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Design of Event Management System for Smart Retail Stores with IoT Edge

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Abstract - *Handling the emergency events from the HVAC and Refrigeration system of the retail store is critical to avoid the food wastage, repair free cold storage, and maintain a comfortable shopping environment so the customer can spend more time and purchase more products. The refrigeration system keeps the food in good condition to avoid wastage before it expires. Proper lighting and air-conditioning provide a better shopping experience.*

IoT Solutions are providing a real-time connected experience by interconnecting the machines, assets, and services. Retail stores can improve business profits, reduce food wastage, and increase the life of refrigeration and HVAC systems by doing predictive analysis from the sensor data. Sensors are attached to those assets to read the temperature, pressure, and setpoints.
Design of IoT Edge informed decision-making system for the retail store is explained, the Data Collector Module extracts the sensor Data (readings) from retail stores in Immediately. Automated work orders are created to assign the responsible team's issues to take care of in a specific time based on the severity.

Keywords: *Smart retail stores; IoT Edge; Building Management System; Event Management system*

I. INTRODUCTION

All the smart retail stores are equipped with an automated Building Management System (BMS) to extract the store devices' values, such as HVAC and refrigeration systems like compressor, condenser, suction units, and air conditioning lighting units. Store controller is a microprocessor-based controller designed to provide complete control of HVAC and refrigeration.
Two types of controllers are widely used in any retail stores:

A. HVAC Rack Controller:

Controlling common environmental equipment such as Air Handling Units (AHU), Roof Top Units (RTU), and Lighting Loads.
HVAC Rack controller controls the HVAC system by monitoring zone temperature sensors and comparing them to store pre-defined set points. Either it calls functions for either for heating or cooling to maintain building comfort.
HVAC Rack controller controls the HVAC system and handles the below functionalities.

- These monitors outside air conditions to lockout equipment if conditions dictate.
- This controller can also maintain indoor air quality.
- Controls interior lighting per store's pre-defined schedules.
- Control dimmable ballasts on stores that have skylights installed.
- Schedule and light level sensors control exterior lighting.

B. Refrigeration Rack Controller:

Controlling compressor groups, condensers, and walk-ins. Controls the refrigeration process by monitoring pressure sensors in the refrigeration system and commanding compressors on the refrigeration rack to maintain a pre-defined pressure by pumping refrigerant through the system at a case level, control fans, lights, and defrost as well as maintain case temperature.
The refrigeration controller controls the refrigeration process by monitoring pressure sensors in the refrigeration system and commanding compressors on
the refrigeration rack to maintain a pre-defined pressure by pumping refrigerant through the system.

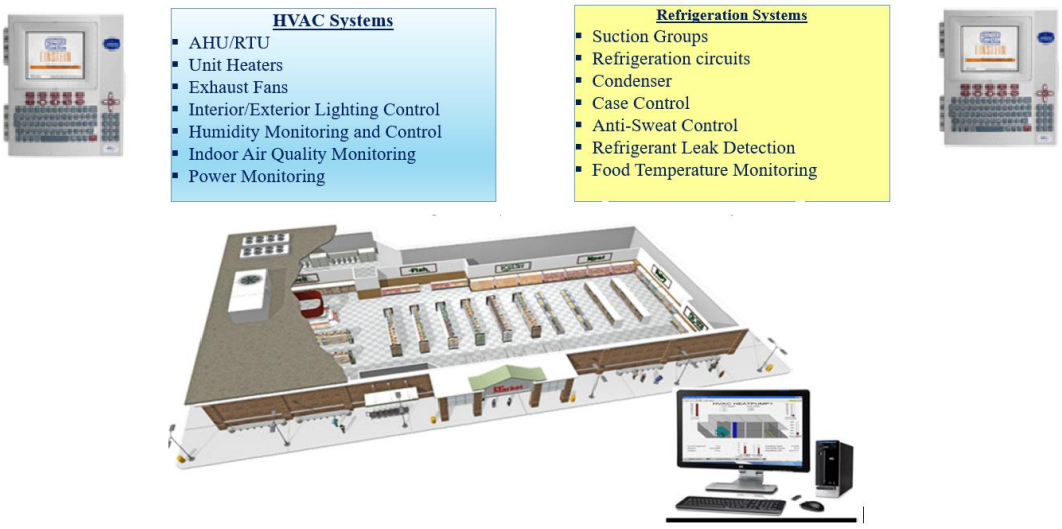

Fig. 1. Typical layout of Retail store's BMS system

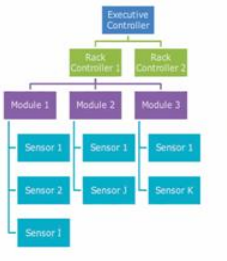

Fig. 2. Logical Layout of store sensor network

Fig. 3. Refrigeration Rack Controller controlling the store's refrigeration system to preserve the foods in the storage area.

Fig. 4. HVAC Rack Controller controlling the store's HVAC system to maintain proper air-conditioning and lighting.

C. Various Components of store's BMS System:

Module: The module is the board that contains a combination of digital inputs, analog outputs, relay outputs, and analog outputs.

Digital Input: An input point on the board that reads signals from digital sensors. Digital inputs usually report the status of a device as open/close or on/off.

Analog Input: An input point on the board that reads signals from analog sensors. Analog inputs usually report the status of a device using an analog value.

Relay Output: An output point on the I/O board that switches equipment on and off.

Sensor: A device connected to an input point that transfer reading back to the controller (temperature, pressure, and light level).

II. Functional Design of Existing system

A. Data collector module: This Module extracts the sensor or setpoint data values from the store controller network and forms a readable JSON message. The data collector module generates multiple JSON messages based on the number of sensors or setpoints. Advanced controllers are capable of responding to the REST requests from the data collector module. Controllers acting as OBIX servers will respond to various REST methods(Get, Put, Post) with the necessary sensor values or write new values or update them into the setpoint.

B. Event Management Module:

IBM® Streams can handle high, very high throughput rates of millions of messages or events per second used to streamline the sensor or setpoint data from the Data collector module. The stream processing engine is creating the manual or automated tasks in case of any alert events received from the Kafka message broker.

Data collector module acting as a Kafka producer and constructing a sensor or setpoint values in JSON format from the raw values are extracted from the controller at 10 minutes polling interval. Kafka broker acting as a subscriber registered for specific topics to receive the real-time sensor or setpoint values from the Data Collector module.

C. Limitation of the Existing on-premise system:

There are few limitations when the Data Collector module is designed as an on-premise stem when we have multiple stores as a chain of a supermarket.

1.Application is deployed locally at the store level needs more infrastructure to maintain and monitor.

2.Data and alert events are also maintained locally at the store level. The store manager is responsible for tracking and takes any action on the alerts. It isn't easy to do data analytics from all the stores of the particular region.

3. Solution is costly, and there is no mechanism to identify store-level application failures, including Data Collector Module.

4.Mass deployment of the Data Collector module is not possible from a centralized repository, each and every store should have executable and configuration files to initiate the module or application.

5. Data Collector running locally at the store level is not scalable for energy savings systems.

6.Integrating the stream analytical process, notification system in the on-premise system, or the cloud with Data Collector module, which is a pure On-Premise system is more complex and difficult to handle.

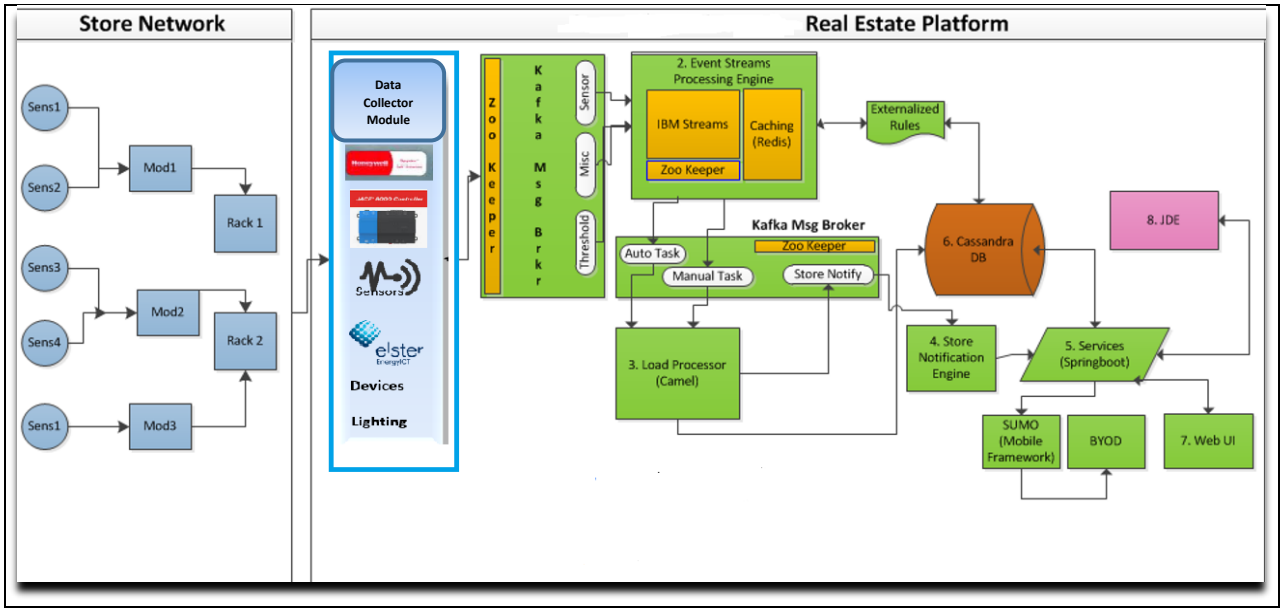

Fig. 5. Functional Design of Existing Event Management System

D. Usage of oBIX Protocol:

Open Building Information Xchange (oBIX) is a standard XML and Web Services guideline to
facilitate the exchange of information between smart buildings, enable systems integration to communicate within the various devices using protocols like Backset, Modbus, and custom device protocol.

The cyclic handler algorithm is used to fetch the store controller's data on a specific interval based on the configuration setup in the Edge Hub. Since the
Modern controllers are capable of responding to any obix request with a specific payload.

III. Overall design of the proposed system

The proposed system designed with an advanced Data Collector Module, IoT Edge-based Event Management System. Graphics applications are to display real-time sensor values.

A. Advanced-Data collector Module:

Data Collector Module is the multi-threaded application, extracting the sensor and setpoint data from the store controller. The number of threads is equal to the number of racks in the store.

Data Collector Module for the proposed system sending the data to IoT Hub instead of Kafka, here the

telemetry data are sent via the topic-based publisher-subscriber paradigm.
Store server behaving as Obix server returning the values of sensor or setpoint to the data collector module. XML based Obix responses are converted into readable JSON packets by the JSON builder module since the Data Collector module runs as s docker container in Edge hub, latter sending the data to IoT Hub.
IoT Hub will send the success or failure responses based on whether it received the Edge hub packet or not. The packet may be dropped out in case of communication loss or time-out.

Module client of Data Collector is sending the data to IoT Hub via Edge Hub with proper route setup made in an azure container registry.
MQTT is the light weighted telemetry protocol which Sending the data from the device side to the Edge hub.
Run time, Agent running in the Edge will restart any custom module running on it, including the Data Collector Module.
Heartbeat signals are sent from every container to ensure that the data is extracted from the store controller and sent to IoT Hub. Any issues in the heartbeat signal will be treated as a failure in Data Collector Module and check-in high priority.

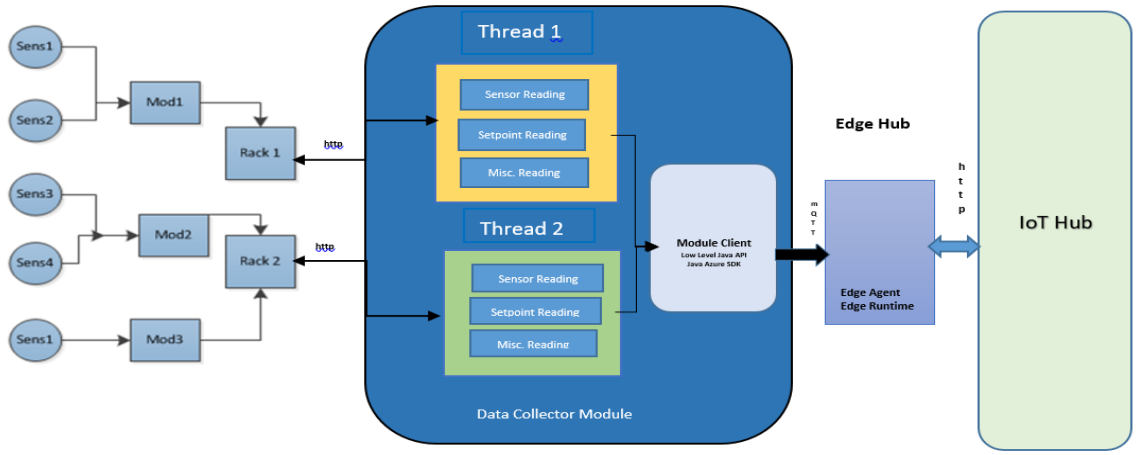

Fig. 6. Functional Design of Data Collector Module


```
{
  "msgSchema": {
    "msgVersion": 1
  },
  "sensorDetails": {
    "uniqueId": "US|865|41|5|INPUT|DIGITAL|1555798017748",
    "cc": "IND",
    "vendorType": "Johnson",
    "storeNo": 865,
    "reqTS": "09/21/2019 04:32:58",
    "resTS": "09/21/2019 04:32:59",
    "rackIndex": 1,
    "modIndex": 41,
    "sensorIndex": 5,
    "sensorIOType": "INPUT",
    "sensorReadingType": "DIGITAL",
    "rackLabel": "HVAC/LIGHTS     ",
    "isHvac": "TRUE",
    "rackStatus": "ACTIVE",
    "modLabel": "RG41 TLE        ",
    "modType": "ETM/ETM-2020",
    "modVersion": 11,
    "modStatus": "ACTIVE",
    "sensorLabel": "SMOKE 1          ",
    "sensorStatus": {
      "reading": "CLOSED",
      "units": ""
    }
  }
}
```


Fig. 7. Sample Sensor from store controllers.


```
"setpointDetails": {
  "uniqueId": "US|865|N|1|EP2|5|0|OUTPUT|SETPOINT|1555821097329",
  "cc": "IND",
  "storeNo": 865,
  "reqTS": "09/21/2020 04:36:33",
  "resTS": "04/21/2020 04:36:37",
  "sensorIOType": "OUTPUT",
  "sensorReadingType": "SETPOINT",
  "rackLabel": "HVAC/LIGHTS     ",
  "loadNumber-Type": "5-2020",
  "modType": "ETM",
  "setpointReading": {
    "coolSetpointType": "FIXED",
    "coolSetpoint1": 73,
    "coolSetpoint2": 0,
    "coolSetpointReset": "INACTIVE",
    "heatSetpoint": 69,
    "coolSetback": 78,
    "heatSetback": 65,
    "fanOperationSchedOn": "AUTO",
    "fanOperationSchedOff": "AUTO",
    "coolStage1StptDiff": 1,
    "coolStage2StptDiff1": "INACTIVE",
    "coolStage2StptDiff2": "INACTIVE",
    "heatStage1StptDiff": 1,
    "heatStage2StptDiff1": "1.000000",
    "heatStage2StptDiff2": "3",
    "damperControl": "INACTIVE",
    "activeCoolMode": "YES",
    "activeHeatMode": "YES - ELECTRIC",
  }
```


Fig. 8. Sample Setpoint data from store controllers.

B. IoT Edge-based Event Management System:

Data coming from the Building Management System of the retail store is Big Data and near real-time in nature with 5-10 minutes of delay. Here 10 minutes of polling time is set to pull the data from the executive controller. Data analyzed at the device side itself to use a real potential of edge analysis. Cloud side analytics is no top cold data (weeks/months).

IoT Hub was acting as a gateway, collecting the data from the storage devices (executive controllers) through Edge hub and sending acknowledgment or error message in case of any network or time out issues.

Store emergency management and store monitoring systems are directly integrated with an automated Work order management system. An IoT Edge is important to decide when there is any issue found at the HVAC or refrigeration systems.

Sensor or Setpoint data ingested into Cosmos DB for better analytics process. This is the first step in in-stream analytics. All the raw data coming from IoT Hub will be sent to Cosmos DB for permanent storage. IoT Hub is having a defined retention period, and after that specific time, data storage will be expired.

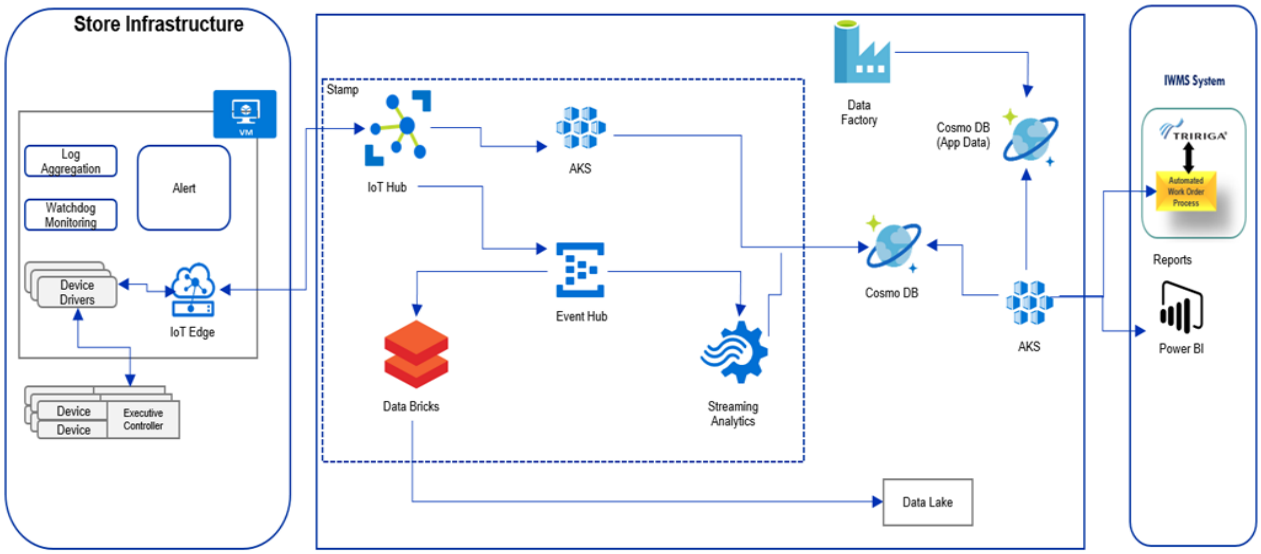

Fig. 9. Overall Solution design of the Event Management System with IoT Edge

Event Hub, as a streaming service with a partitioned model, is loaded with all the telemetry data coming from the store controller. Sensor and setpoints are the two different partitions designed for streaming analytics. UI applications showing the sensor trend will use the Sensor Events, and energy savings applications controlling the setpoint of stores will use setpoint events.

Normalized telemetry data from Data Bricks and raw sensor data will be saved in Data Lake to apply any machine learning logic or pattern processing mechanism to understand the store operational efficiency and suggest more ideas for better customer experience with minimized failures in HVAC and refrigeration system. Event Hub helps to track failure events or anomalies from the telemetry data.

Data factory is also the cloud service to orchestrate and operational sensor data into actionable business insights. Here application-specific Cosmos DB helps by collecting the Data Collector logs and watchdog logs. Work orders to attend to the emergency issues are created from the actions created by the Data factory.

C. Graphics applications for Events: There are thousands are sensors fixed in any retail store to measure important parameters like temperature, smoke, suction pressure, defrost schedules. Event management is very important to monitor any anomalies happening within the store or asset. Continuous monitoring of those values and raising an automatic work order play a key role.

All digital or analog sensors placed in HVAC or refrigeration systems are monitored in the sensor UI applications. The sensor trend for the last 12 hours or 24 hours can be visualized to understand the trend.

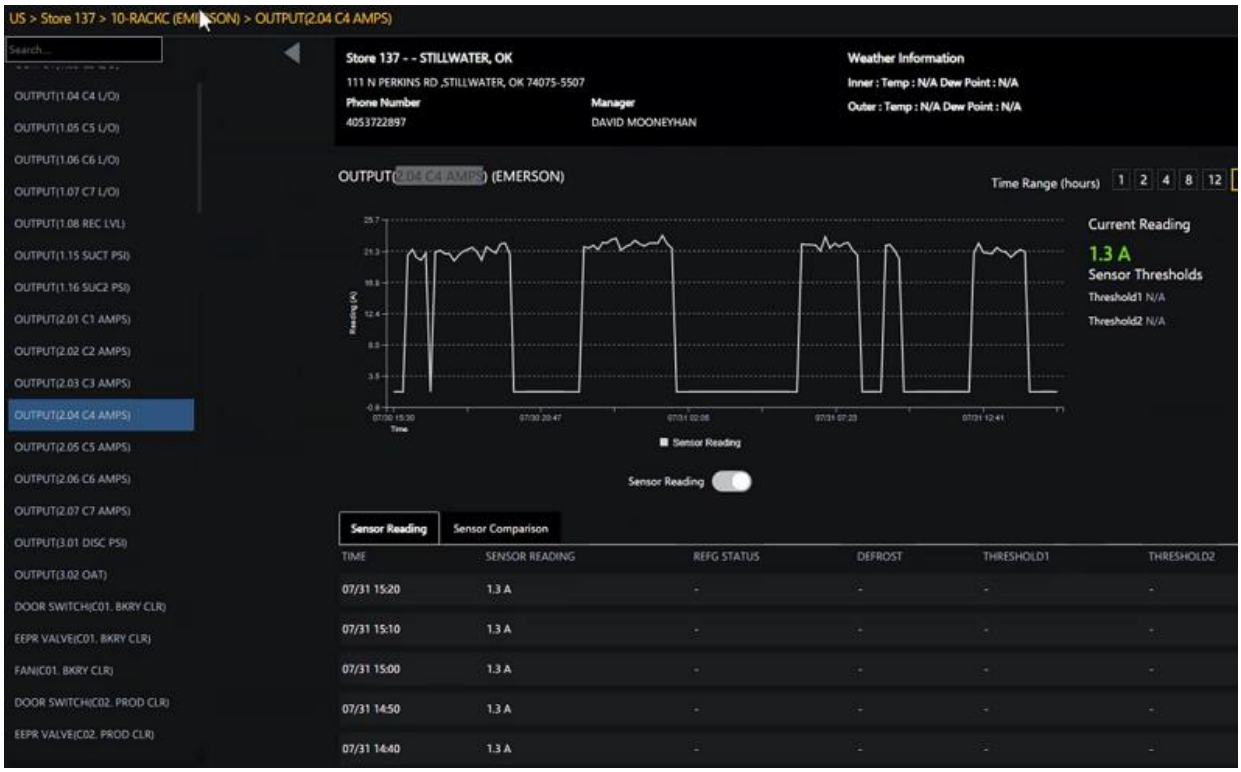

Fig. 10. Application snapshot showing analog sensor value

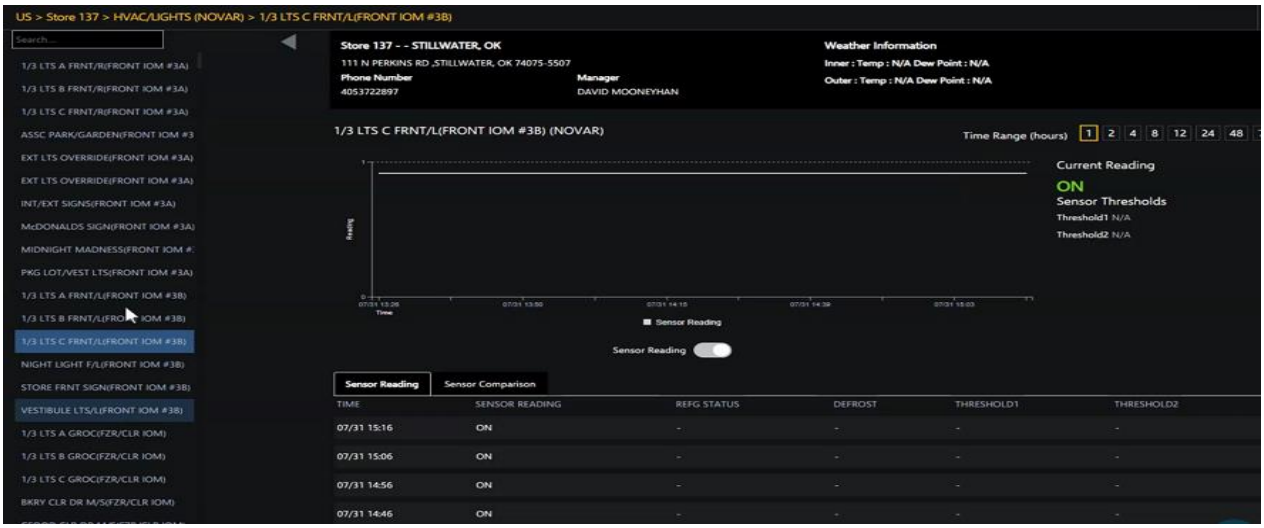

Fig. 11. Application snapshot showing analog sensor value

D. Work Order Management for Critical Events:

The store's energy management sytem of the store could be effective when the alerts from the building management system are transormed into work tasks and should be addressed by technicians as an emergency ticket of the work order management system.

Communication loss on the rack, modules, and the sensors become critical alert. Phase loss to the executive controller, stale reading from the sensor showing the store asset's failure scenario.

Generally, the work orders are managed by the IWMS system like TRIRIGA, there responsible people like store manager, technician, service provider, and their workflow is defined and managed.

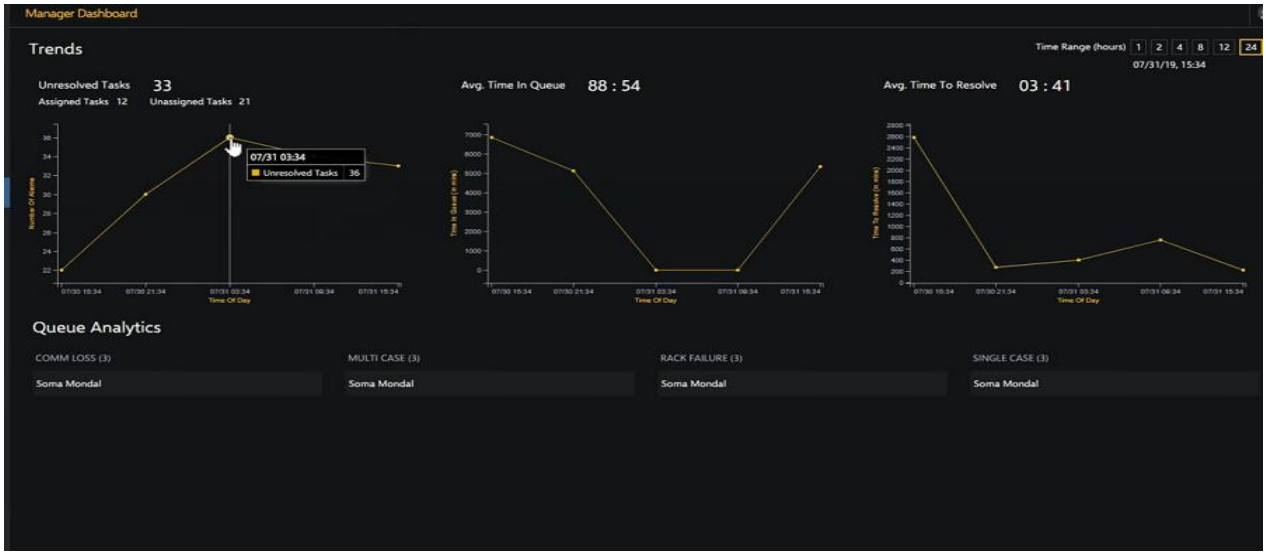

Figure. 12. Snapshot showing work orders in the queues with status and waiting time

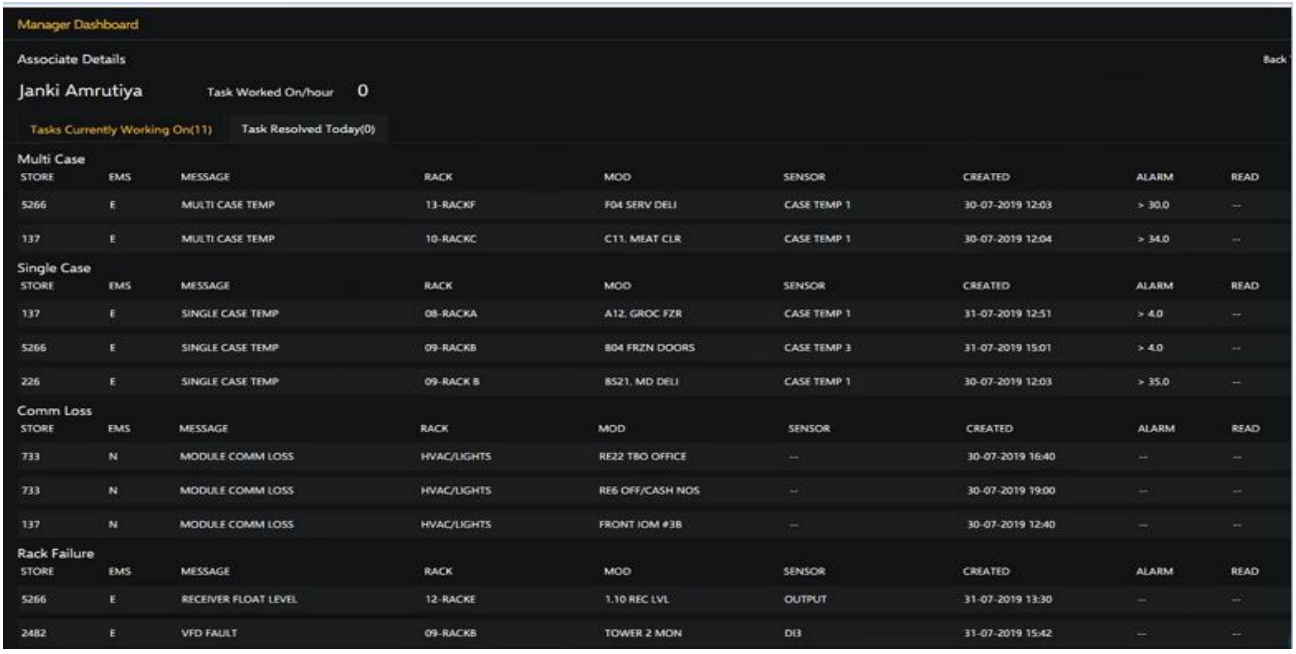

Fig. 13. Snapshot showing the various alerts in the store manager dashboard

E. Container Monitoring Solution: Since the application is deployed as the Docker container in all the store's virtual machines, it is important to monitor the container status to know whether the Data Collector module is running or not. Since the custom module is extracting the store executive controller's sensor values, continuous monitoring is important to that custom module.

Edge Hub is playing a crucial role in restarting the custom modules with the help of Edge Agent.

Containers packing the application and all dependencies and uses the standard run time environment to run the custom modules.

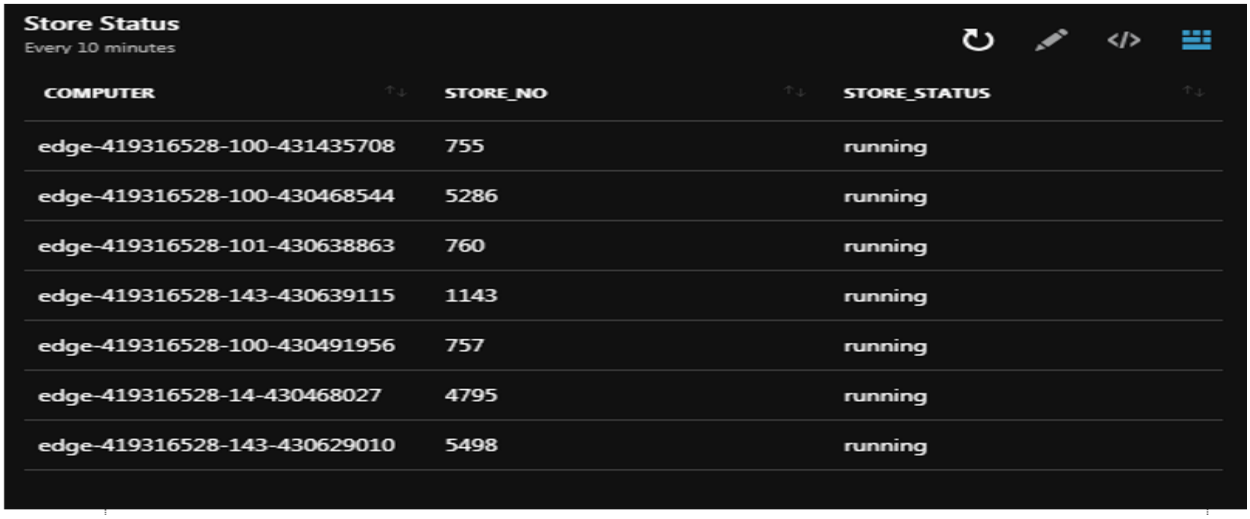

Fig 14. Snapshot showing the container status of Data Collector Modules in different stores.

IV. Conclusion

A detailed study was carried out on the existing on-premise system before designing the Azure cloud environment solution. Since the huge volume of data coming from the store's Building Management System, storing them in a centralized IoT system with Azure services' help to address the emergency events will be suitable. With this solution, most of the store's alerts can be addressed with an automated work order system without manual intervention.

Since the functionalities are shared between Edge and Cloud platform, the performance of the proposed system is improved. Decision-making process activities are carried at IoT Edge environment, cold data processing, and finding the business insights from the multiple stores around the world is carried at the cloud environment. Since the applications are deployed as the Docker containers from the centralized place using a single Docker image, configurations like store IP, executive controller type, store info, and edge configurations are kept at initialization level without affecting the container's docker image.

Any emergencies from the HVAC and refrigeration systems of the store are sent as an alert to the event management system to address those issues by the technician. Thus the systems attempt to solve the crash in the controller, phase loss, issue in emergency power back-up, communication loss to the system.

V. FUTURE WORK

Since the solution is a cloud-based system, there is a lot of scope for future work. Electrical grids can be loaded less when the energy costs are peak with the cloud to the device mechanism. Set of stores from the selected region can increase the setpoint value without affecting the customer comfort level so that energy consumption will be less and result in reduced carbon emission and as well as dollar savings.

Any store-level activities like monitoring the store's daily defrost schedules, parking lot lighting control will boost the energy savings; these edge applications get their own schedules from cloud UI application where the energy manager can set the values for a group of stores from a central place. He could select multiple stores and apply setpoints from the UI.

Even though watchdog modules are monitoring the Data Collector Module to check the pattern of sensor or setpoint extraction from the store controller, more container monitoring solutions from Azure Operational Management Suite will help leaders to monitor the edge applications. Log mining services are much useful to extract meaningful insights from the edge logs and custom modules logs.

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