTT Broker.

Transform and store data received from the sensors:

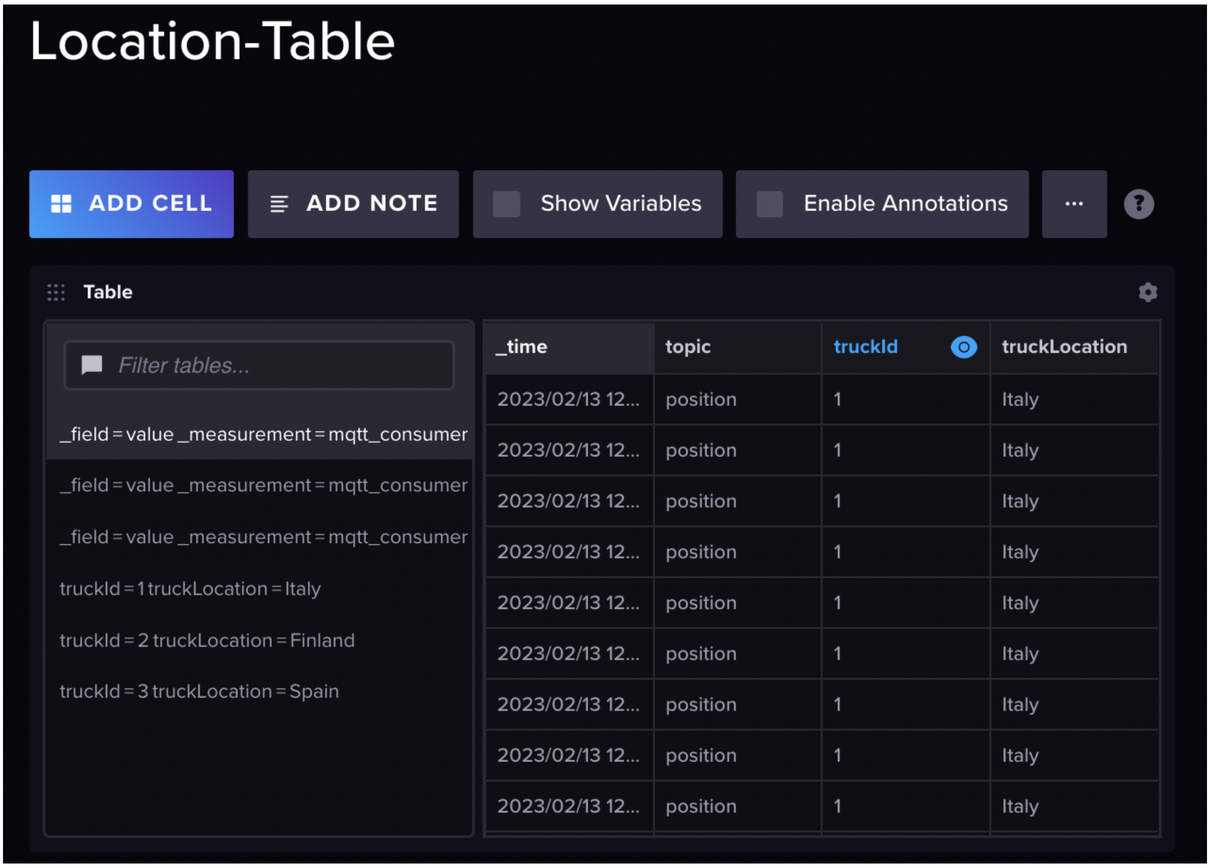
We use InfluxDB to transform and query data from the sensors as required. We also make use of the data storage buckets which act as time-series databases.

The below figures show the queries used for obtaining values of the different parameters from the containers for the past 15 minutes.





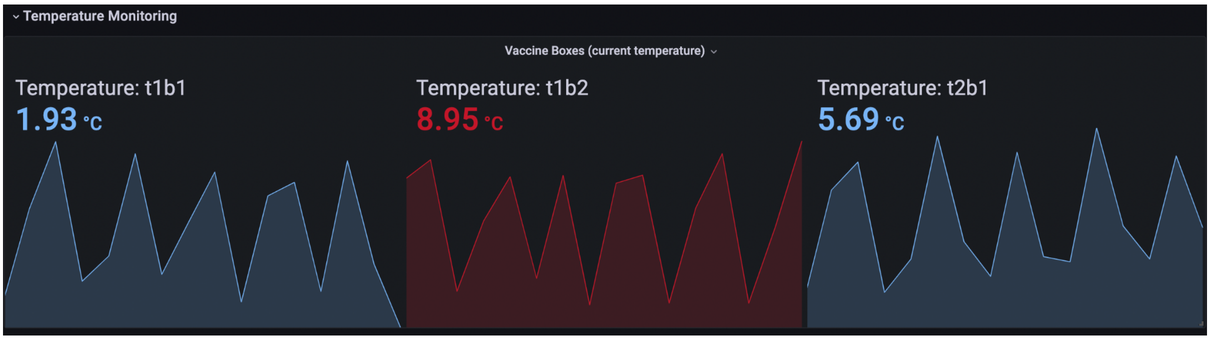
We also created a dashboard on Influx to display the locations of the trucks carrying the vaccines as illustrated in the figure below.



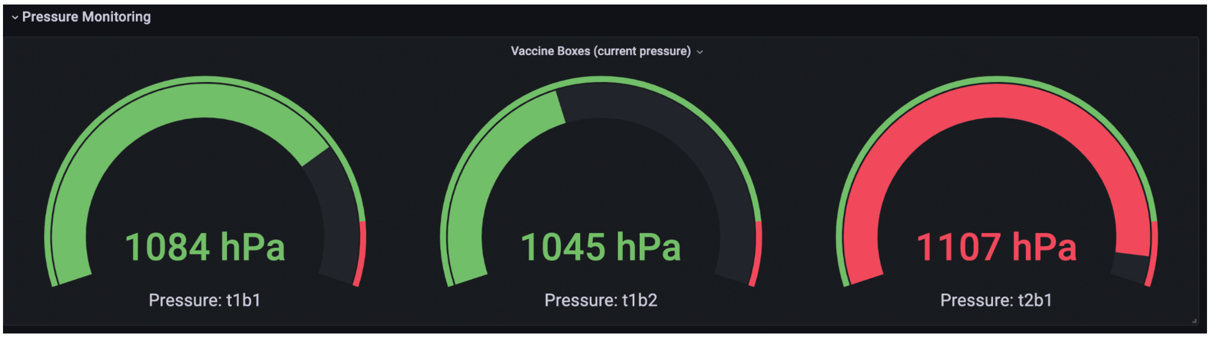
Visualise data from each container:

We use Grafana for creating Dashboards which enable the administrator to easily visualise the data which is being received from the sensors. Grafana uses InfluxDB as a datasource for obtaining temperature, humidity and pressure data from the vaccine containers and displays them as different forms of graphs. The graphs are also configured to show the data in different colours depending on how close the real-time data is to the preset thresholds.

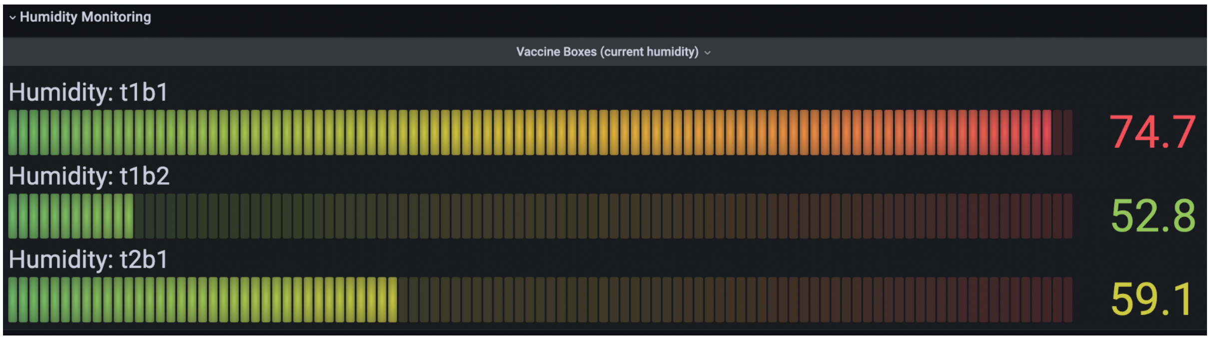
The figure below shows the Temperature Monitoring section of the dashboard and we can identify that the container t1b2 has a temperature over the threshold and is highlighted to the Admin.



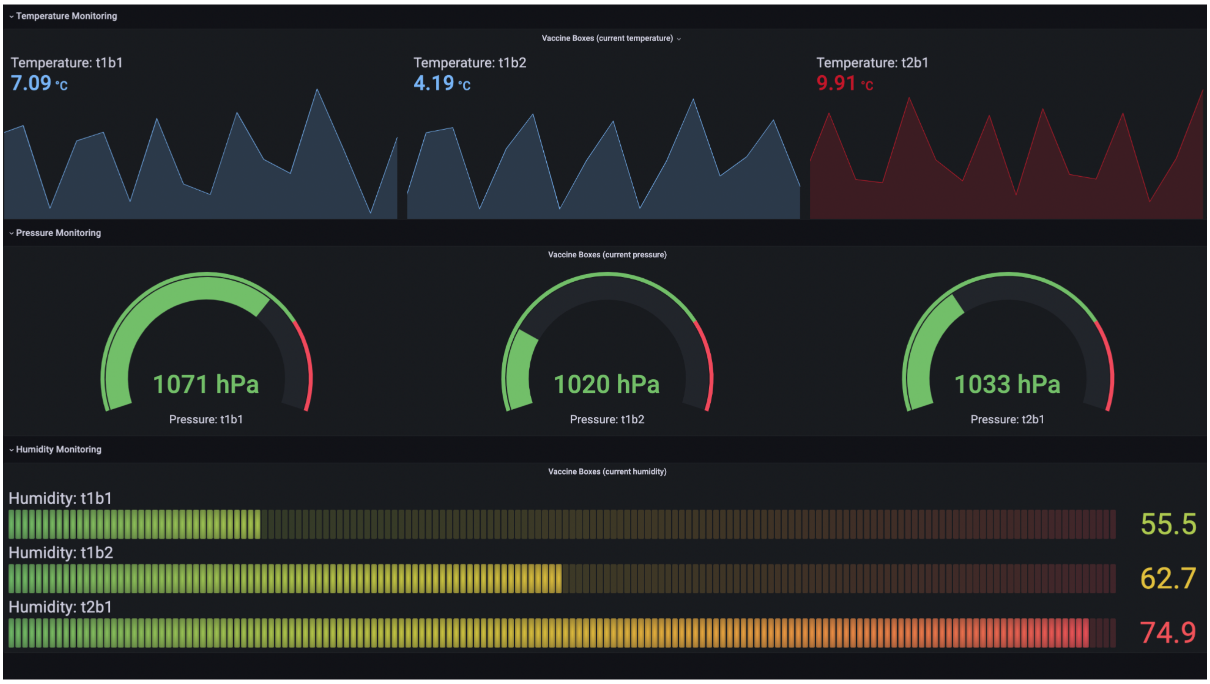
The figure below shows the Pressure Monitoring section of the dashboard and we can identify that the container t2b1 has a pressure over the threshold and is highlighted to the Admin.



The figure below shows the Humidity Monitoring section of the dashboard and we can identify that the container t1b1 has a humidity percentage over the threshold and is highlighted to the Admin.



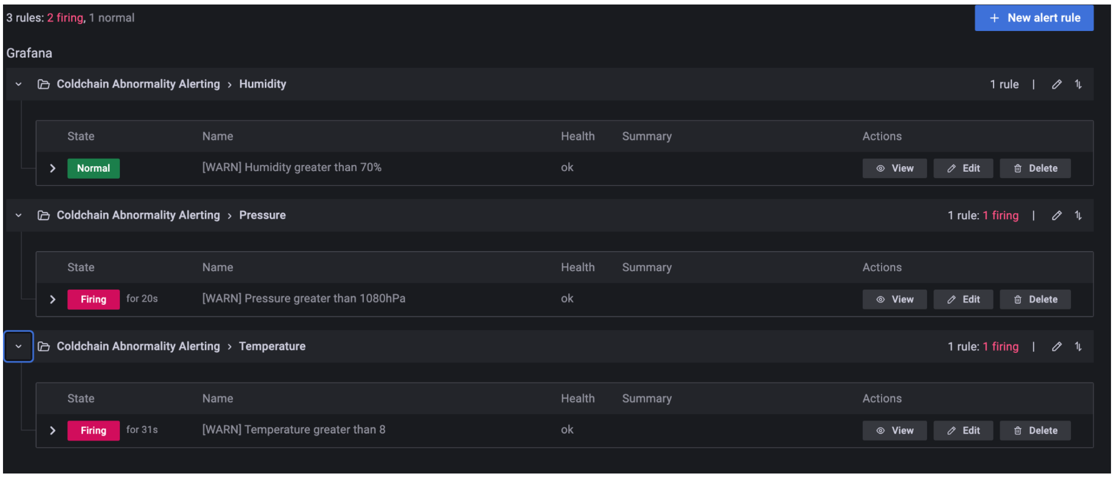
The figure below depicts our overall dashboard where the parameters from all the vaccine containers are displayed for the Admin to view. We have set the data to get updated every 5 seconds.



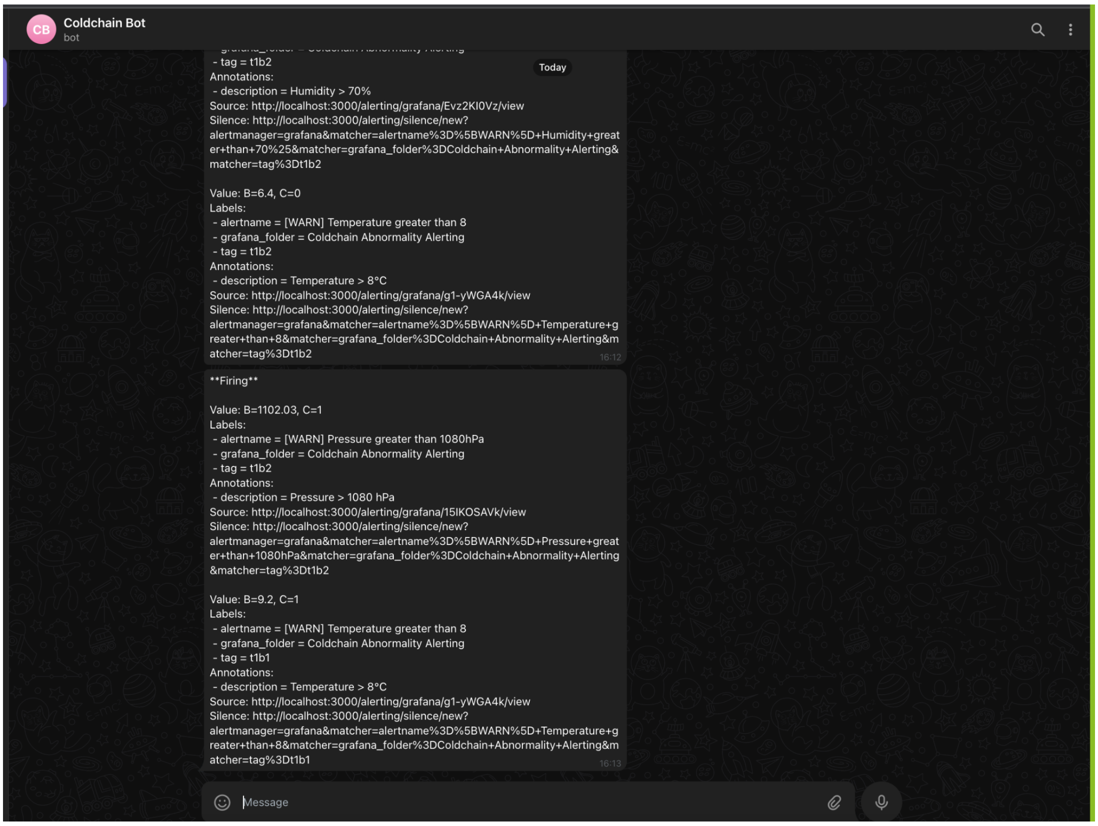
Send alerts to the administrator of the cold chain system:

We also make use of Grafana's alerting capabilities to inform the administrators in case of abnormal readings from the sensors in the vaccine containers. We selected Telegram as our contact point of choice since it offers easy integration into the Instant Messaging system with the use of bots.

The below figure represents the Alert Rules which are essentially rules for establishing thresholds to the system so that it can fire an alert to the Admin if the value of a parameter exceeds the set threshold.



The figure below is an example of an alert message from the Telegram Bot sent to a Telegram Group containing all concerned Administrators of the cold chain system.

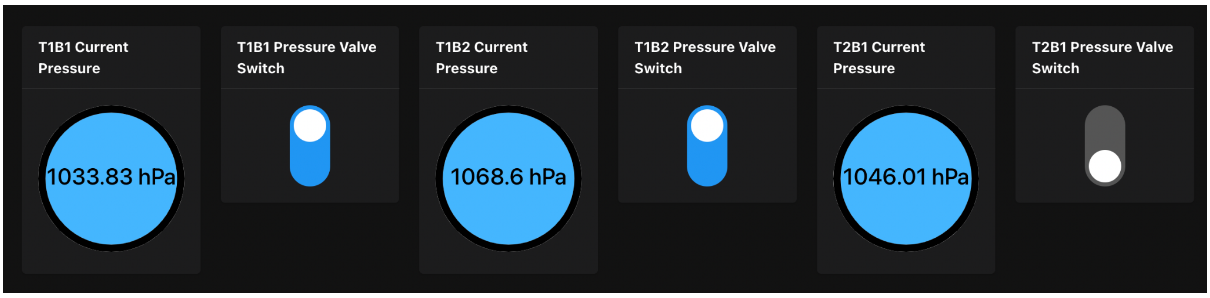


Control the actuators in different containers:

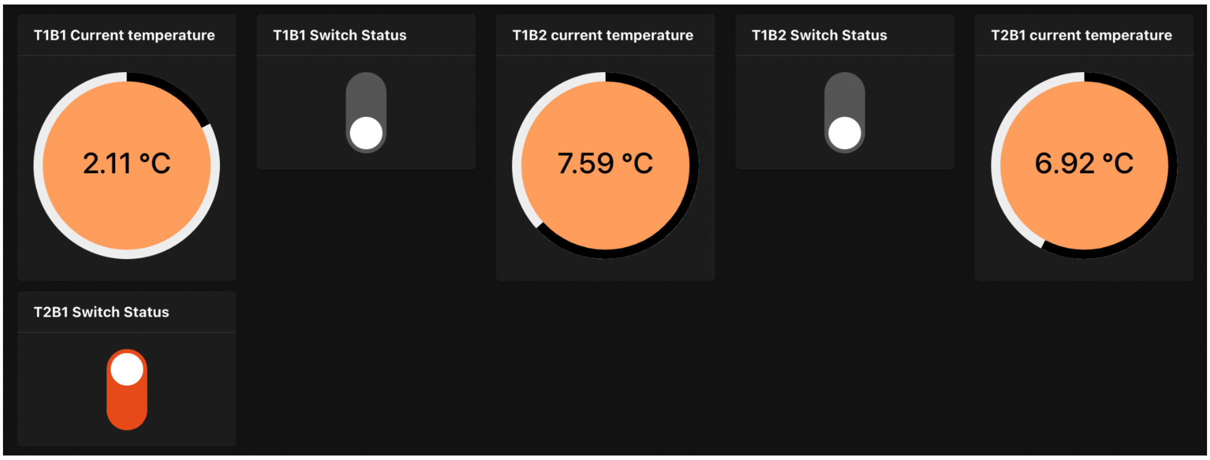
We utilise the OpenHab automation system to control actuators autonomously when there are abnormalities in the parameters received from the sensors. By switching on the cooling/dehumidifying solutions only when necessary, we optimise energy usage.

The below figure represents the UI from OpenHab automation system which displays the pressure data and their respective valve switches. It switches on the

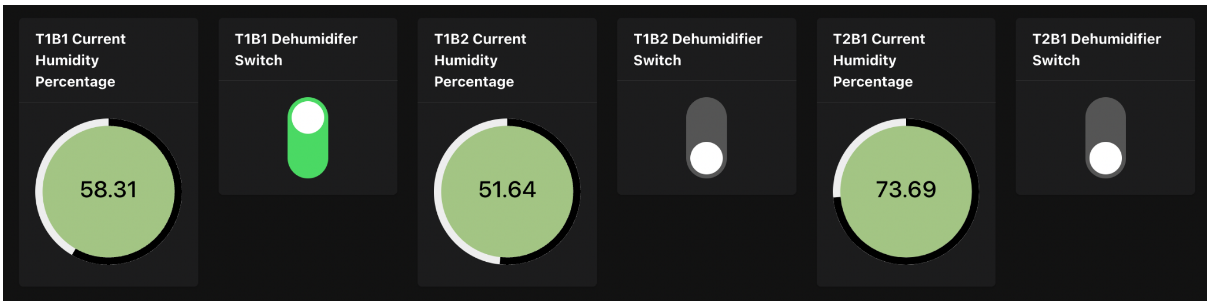
Pressure Valve when the value of pressure in a vaccine container exceeds 1100hPa and switches it off when the pressure goes down to 1000hPa.



The below figure represents the UI from OpenHab automation system which displays the temperature data and their respective Cooling System switches. It switches on the Cooling System when the value of temperature in a vaccine container exceeds +10 °C and switches it off when the temperature goes down to +2°C.



The below figure represents the UI from OpenHab automation system which displays the humidity data from the containers and their respective Dehumidifier switches. It switches on the Dehumidifier when the value of humidity in a vaccine container exceeds 75% relative humidity and switches it off when the humidity goes down to 50% relative humidity.



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