DIGITAL TWIN FOR WAREHOUSE MANAGEMENT

J-COMPONENT PROJECT REPORT

Submitted in partial fulfilment for the course

MEE2013 - MODELLING AND SIMULATION OF MANUFACTURING SYSTEMS

In

Mechanical Engineering

By

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School of Mechanical Engineering

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DECLARATION

I the undersigned solemnly declare that the project report on the topic “BUILDING A DIGITAL TWIN FOR WAREHOUSE MANAGEMENT” is based on my work carried out during the course of my study under the supervision of Dr. Rajyalaxmi G, Senior Associate Professor, School of mechanical engineering VIT. I assert the statements made and the conclusions that are drawn are outcomes of my research work. I further certify that the work contained in the report is original and has been done by me under the general supervision of my supervisor. The work has not been submitted to any other Institution for any other degree/diploma/certificate in this university or any other University of India or abroad. I have followed the guidelines provided by the university in writing the report. Whenever I have used materials (data, theoretical analysis, and text) from other sources, I have given due credit to them in the text of the report and given their details in the references.

Ishani Mishra (20BME0136)

ABSTRACT

Digital Twins possess the capability for safer and more efficient engineering systems, equip us with a greater understanding of the natural world around us, realise better medical outcomes for all of us as individuals. Data collection from an entity, human, machine or enterprise, are personalized. These data are assimilated and the digital models are updated. Powerful statistical and mathematical tools are used to interpret the data and make predictions and recommendations that are tailored to the entity. This project is an attempt to understand the ease of building a simple digital twin of trailer trucks for smooth warehouse and inventory management. This basic model can be extended to a much more large and complex system. Furthermore, a layer of machine learning and AI can add features such as predictive maintenance and providing optimized solutions to real world systems.

ABBREVIATIONS

DT - Digital Twin

DTP - Digital Twin Prototype

DTI - Digital Twin Instance

DTA - Digital Twin Aggregate

RPA - Robotic Process Automation

BIM - Building simulation modelling

API - Application programming interface

RBAC - Role based access control

DTDL - Digital twin definition language

INTRODUCTION

Digital twin

Dr. Michael Grieves provided the first characterization of the digital twin concept in the Society of manufacturing engineers conference in Troy, Michigan, 2002. He introduced DT as the conceptual model underlying product lifecycle management. Next, in 2010 roadmap report, John Vickers of NASA pointed out that a DT consisted of three components, a physical product in real space, a virtual representation of that product in the virtual space and the connections of data and information that tie the virtual and real products together. Digital twins are digital replicas of real-world things, places, business processes, and people.

Idealized representation of physical reality

It is recognized that any attempt to model the physical reality requires the idealization of that reality based on some level of abstraction. These idealizations often take the form of data models (data structures) and/or behaviour models (mathematical or computational models).

A data model refers to a data structure that retains all the variables describing the reality at the level of abstraction chosen.

Behaviour models refer to computational models that describe how the variables of interest relate to each other.

Basic working of DTs

The Digital Twin is constructed so that it can receive data as input from sensors which are a part of real-world counterpart. These data allow the twin to simulate the physical object in real time. Telemetry data from sensors is processed by an IoT platform where they are picked up and processed by DT functions. Some DT functions also listen to the data from IoT platform and calls an API to update the sensor property in the DT instance.

Simulation v/s DT v/s BIM

Simulation models project what can happen and not what is happening at the moment. The basic difference between simulation models and DTs is that in DTs there is bi-directional sync with the origin. Similarly, BIM isn't designed for real-time operational response. Moreover, the focus is on the building rather than the people.

LITERATURE SURVEY

Sl. No.	Name of the paper	Key findings	Scope for future work	Research gaps
1.	Models for warehouse management: classification and examples [6]	The combined problem of order sizing and delivery staggering is known as the economic warehouse lot problem (EWLSP). The forward-reserve problem (FRP) is the problem of deciding which products should be stored in the forward area and in what quantities. The storage location assignment problem (SLAP) concerns the assignment of incoming stock to storage locations.	In the food and retail sector, where many stores have moved towards just in time delivery, there is a constant pressure to improve response times of the warehouses. The introduction of electronic shopping and ordering will radically change the logistics of the supply chain and lead to a drastic change in inventory management. Trends such as cross-docking and electronic shopping are expected to remove some intermediate stages in the supply chain and lead to an, already observable, renewed interest in production warehouses as opposed to distribution warehouses.	The attention paid by researchers in the inventory theory to the management of storage systems such as warehouses has been relatively limited.

2.	Digital twin driven joint optimization of packing and storage assignment in large-scale automated high-rise warehouse product-service system. [7]	Optimization of warehouse system could be categorized into the design stage and operation stage. Variables at design stage involve material flow, department identification, size of warehouse, pallet block-stacking pattern, aisle orientation, number, length and width of aisle, door locations, storage equipment selection, material handling equipment selection, storage selection, and order picking method selection. The variables in operation optimization include assignment, space allocation, truck dispatch schedule, batch size, routing and sequencing of order picking tours. Studies show that order picking is the costliest among the warehousing activities. Optimization of packing is tightly coupled with the warehousing optimization. This framework can realise the validating and on-line testing of decisions/ solutions.	Based on the analysis of the system's overall operating efficiency, the bottleneck reduction model of the warehouse product-service system should be established in future.	1. The proposed digital twin system lacks an analysis of the physical random disturbance on system robustness. 2. Failure at a station not only leads to the warehousing stagnation at this stage but also propagates even to the entire warehouse product-service system. The bottleneck prediction and reduction model of the warehouse should be established based on the deep learning and data mining analysis of the operating efficiency, and then various indicators of the warehouse product-service system can be further adjusted and optimized iteratively.
3.	A warehouse management system with UAV based on digital twin and 5G technologies. [8]	Ali cloud is used as a data processing centre. Core means of communication is 5G. Flight and cargo information are sent to cloud and then to digital twin platform for a real time warehouse data and visual feedback. At the same time, the instructions are sent to the entity warehouse to control the UAVs through cloud. This real-time remote control of the UAV, realizes the two-way data exchange between virtual and real platform. UAV equipped with 5G communication module, which greatly reduces the delay compared with the existing logistics robots using 4G communication module.	Due to the mode of cloud platform + remote monitoring, the labour cost of the whole warehouse management system is greatly reduced. In the later stage it is expected to use digital twin combined with 5G to realize the remote monitoring operation.	Cost reduction of such system.
4.	Digital Twin: Generalization, characterization and implementation [9]	Generalized definition of digital twins: a virtual representation of a physical system (and its associated environment and processes) that is updated through the exchange of information between the physical and virtual systems. The design and implementation of a digital twin, including the details of its components, should be driven by desired outcomes.		1. Some challenges to digital twin implementation are technical in nature and can be resolved through continued research and development. 2. Digital twin implementations require the incorporation of a variety of different enabling technologies, and bringing these technologies together is still an ongoing challenge.
5.	Smart Warehouse Management System: Architecture, Real-Time Implementation and Prototype Design. [10]	The proposed IoT-based WMS can manage a complex and integrated supply chain network by modelling it into simpler architectures that are equally understandable by the developers, as well as the business stakeholders. The prototype system integrated with IoT was successfully deployed within a textile factory's warehouse. The successful deployment and the performance parameter results showed an overall efficiency of up to 88% compared to previous architecture.	The architecture can be extended to include external stakeholders integrating them into the system and provide efficient tracking and visibility. The system security can be improved by adding authentication and decryption algorithms.	
6.	Investigation of UHF Signal Strength Propagation at Warehouse Management Applications Based on Drones and RFID Technology Utilization. [11]	Utilization of UHF RFID technology in combination with UAV was successfully realized. This work focused on finding an optimal flight level as a compromise between the reliability and accuracy of identification on one hand and easy flight control and safety on the other.	This methodology can be also used for BAP (battery assisted passive) tags that offer much longer reading distances.	
7.	An efficient key-less RFID Authentication on protocol based on ECDLP for consumer warehouse management system. [12]	Elliptic curve cryptography-based authentication scheme for RFID environment has emerged as a very safe, secure and robust candidate for mutual authentication. This scheme is primarily aimed at efficient implementation of authentication in warehouse management systems. Computation cost, memory space and storage costs are all reduced to a great extent, both in the tag and the server.		
8.	Toward the next generation of digitalization in agriculture based on digital twin paradigm. [13]	Deployment of state-of-the-art technologies like AI, advanced statistical and optimization models, big data analytics, and three-dimensional simulation will offer innumerable possibilities in farm management. With real time data flow about agricultural assets, the virtual models can predict and address unseen issues in the fields.	Further attempts need to be considered towards developing a twin model for predicting and prescribing the best decision for farm management.	DT concepts in agriculture and food processing have been exploited very little in research. Researchers can explore methods to track and monitor crop farm machinery, agricultural and post-harvest products or reduce water, chemicals, and energy usage in digital farming.
9.	Smart water management using intelligent digital twins. [14]	Framework based on multi-agent systems and DT paradigm to close the gaps within the loop of data acquisition and processing as well as asset control, service generation and delivery. Five layered architecture includes physical layer, control layer, DT layer, application layer, and advising layer.	This multi-agent system showed its capabilities in managing the data collected, identifying the appropriate pricing policies, and generating the relevant outputs to the customer. He future work will focus on realising these functions and test them in a test bed setup.	The use of DT in the field of water management remails limited.
10	Digital twins in smart farming. [15]	A conceptual framework comprising of a control model based on a general systems approach and an implementation model for DT systems based on the IoT-A was proposed.	Further elaboration of this conceptual framework into an information architecture framework consisting of a consistent set of architectural viewpoints for modelling DT-based software systems.	
11	AgriLoRa: A digital twin framework for smart agriculture. [16]	AgriLoRa consists of a wireless sensor network established in the farmland and cloud servers that run computer vision algorithms to detect plant diseases, weed clusters and plant nutrient deficiencies.	The proposed model will lay the ground for exciting research in IoT-based sustainable smart agriculture, by design and development of a framework that digitally represents a farm field to enable constant monitoring of soil parameters, automated detection of crop diseases and prescription of fertilizer treatment plans to achieve high yields at low cost.	Farmers who live in developing countries don't have access to hardware and the maintenance cost associated with is difficult to manage.

12	Digital twin-based reference architecture for petrochemical monitoring and fault diagnosis. [17]	The DT technology can be used to improve fault monitoring, fault analysis, and fault prediction technologies. The paper proposed a method to decompose structures from top to bottom and construct them from bottom to top to avoid complications by involving too many parameters.	As the concept of DT attains maturity, it can be expected that the advancement of IT and other technologies associated with DT will gain rapid development in the field of petrochemical industry.	
13	Simulation ready digital twin for real time management of logistics systems. [18]	The proposed architecture is a split of static and dynamic parts of the model making past, present and future of the logistics system efficiently available for decision support in the same semantic and syntactic data model.	Empty DT will be allowed to collect data for an adequate span of time and that data will be used to tarin artificial neural networks that can replace the controller in the simulation.	Efficient integration of event-discrete simulation into a digital twin architecture in real-time logistics use cases.
14	Simulation-based decision support tool for in-house logistics: the basis for a digital twin. [19]	A simulation-based decision support tool is proposed for in-house logistics. It analyses the activities that occur in both a distribution facility and a production facility. Fields like real-time information, intelligent autonomous vehicles, and a flexible and lively operations environment were integrated and explored.	Developing the complexity of the models by analysing more deeply different case studies still remains unexplored.	Integrating these models in the complete DT tool and addressing all the solutions is still difficult to achieve.
15	Blockchain-based digital twin sharing platform for reconfigurable socialized manufacturing resource integration. [20]	This work proposed a blockchain-based DT sharing platform to enable software copyright protection and simplify heterogeneous manufacturing resource integration in decentralized and distributed environments. The encapsulation granules for DTs are innovatively defined and implemented in this model. These can be migrated to wrap more kinds of software entities that need to be implemented over different runtimes.	This approach of using blockchain technology in DTs can be further improved to enable potential commercialization of open-source software.	A measurement system is need to quantify the contributions of DTs as a basis to distribute the potential benefits from DT sharing and transactions.

PLATFORM AND METHEDOLOGY

Available platforms:

1. Ansys Twin Builder
2. Autodesk Digital twin
3. Azure digital twin
4. Siemen's - Simcentre digital twin includes a wide range of dedicated solutions that are specifically designed to support various areas of space 4.0.

Digital twin software features:

1. An integrated IoT device management software for remote asset monitoring.
2. Predictive maintenance and analytics.
3. IoT prototyping and a virtual model.
4. Event simulations

Tech stack - Software and services related to digital twin software:

1. Prior to integrating factory machines into an IoT environment, manufacturers and equipment suppliers may utilize this tech stack to create blue prints.
2. Computer aided manufacturing software or CAM tools allow users to program the production operations using existing CAD models of machines in question, then deliver this workflow information to the machines as needed.
3. Manufacturing execution systems are tools that may allow for the creation of production plans and schedules along with the allocation of resources, both human and material.
4. IoT analytics software helps make sense of the continuous data flow from sensors.

Methodology

The platform selected for this project is *Azure Digital Twins*. "ADT is a platform as a service (PaaS) offering that enable the creation of twin graphs based on digital models of entire environments, which could be buildings, factories, farms, energy networks, railways, stadiums, and more - even entire cities." - https://learn.microsoft.com/en-us/azure/digital-twins/overview

Functionalities that can be achieved with this platform are spatial intelligence graph, harness IoT devices, RBAC and tenancy support, and rich integration.

Digital Twin Architecture:

DT has APIs, shared resources, and instances. APIs include Management API, Twin API, Thing API, Twin-to-Twin API. The instances contain instance state, instance log of events, instance context data, instance graph references. Shared resources include Metadata (rules, models, Id), Stream analysis/learning, adapters, quality, integration, security, identity, and custom code. The thing API sends and receives telemetry data from physical things and the twin API helps in data flow to information systems.

Setting up ADT:

https://www.youtube.com/watch?v=m1MdmPQZSaM&t=1s

EXPERIMENTAL WORK

A trailer is a container on wheels pulled by a car or another vehicle used to transport large or heavy cargo. In this project, a twin is made to monitor the temperature of the goods in a trailer truck and create alert if and when temperature exceeds the required limit. This live monitoring will help take optimized decisions about the future fleets.

One of the pre-requisites that are required for the making an ADT is the ability to run .NET code for the device simulators and the azure function to ingest data. The tools that are used to complete the project are Azure CLI (could be optional), DTDL Validator, Azure IoT explorer, The ADT explorer.

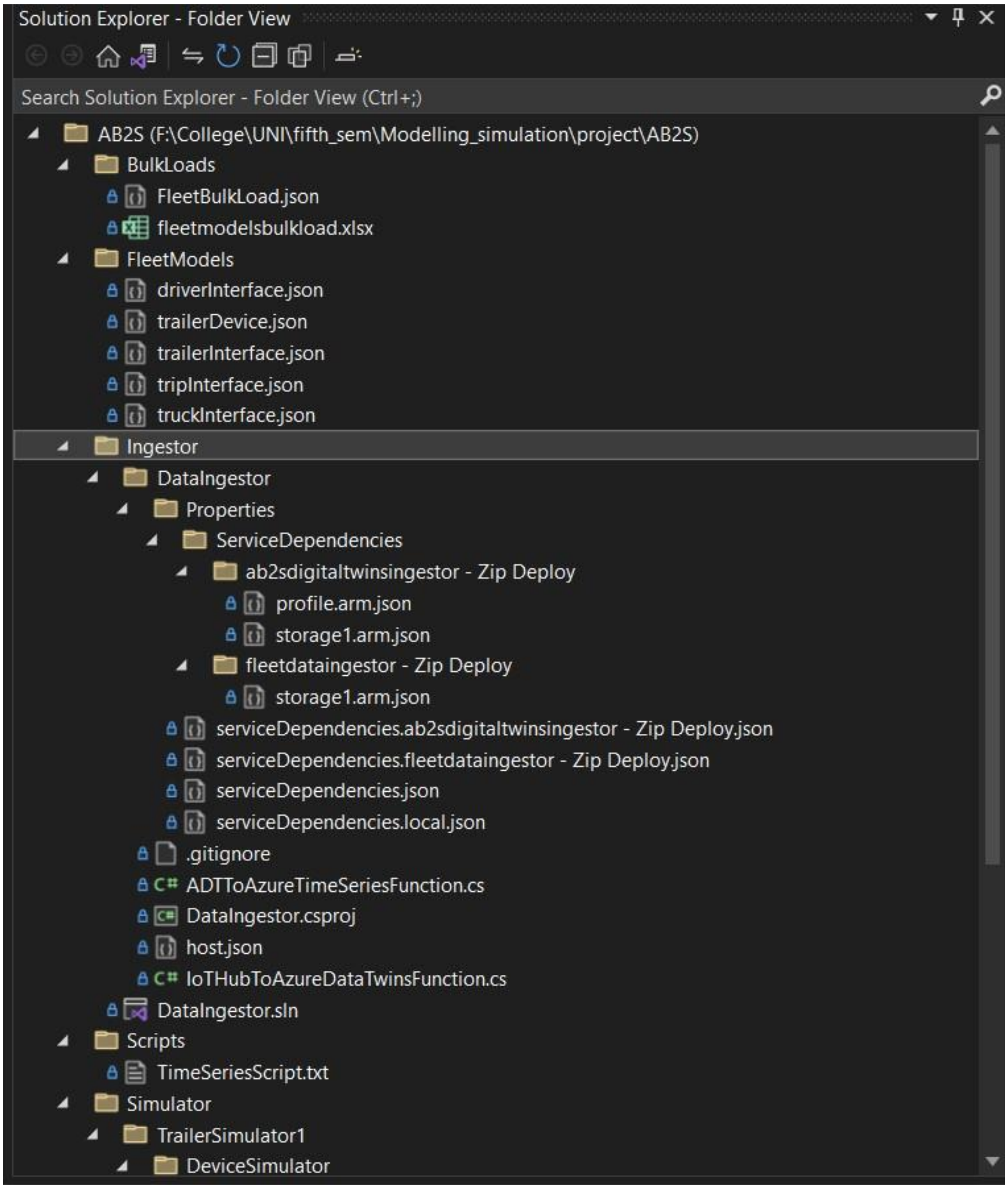
An azure digital twin instance was created on the Azure portal. An IoT Hub was created. Next, digital models of the real-life systems were made. The following models were created, a truck with an ID and a location, a trailer with an ID, a temperature, a location and a temperature alert. Only the temperature and temperature alert are simulated in this project. A driver model is made with an ID and a name. A trip model which has a driver, a truck, and a trailer.

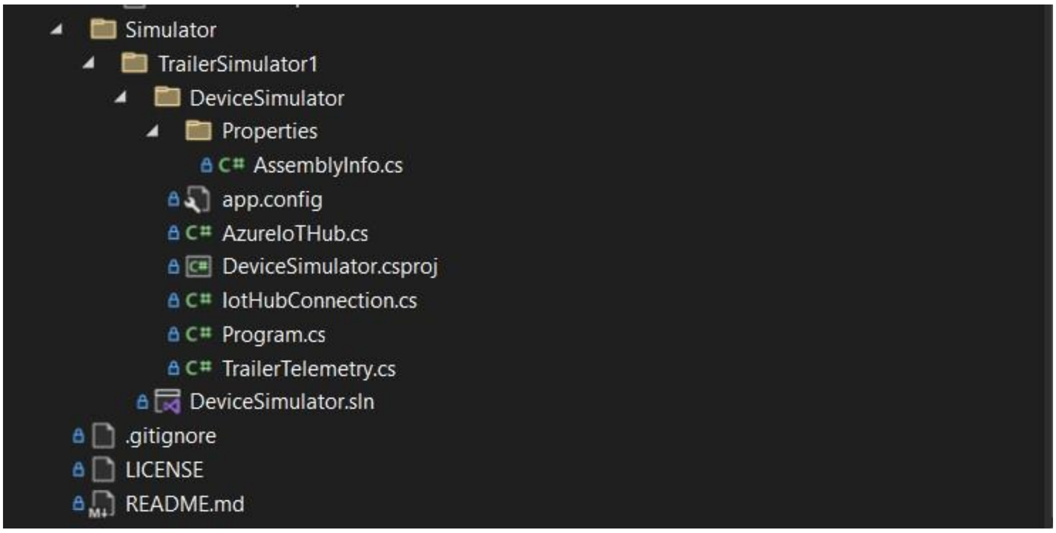
After the models are created, the DTDL validator is used to validate the syntax so that we don't end up deploying resources that have definition problems as it will be very difficult to track those down later.

The IoT ADT Explorer was built out locally. Devices were added from the IoT Hub at Azure in the portal. Then the simulators were loaded to simulate the devices by connection string.

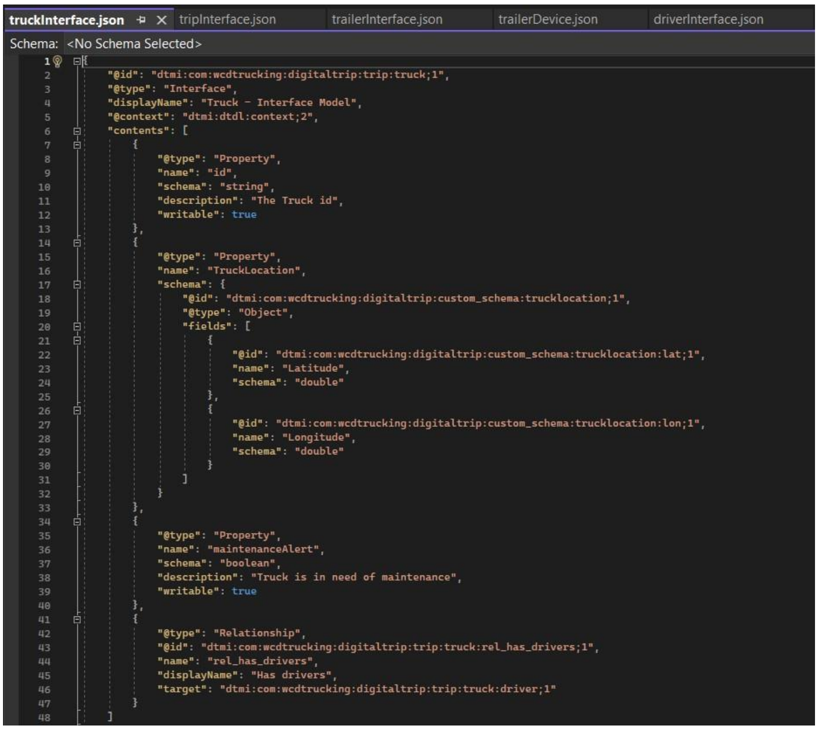
An Azure Function app was built with a managed identity for authentication to the ADT instance. The function app is configured such that the app connects to the ADT environment. Now, the function app code is ready to be published. The function app code is deployed into the azure function app. An event grid trigger is created from the function app. The simulators are put into action and the data streams start flowing in. The twins are updated with the real-time data from the sensors.

Folder Structure:





Model Definitions:

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{
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    "@type": "Interface",
    "displayName": "Truck - Interface Model",
    "@context": "dtmi:dtdl:context;2",
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            "@type": "Property",
            "name": "id",
            "schema": "string",
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                    }
                ]
            }
        },
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            "name": "maintenanceAlert",
            "schema": "boolean",
            "description": "Truck is in need of maintenance",
            "writable": true
        },
        {
            "@type": "Relationship",
            "@id": "dtmi:com:wcdtrucking:digitaltrip:trip:truck:rel_has_drivers;1",
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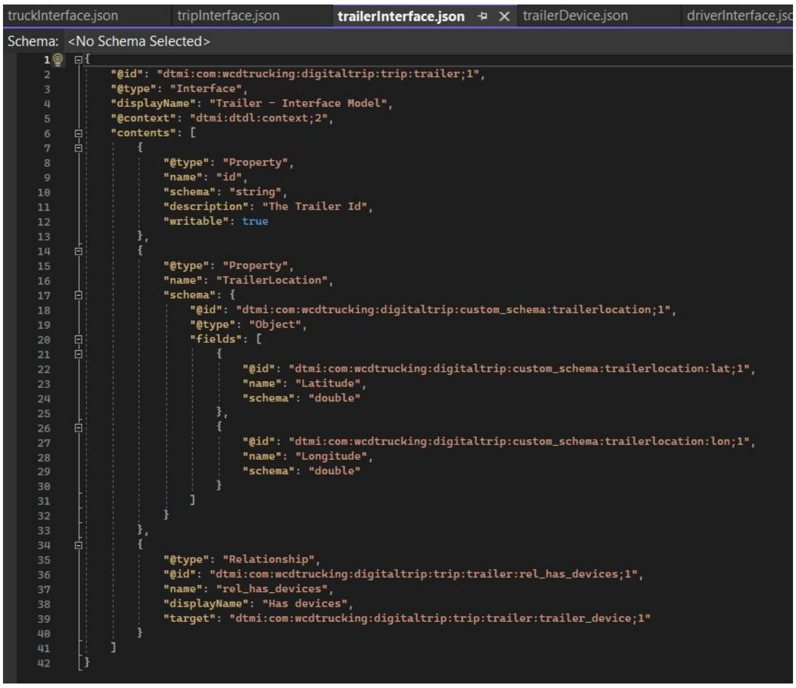
        }
    ]
```




```json
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    "@context": "dtmi:dtdl:context;2",
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            "@type": "Property",
            "name": "id",
            "schema": "string",
            "description": "The Trailer Id",
            "writable": true
        },
        {
            "@type": "Property",
            "name": "TrailerLocation",
            "schema": {
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                "@type": "Object",
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                        "schema": "double"
                    },
                    {
                        "@id": "dtmi:com:wcdtrucking:digitaltrip:custom_schema:trailerlocation:lon;1",
                        "name": "Longitude",
                        "schema": "double"
                    }
                ]
            }
        },
        {
            "@type": "Relationship",
            "@id": "dtmi:com:wcdtrucking:digitaltrip:trip:trailer:rel_has_devices;1",
            "name": "rel_has_devices",
            "displayName": "Has devices",
            "target": "dtmi:com:wcdtrucking:digitaltrip:trip:trailer:trailer_device;1"
        }
    ]
}
```

truckInterface.json | tripInterface.json | trailerInterface.json | **trailerDevice.json**

Schema: <No Schema Selected>

```json
{
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    "@id": "dtmi:com:wcdtrucking:digitaltrip:trip:trailer:trailer_device;1",
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            "name": "id",
            "schema": "string",
            "description": "Device Id",
            "writable": true
        },
        {
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            "name": "temperature",
            "schema": "double",
            "description": "Current measured temperature",
            "writable": true
        },
        {
            "@type": "Property",
            "name": "temperatureAlert",
            "schema": "boolean",
            "description": "outside of desired temperature alert",
            "writable": true
        }
    ]
}
```

truckInterface.json | **tripInterface.json** | trailerInterface.json | trailerDevice.json

Schema: <No Schema Selected>

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{
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            "name": "TripId",
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            "writable": true
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        {
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            "name": "rel_has_trucks",
            "displayName": "Has trucks",
            "target": "dtmi:com:wcdtrucking:digitaltrip:trip:truck;1"
        },
        {
            "@type": "Relationship",
            "@id": "dtmi:com:wcdtrucking:digitaltrip:trip:rel_has_trailers;1",
            "name": "rel_has_trailers",
            "displayName": "Has trailers",
            "target": "dtmi:com:wcdtrucking:digitaltrip:trip:trailer;1"
        }
    ]
}
```

truckInterface.json | tripInterface.json | trailerInterface.json | trailerDevice.json | **driverInterface.json**

Schema: <No Schema Selected>

```json
{
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    "displayName": "Driver - Interface Model",
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            "name": "id",
            "schema": "string",
            "description": "Truck Driver Id",
            "writable": true
        },
        {
            "@type": "Property",
            "name": "Name",
            "schema": "string",
            "description": "Truck Driver Name",
            "writable": true
        }
    ]
}
```
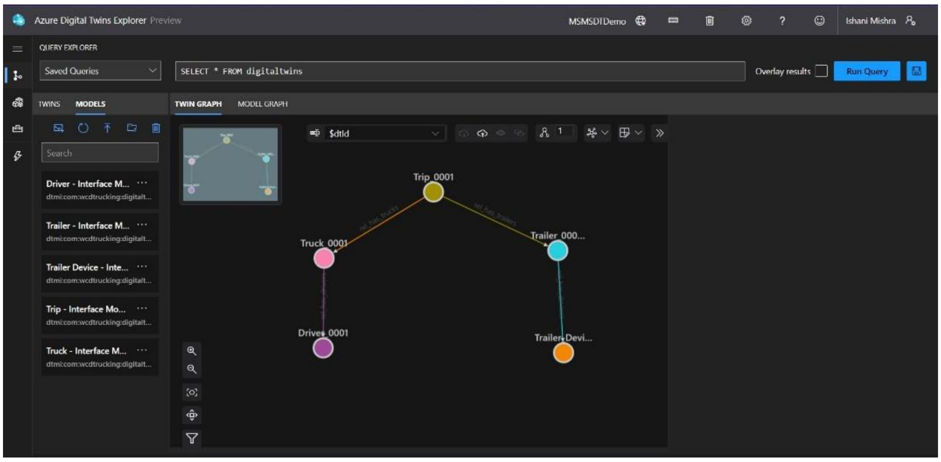
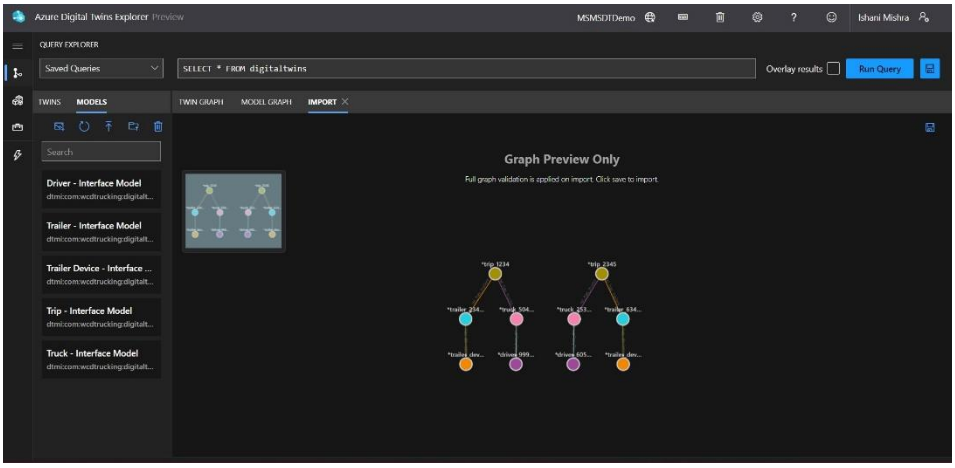
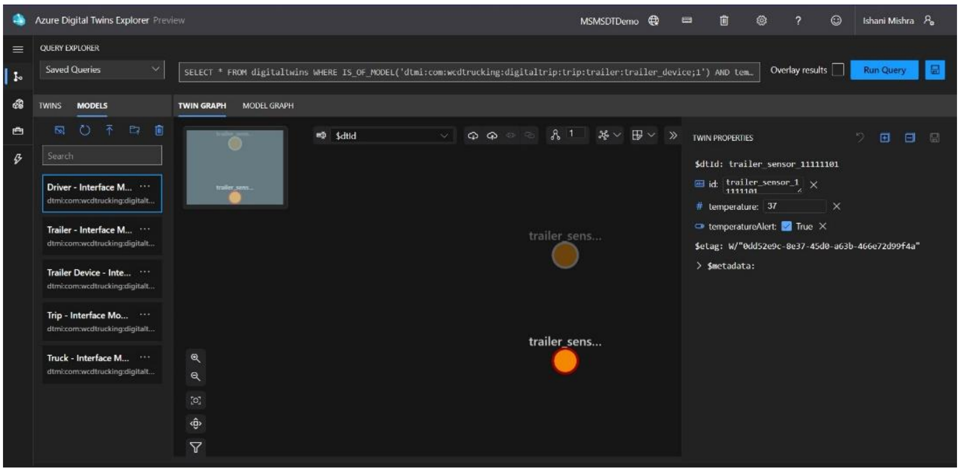
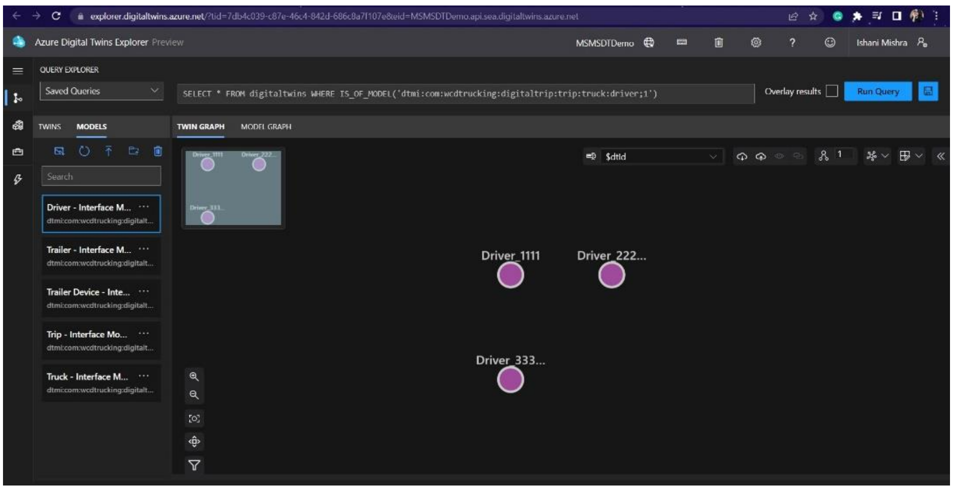
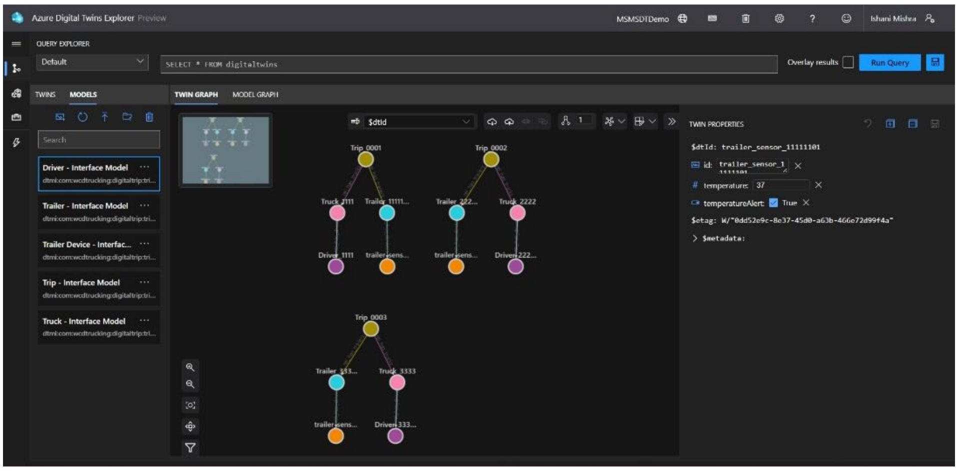

Importing models and query:










Azure Digital Twins Explorer Preview
MSMSDTDemo
Ishani Mishra
QUERY EXPLORER
Default
SELECT * FROM digitaltwins
Overlay results
Run Query
TWINS
MODELS
TWIN GRAPH
MODEL GRAPH
TWIN PROPERTIES
Driver - Interface Model
Trailer - Interface Model
Trailer Device - Interfac...
Trip - Interface Model
Truck - Interface Model
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temperatureAlert: True
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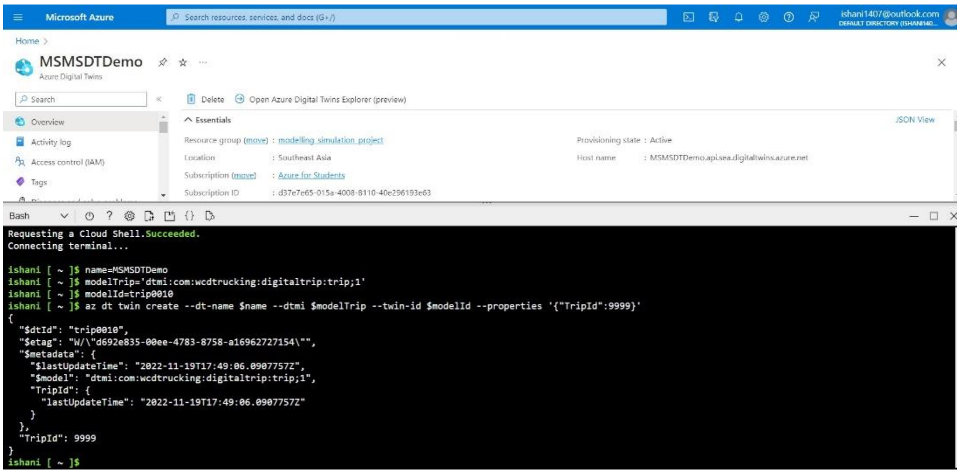
Trip_0001
Trip_0002
Trip_0003


Microsoft Azure
Search resources, services, and docs (G+/)
ishani1407@outlook.com
Home
MSMSDTDemo
Azure Digital Twins
Delete
Open Azure Digital Twins Explorer (preview)
Essentials
JSON View
Resource group (move) : modelling_simulation_project
Location : Southeast Asia
Subscription (move) : Azure for Students
Subscription ID : d37e7e65-015a-4008-8110-40e296193e63
Provisioning state : Active
Host name : MSMSDTDemo.api.sea.digitaltwins.azure.net
Overview
Activity log
Access control (IAM)
Tags
Bash
Requesting a Cloud Shell.Succeeded.
Connecting terminal...
ishani [~]$ name=MSMSDTDemo
ishani [~]$ modelTrip='dtmi:com:wcdtrucking:digitaltrip:trip;1'
ishani [~]$ modelId=trip0010
ishani [~]$ az dt twin create --dt-name $name --dtmi $modelTrip --twin-id $modelId --properties '{"TripId":9999}'
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},
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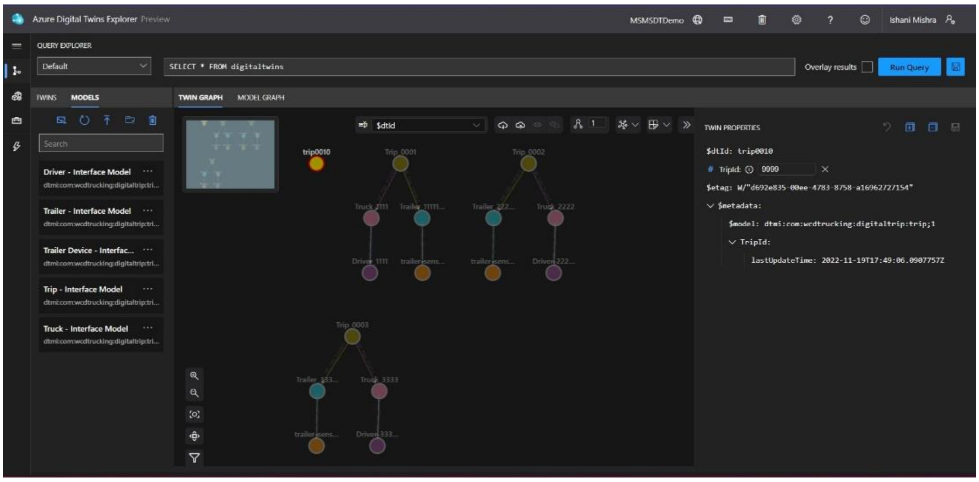
}
ishani [~]$


Azure Digital Twins Explorer Preview
MSMSDTDemo
Ishani Mishra
QUERY EXPLORER
Default
SELECT * FROM digitaltwins
Overlay results
Run Query
TWINS
MODELS
TWIN GRAPH
MODEL GRAPH
TWIN PROPERTIES
Driver - Interface Model
Trailer - Interface Model
Trailer Device - Interfac...
Trip - Interface Model
Truck - Interface Model
$dtId: trip0010
TripId: 9999
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$metadata:
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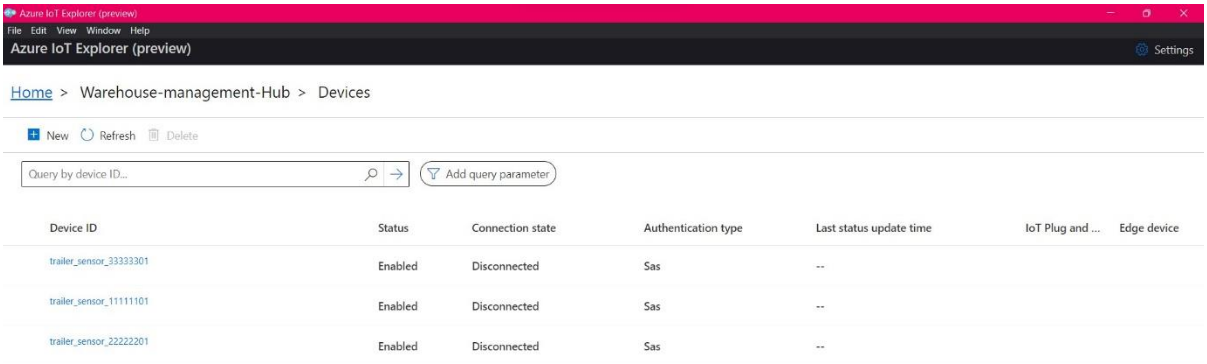
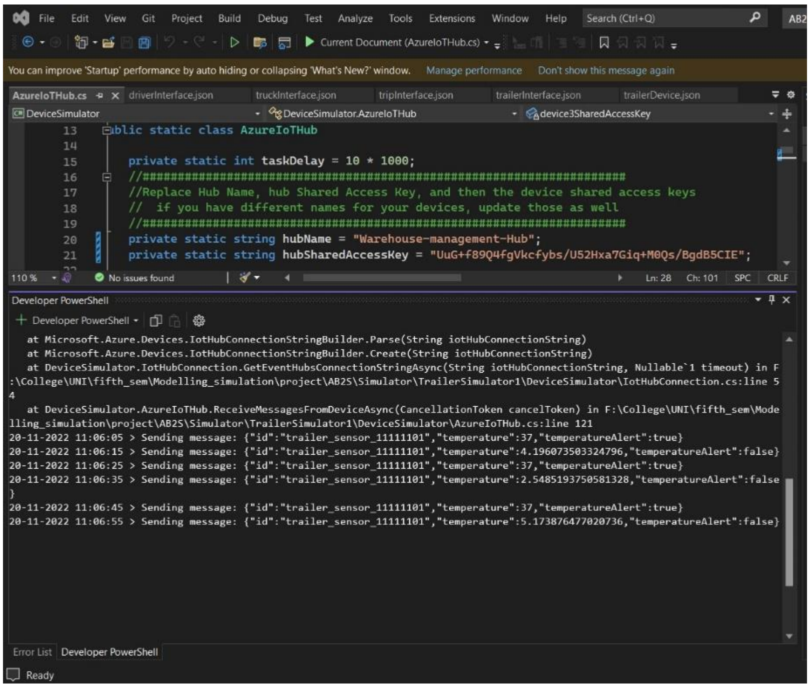
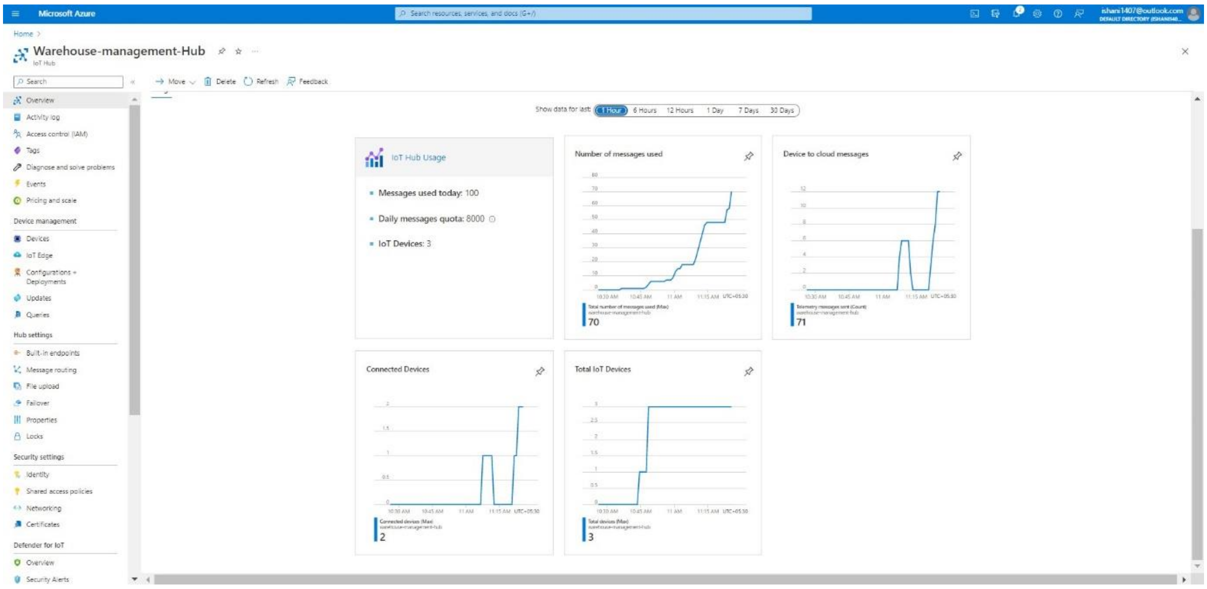
TripId:
lastUpdateTime: 2022-11-19T17:49:06.0907757Z
trip0010
Trip_0001
Trip_0002
Trip_0003

Azure IoT Hub:

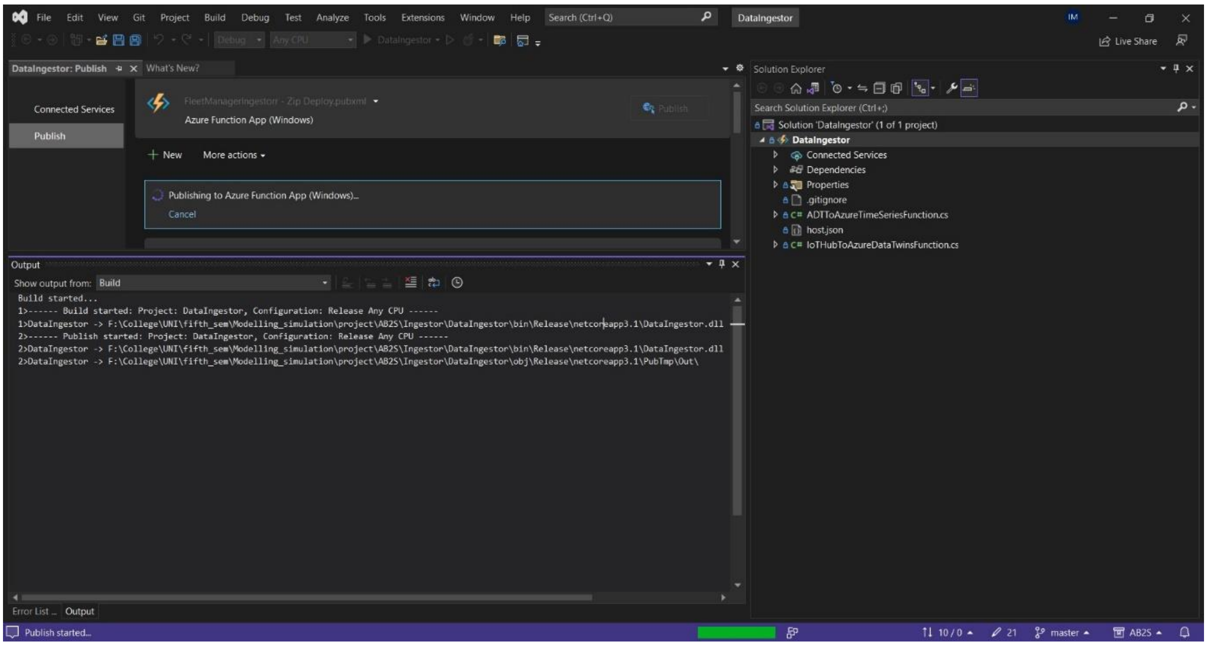
```csharp
public static async Task SendDeviceToCloudMessageAsync(CancellationToken cancelToken)
{
    var deviceClient = DeviceClient.CreateFromConnectionString(deviceConnectionString);

    double avgTemperature = 2.0D;
    var rand = new Random();

    while (!cancelToken.IsCancellationRequested)
    {
        double currentTemperatureLocal = avgTemperature + rand.NextDouble() * 4;

        if (DateTime.Now.Millisecond % 2 == 0)
        {
            currentTemperatureLocal = 37.0D;
        }

        var telemetryDataPoint = new TrailerTelemetry
        {
            id = deviceId,
            temperature = currentTemperatureLocal,
            temperatureAlert = currentTemperatureLocal > 30.0D
        };
        var messageString = JsonSerializer.Serialize(telemetryDataPoint);

        var message = new Microsoft.Azure.Devices.Client.Message(Encoding.UTF8.GetBytes(messageString))
        {
            ContentType = "application/json",
            ContentEncoding = "utf-8"
        };
        await deviceClient.SendEventAsync(message);
        Console.WriteLine($"{DateTime.Now} > Sending message: {messageString}");

        //Keep this value above 1000 to keep a safe buffer above the ADT service limits
        //See https://aka.ms/adt-limits for more info
        await Task.Delay(taskDelay);
    }
```

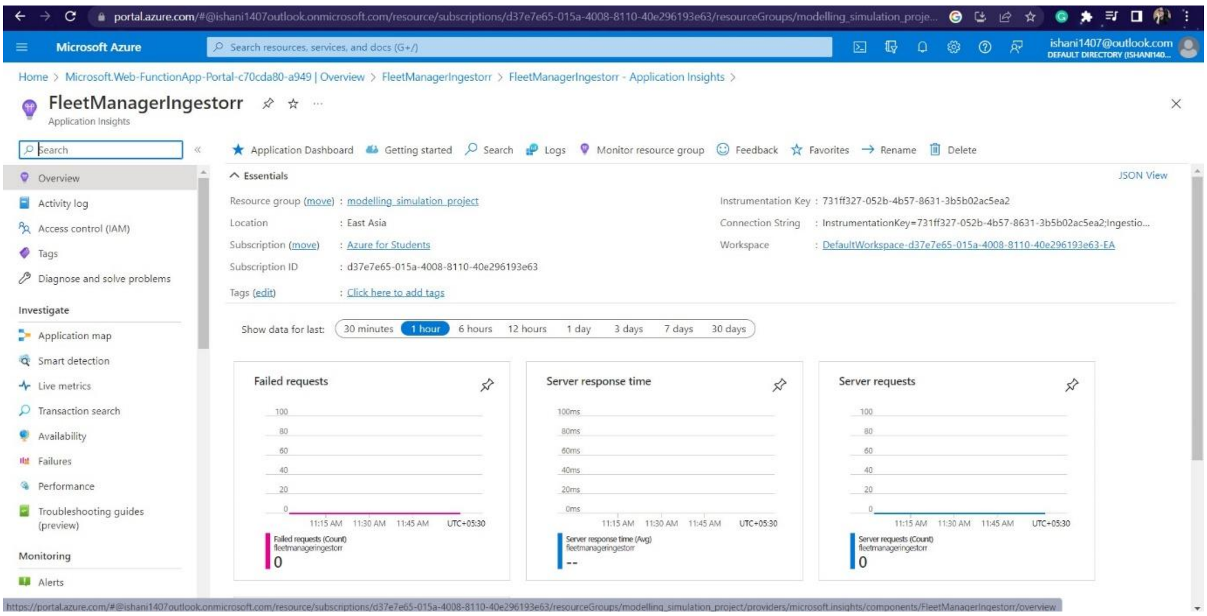




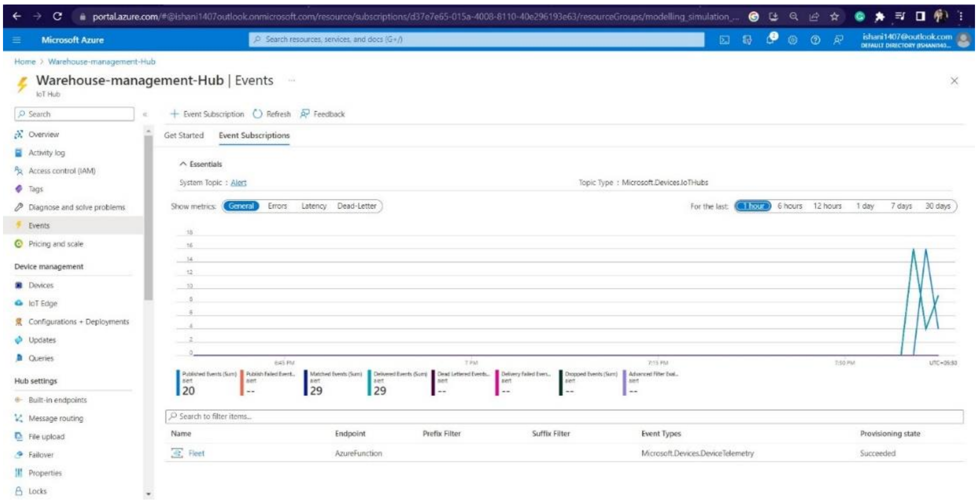


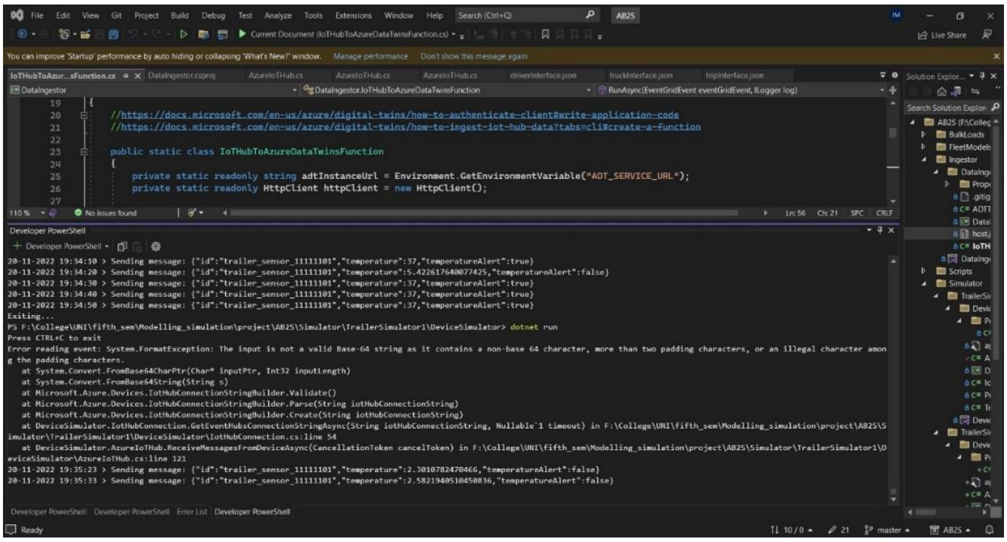
Deploying the function app:

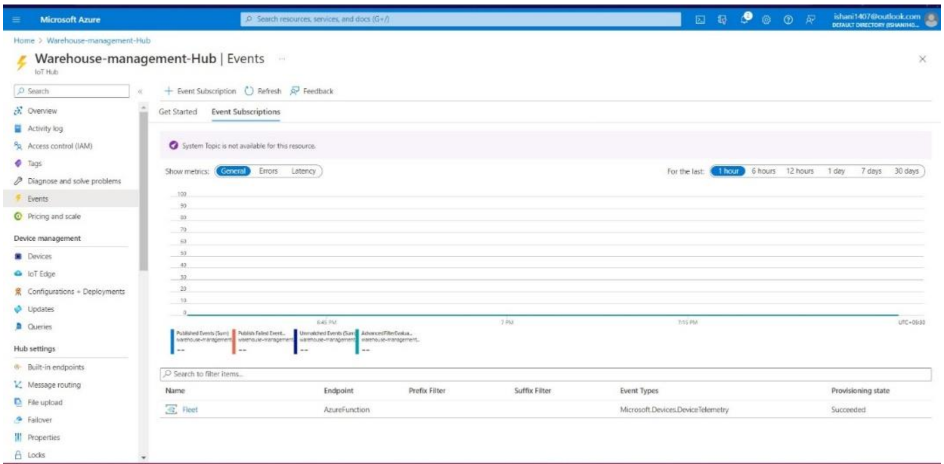




Making an event:



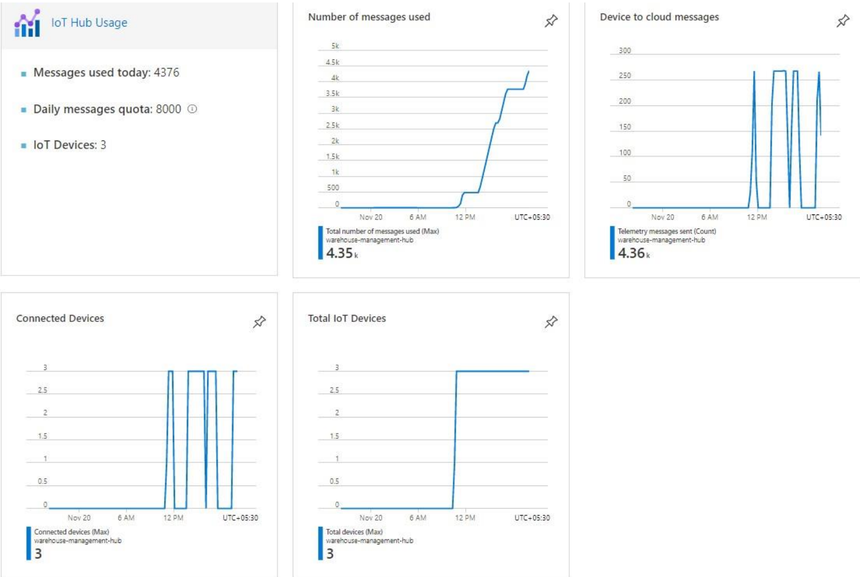


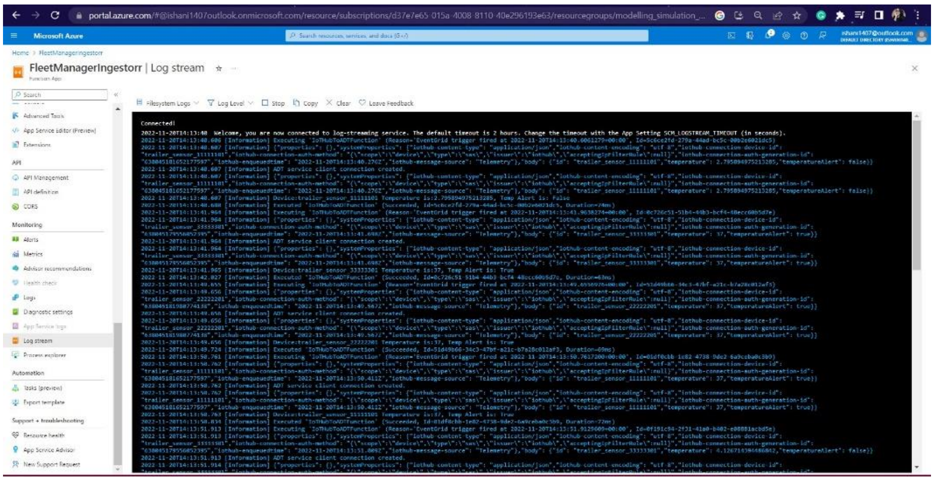


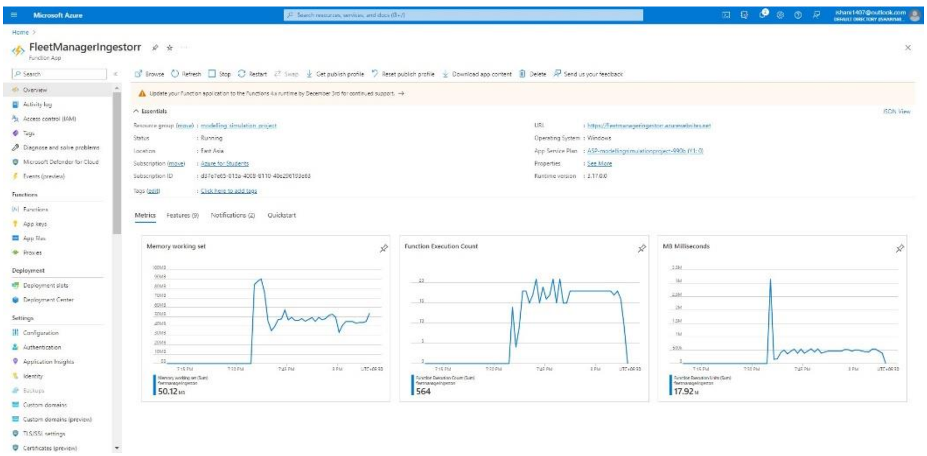
RESULTS AND DISCUSSION

The following repository contains the codes of the models and the simulators used.

https://github.com/Ishani-Mishra/DigitalTwin.git







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