Configuration Manual

MSc Research Project
Cloud Computing

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MSc Project Submission Sheet

School of Computing

Student Name:	Bharadwaj Kante		
Student ID:	23325666		
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Lecturer:	Prof. Sean Heeney		
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Date:	15/09/2025

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Configuration Manual

Bharadwaj Kante

Student ID: 23325666

1. Introduction

This configuration manual provides everything needed to reproduce the smart-traffic Digital Twin (DT) MVP:

- Real-time telemetry via Azure IoT Hub
- Stream ingestion via Event Hub–compatible endpoint
- Twin updates in Azure Digital Twins (ADT)
- A lightweight predictor and controller writing back to the twin

You can run the entire system from Azure Cloud Shell (Bash).

2. System Requirements

2.1. Hardware

- Any machine with a browser (to open Cloud Shell)
- Azure subscription (Azure for Students credit is sufficient)

2.2. Azure Services

- Resource Group (e.g., rg-dt-traffic-mvp)
- IoT Hub (S1 tier)
- Azure Digital Twins

2.3. Software (in Cloud Shell)

- Azure CLI (preinstalled)
- Azure IoT CLI extension
- Python 3 (preinstalled) + libs:
    - azure-iot-device, azure-eventhub, azure-digitaltwins-core, azure-identity

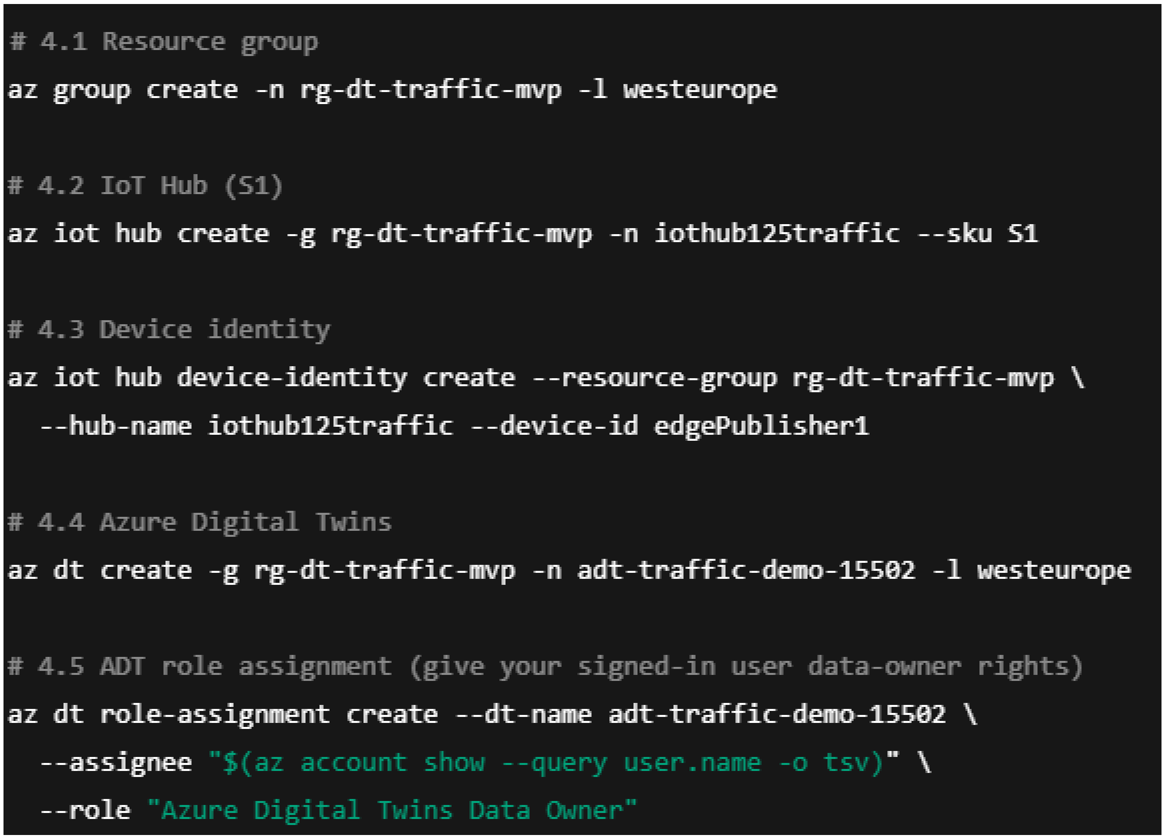
3. Folder Structure (Cloud Shell home)

~/ (home)

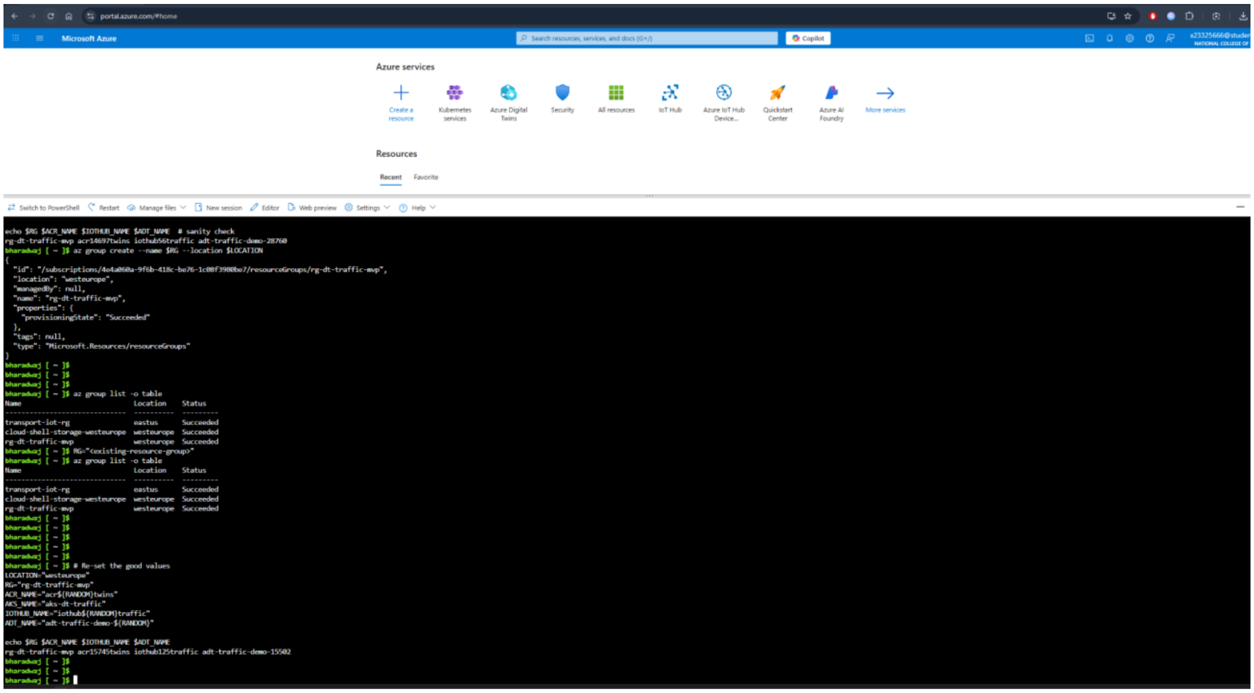
- vars.sh   # reusable environment variables
- junctionModel.json   # DTDL model
- publisher.py   # telemetry publisher
- ingest.py   # EventHub → ADT currentFlow patcher
- predictor.py   # rolling-mean predictor → predictedFlow5min
- control.py   # rule-based controller → signalPhase

4. One-Time (If project is started from scratch)

If you already created resources, skip to Section 5.

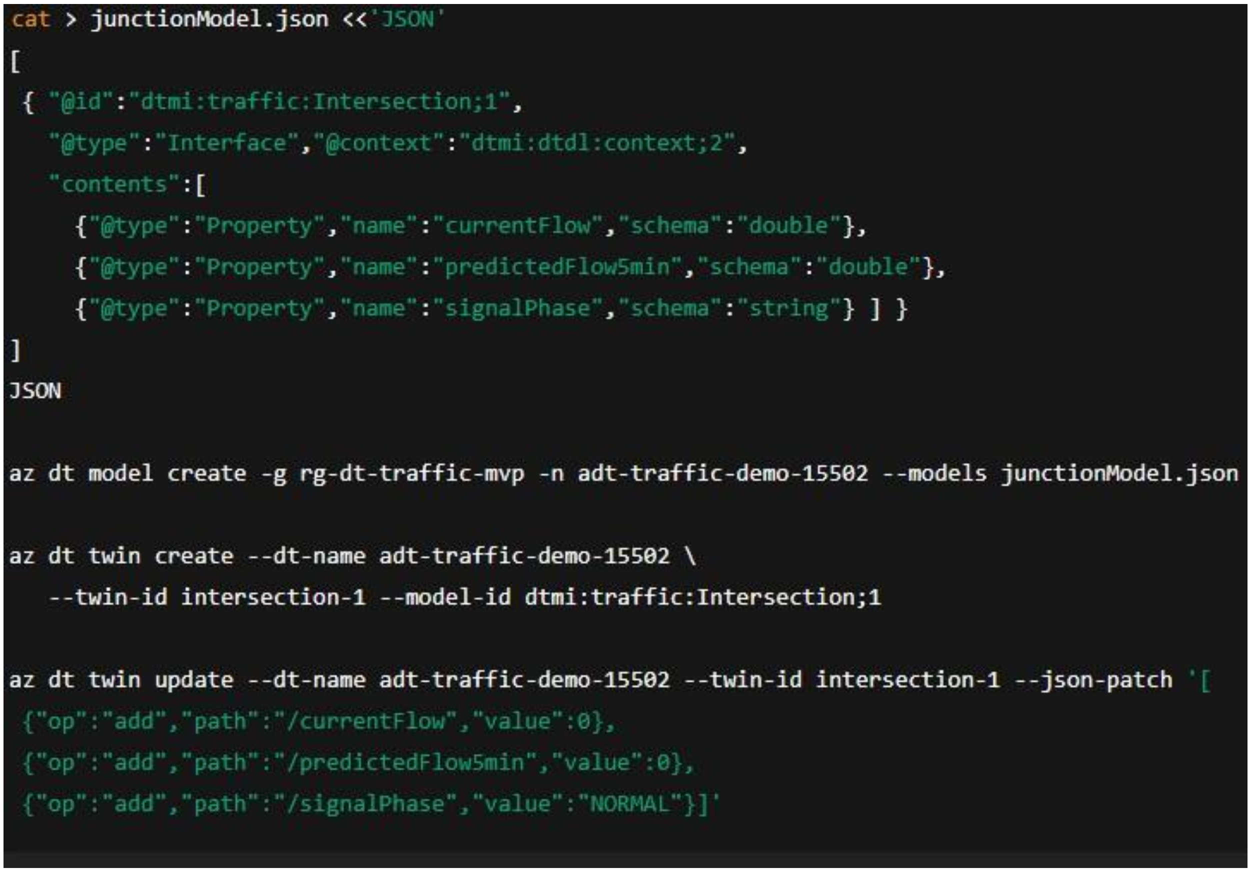


```
# 4.1 Resource group
az group create -n rg-dt-traffic-mvp -l westeurope

# 4.2 IoT Hub (S1)
az iot hub create -g rg-dt-traffic-mvp -n iothub125traffic --sku S1

# 4.3 Device identity
az iot hub device-identity create --resource-group rg-dt-traffic-mvp \
  --hub-name iothub125traffic --device-id edgePublisher1

# 4.4 Azure Digital Twins
az dt create -g rg-dt-traffic-mvp -n adt-traffic-demo-15502 -l westeurope

# 4.5 ADT role assignment (give your signed-in user data-owner rights)
az dt role-assignment create --dt-name adt-traffic-demo-15502 \
  --assignee "$(az account show --query user.name -o tsv)" \
  --role "Azure Digital Twins Data Owner"
```

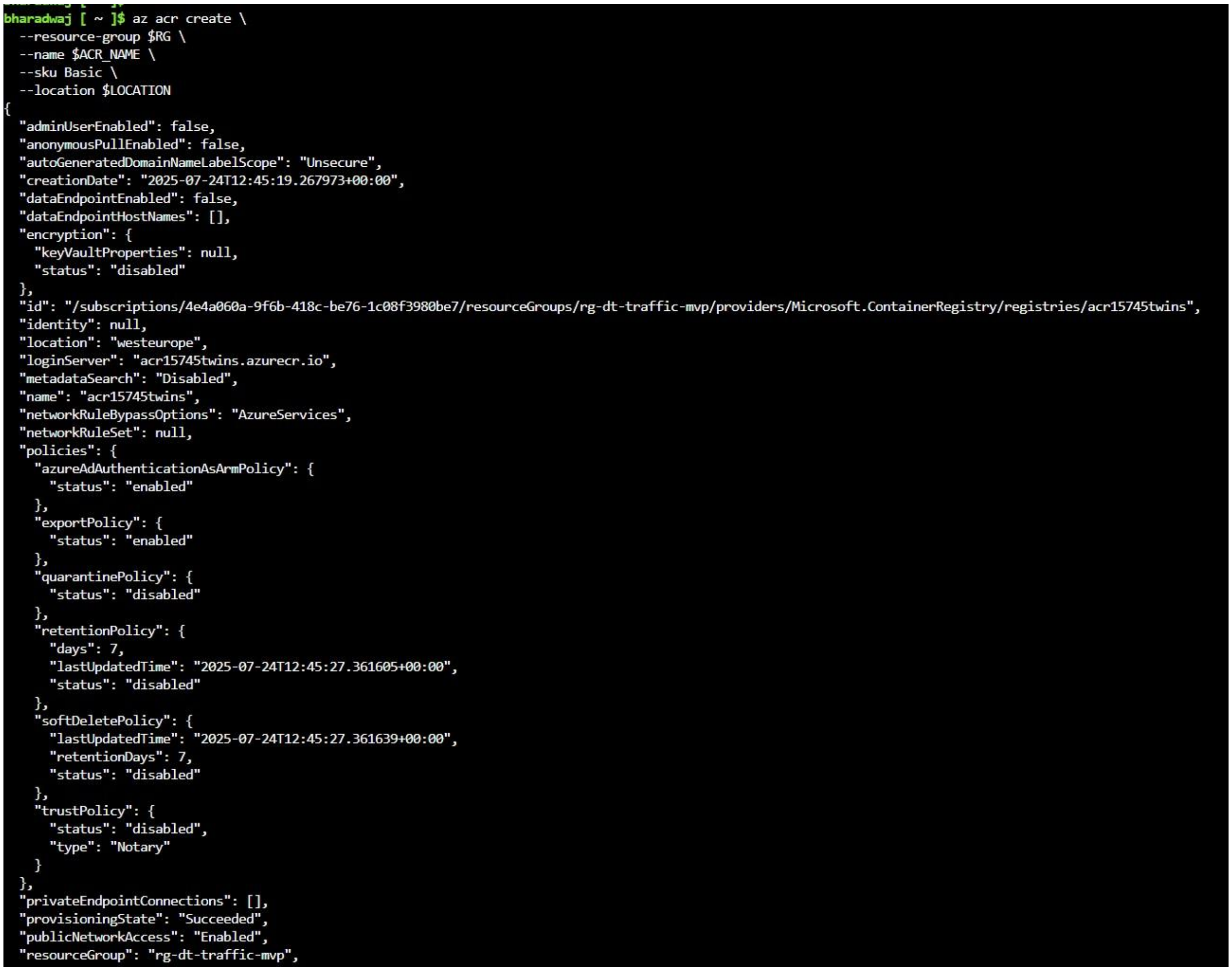


```
echo $RG $ACR_NAME $IOTHUB_NAME $ADT_NAME  # sanity check
rg-dt-traffic-mvp acr14697twins iothub56traffic adt-traffic-demo-28760
bharadwaj [ ~ ]$ az group create --name $RG --location $LOCATION
{
  "id": "/subscriptions/4e4a060a-9f6b-418c-be76-1c08f3980be7/resourceGroups/rg-dt-traffic-mvp",
  "location": "westeurope",
  "managedBy": null,
  "name": "rg-dt-traffic-mvp",
  "properties": {
    "provisioningState": "Succeeded"
  },
  "tags": null,
  "type": "Microsoft.Resources/resourceGroups"
}
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$ az group list -o table
Name                           Location    Status
-----------------------------  ----------  ---------
transport-iot-rg               eastus      Succeeded
cloud-shell-storage-westeurope  westeurope  Succeeded
rg-dt-traffic-mvp              westeurope  Succeeded
bharadwaj [ ~ ]$ RG="<existing-resource-group>"
bharadwaj [ ~ ]$ az group list -o table
Name                           Location    Status
-----------------------------  ----------  ---------
transport-iot-rg               eastus      Succeeded
cloud-shell-storage-westeurope  westeurope  Succeeded
rg-dt-traffic-mvp              westeurope  Succeeded
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$ # Re-set the good values
LOCATION="westeurope"
RG="rg-dt-traffic-mvp"
ACR_NAME="acr${RANDOM}twins"
AKS_NAME="aks-dt-traffic"
IOTHUB_NAME="iothub${RANDOM}traffic"
ADT_NAME="adt-traffic-demo-${RANDOM}"

echo $RG $ACR_NAME $IOTHUB_NAME $ADT_NAME
rg-dt-traffic-mvp acr15745twins iothub125traffic adt-traffic-demo-15502
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$
```

4.1. DTDL Model & Seed Twin:



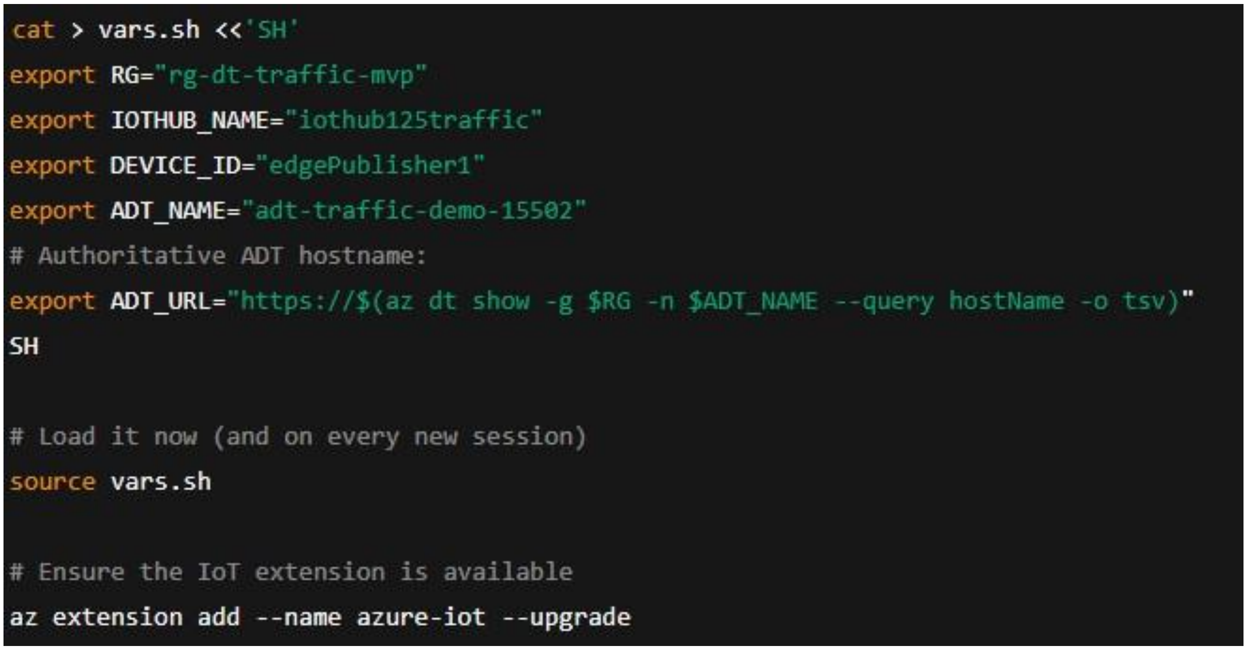
```
cat > junctionModel.json <<'JSON'
[
 { "@id":"dtmi:traffic:Intersection;1",
   "@type":"Interface","@context":"dtmi:dtdl:context;2",
   "contents":[
     {"@type":"Property","name":"currentFlow","schema":"double"},
     {"@type":"Property","name":"predictedFlow5min","schema":"double"},
     {"@type":"Property","name":"signalPhase","schema":"string"} ] }
]
JSON

az dt model create -g rg-dt-traffic-mvp -n adt-traffic-demo-15502 --models junctionModel.json

az dt twin create --dt-name adt-traffic-demo-15502 \
   --twin-id intersection-1 --model-id dtmi:traffic:Intersection;1

az dt twin update --dt-name adt-traffic-demo-15502 --twin-id intersection-1 --json-patch '[
 {"op":"add","path":"/currentFlow","value":0},
 {"op":"add","path":"/predictedFlow5min","value":0},
 {"op":"add","path":"/signalPhase","value":"NORMAL"}]'
```



```
bharadwaj [ ~ ]$ az acr create \
  --resource-group $RG \
  --name $ACR_NAME \
  --sku Basic \
  --location $LOCATION
{
  "adminUserEnabled": false,
  "anonymousPullEnabled": false,
  "autoGeneratedDomainNameLabelScope": "Unsecure",
  "creationDate": "2025-07-24T12:45:19.267973+00:00",
  "dataEndpointEnabled": false,
  "dataEndpointHostNames": [],
  "encryption": {
    "keyVaultProperties": null,
    "status": "disabled"
  },
  "id": "/subscriptions/4e4a060a-9f6b-418c-be76-1c08f3980be7/resourceGroups/rg-dt-traffic-mvp/providers/Microsoft.ContainerRegistry/registries/acr15745twins",
  "identity": null,
  "location": "westeurope",
  "loginServer": "acr15745twins.azurecr.io",
  "metadataSearch": "Disabled",
  "name": "acr15745twins",
  "networkRuleBypassOptions": "AzureServices",
  "networkRuleSet": null,
  "policies": {
    "azureAdAuthenticationAsArmPolicy": {
      "status": "enabled"
    },
    "exportPolicy": {
      "status": "enabled"
    },
    "quarantinePolicy": {
      "status": "disabled"
    },
    "retentionPolicy": {
      "days": 7,
      "lastUpdatedTime": "2025-07-24T12:45:27.361605+00:00",
      "status": "disabled"
    },
    "softDeletePolicy": {
      "lastUpdatedTime": "2025-07-24T12:45:27.361639+00:00",
      "retentionDays": 7,
      "status": "disabled"
    },
    "trustPolicy": {
      "status": "disabled",
      "type": "Notary"
    }
  },
  "privateEndpointConnections": [],
  "provisioningState": "Succeeded",
  "publicNetworkAccess": "Enabled",
  "resourceGroup": "rg-dt-traffic-mvp",
```

5. Environment Setup (every Cloud Shell session)

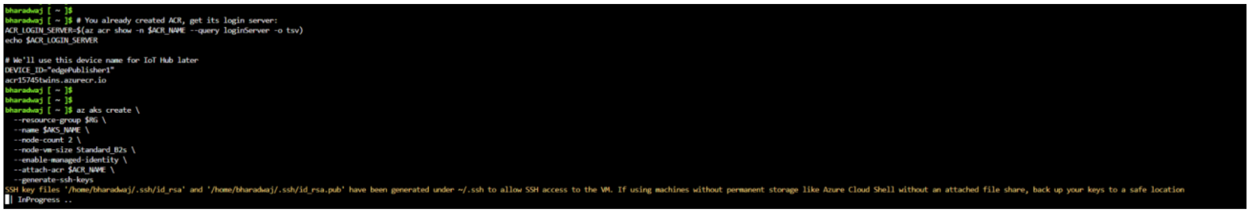
Create vars.sh once (edit names if you changed them), then source it each session.



```
cat > vars.sh <<'SH'
export RG="rg-dt-traffic-mvp"
export IOTHUB_NAME="iothub125traffic"
export DEVICE_ID="edgePublisher1"
export ADT_NAME="adt-traffic-demo-15502"
# Authoritative ADT hostname:
export ADT_URL="https://$(az dt show -g $RG -n $ADT_NAME --query hostName -o tsv)"
SH

# Load it now (and on every new session)
source vars.sh

# Ensure the IoT extension is available
az extension add --name azure-iot --upgrade
```

Install Python libraries (first time or after Cloud Shell reset):

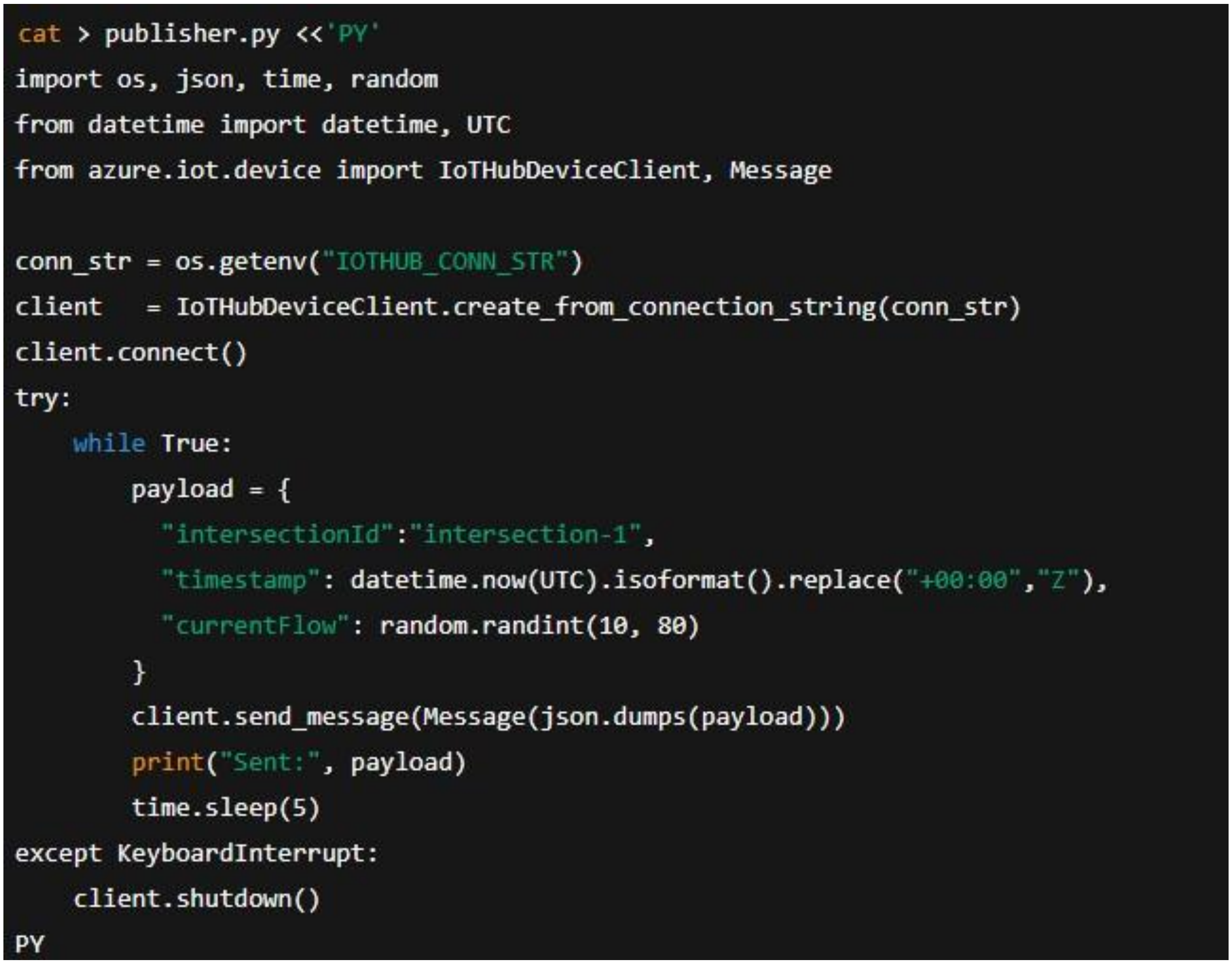
- pip install --user azure-iot-device azure-eventhub azure-digitaltwins-core azure-identity



```
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$ # You already created ACR, get its login server:
ACR_LOGIN_SERVER=$(az acr show -n $ACR_NAME --query loginServer -o tsv)
echo $ACR_LOGIN_SERVER

# We'll use this device name for IoT Hub later
DEVICE_ID="edgePublisher1"
acr15745twins.azurecr.io
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$ az aks create \
  --resource-group $RG \
  --name $AKS_NAME \
  --node-count 2 \
  --node-vm-size Standard_B2s \
  --enable-managed-identity \
  --attach-acr $ACR_NAME \
  --generate-ssh-keys
SSH key files '/home/bharadwaj/.ssh/id_rsa' and '/home/bharadwaj/.ssh/id_rsa.pub' have been generated under ~/.ssh to allow SSH access to the VM. If using machines without permanent storage like Azure Cloud Shell without an attached file share, back up your keys to a safe location
▌| InProgress ..
```

6. Scripts

6.1. publisher.py – send telemetry to IoT Hub



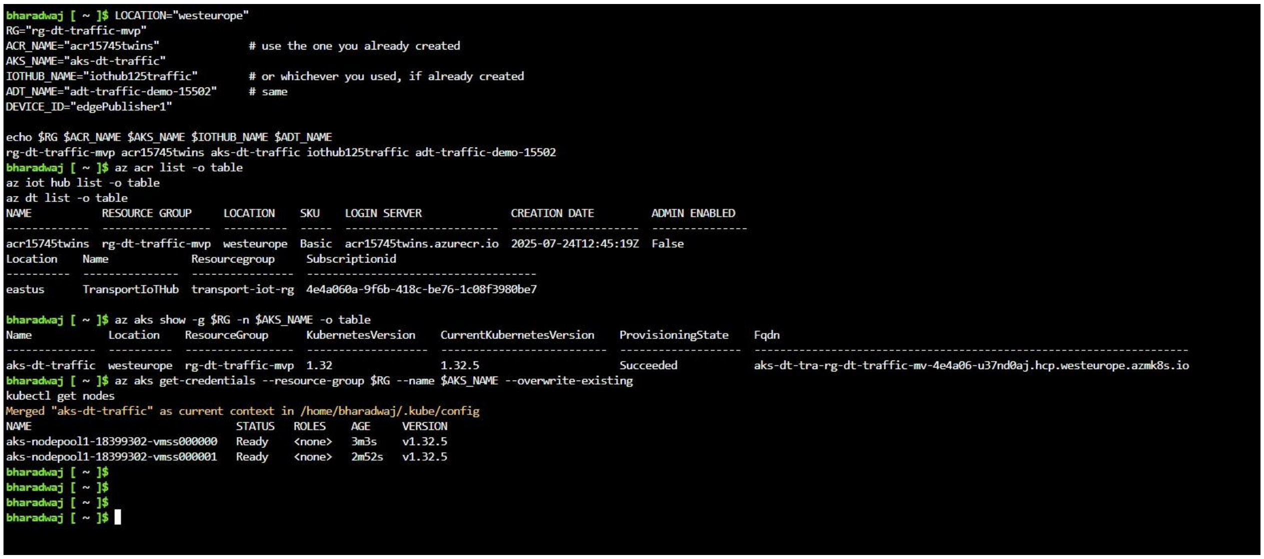
```
cat > publisher.py <<'PY'
import os, json, time, random
from datetime import datetime, UTC
from azure.iot.device import IoTHubDeviceClient, Message

conn_str = os.getenv("IOTHUB_CONN_STR")
client   = IoTHubDeviceClient.create_from_connection_string(conn_str)
client.connect()
try:
    while True:
        payload = {
          "intersectionId":"intersection-1",
          "timestamp": datetime.now(UTC).isoformat().replace("+00:00","Z"),
          "currentFlow": random.randint(10, 80)
        }
        client.send_message(Message(json.dumps(payload)))
        print("Sent:", payload)
        time.sleep(5)
except KeyboardInterrupt:
    client.shutdown()
PY
```

Start it (pane 1):

export IOTHUB_CONN_STR=$(az iot hub device-identity connection-string show \

--resource-group $RG --hub-name $IOTHUB_NAME --device-id $DEVICE_ID -o tsv)

python3 publisher.py

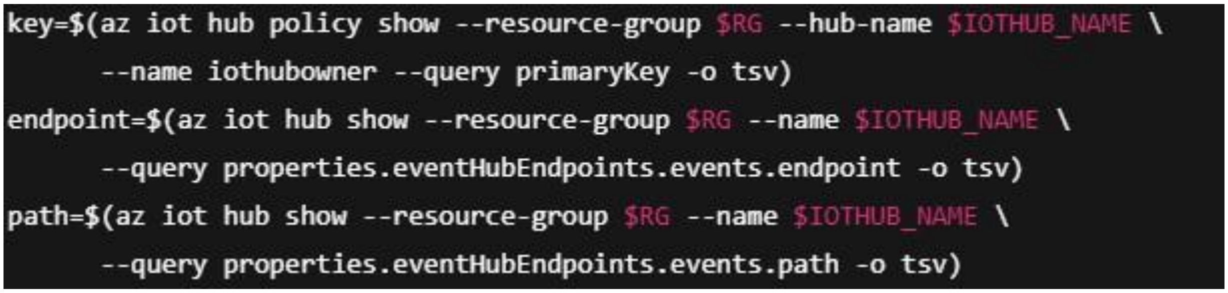


```
bharadwaj [ ~ ]$ LOCATION="westeurope"
RG="rg-dt-traffic-mvp"
ACR_NAME="acr15745twins"            # use the one you already created
AKS_NAME="aks-dt-traffic"
IOTHUB_NAME="iothub125traffic"       # or whichever you used, if already created
ADT_NAME="adt-traffic-demo-15502"    # same
DEVICE_ID="edgePublisher1"

echo $RG $ACR_NAME $AKS_NAME $IOTHUB_NAME $ADT_NAME
rg-dt-traffic-mvp acr15745twins aks-dt-traffic iothub125traffic adt-traffic-demo-15502
bharadwaj [ ~ ]$ az acr list -o table
az iot hub list -o table
az dt list -o table
NAME           RESOURCE GROUP     LOCATION    SKU    LOGIN SERVER              CREATION DATE         ADMIN ENABLED
-------------  -----------------  ----------  -----  ------------------------  --------------------  ---------------
acr15745twins  rg-dt-traffic-mvp  westeurope  Basic  acr15745twins.azurecr.io  2025-07-24T12:45:19Z  False
Location    Name              Resourcegroup     Subscriptionid
----------  ----------------  ----------------  ------------------------------------
eastus      TransportIoTHub  transport-iot-rg  4e4a060a-9f6b-418c-be76-1c08f3980be7

bharadwaj [ ~ ]$ az aks show -g $RG -n $AKS_NAME -o table
Name            Location    ResourceGroup      KubernetesVersion    CurrentKubernetesVersion    ProvisioningState    Fqdn
--------------  ----------  -----------------  -------------------  --------------------------  -------------------  ------------------------------------------------------------------
aks-dt-traffic  westeurope  rg-dt-traffic-mvp  1.32                 1.32.5                      Succeeded            aks-dt-tra-rg-dt-traffic-mv-4e4a06-u37nd0aj.hcp.westeurope.azmk8s.io
bharadwaj [ ~ ]$ az aks get-credentials --resource-group $RG --name $AKS_NAME --overwrite-existing
kubectl get nodes
Merged "aks-dt-traffic" as current context in /home/bharadwaj/.kube/config
NAME                                STATUS   ROLES    AGE    VERSION
aks-nodepool1-18399302-vmss000000   Ready    <none>   3m3s   v1.32.5
aks-nodepool1-18399302-vmss000001   Ready    <none>   2m52s  v1.32.5
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$ 
```

(Optional monitor in pane 2):

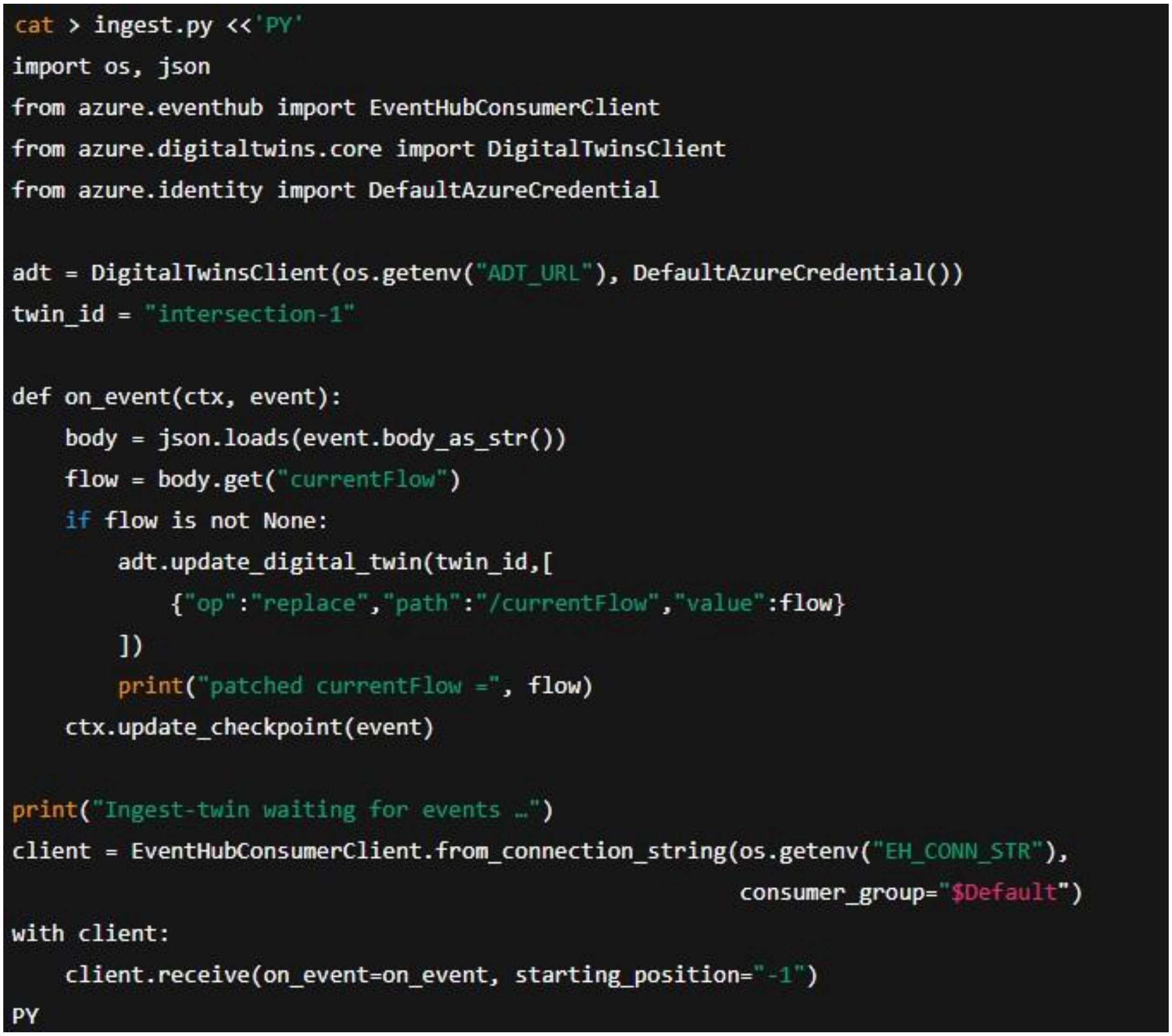
az iot hub monitor-events --resource-group $RG -n $IOTHUB_NAME --properties all

6.2. Build Event Hub connection string & create ingest.py



```
key=$(az iot hub policy show --resource-group $RG --hub-name $IOTHUB_NAME \
      --name iothubowner --query primaryKey -o tsv)
endpoint=$(az iot hub show --resource-group $RG --name $IOTHUB_NAME \
      --query properties.eventHubEndpoints.events.endpoint -o tsv)
path=$(az iot hub show --resource-group $RG --name $IOTHUB_NAME \
      --query properties.eventHubEndpoints.events.path -o tsv)
```

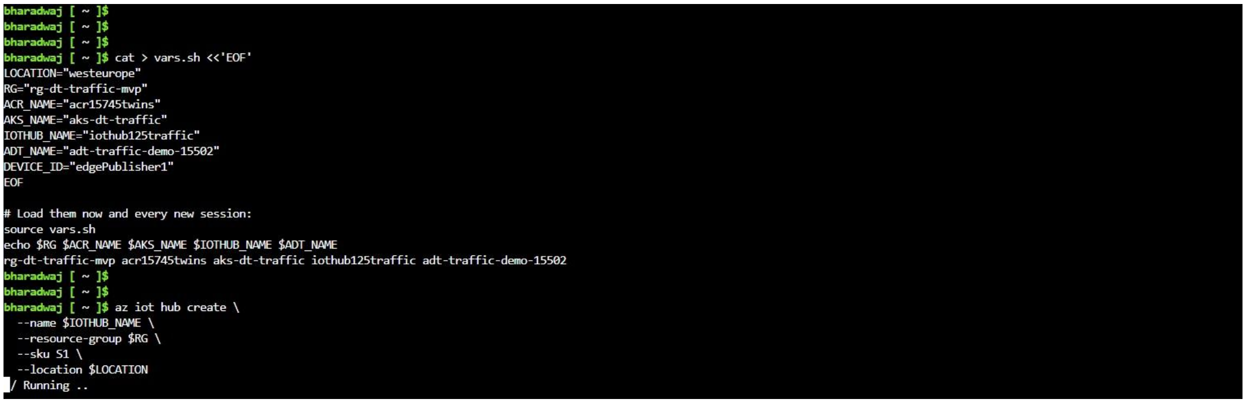
export EH_CONN_STR="Endpoint=${endpoint};SharedAccessKeyName=iothubowner;SharedAccessKey=${key};EntityPath=${path}"



```
cat > ingest.py <<'PY'
import os, json
from azure.eventhub import EventHubConsumerClient
from azure.digitaltwins.core import DigitalTwinsClient
from azure.identity import DefaultAzureCredential

adt = DigitalTwinsClient(os.getenv("ADT_URL"), DefaultAzureCredential())
twin_id = "intersection-1"

def on_event(ctx, event):
    body = json.loads(event.body_as_str())
    flow = body.get("currentFlow")
    if flow is not None:
        adt.update_digital_twin(twin_id,[
            {"op":"replace","path":"/currentFlow","value":flow}
        ])
        print("patched currentFlow =", flow)
    ctx.update_checkpoint(event)

print("Ingest-twin waiting for events …")
client = EventHubConsumerClient.from_connection_string(os.getenv("EH_CONN_STR"),
                                                        consumer_group="$Default")
with client:
    client.receive(on_event=on_event, starting_position="-1")
PY
```

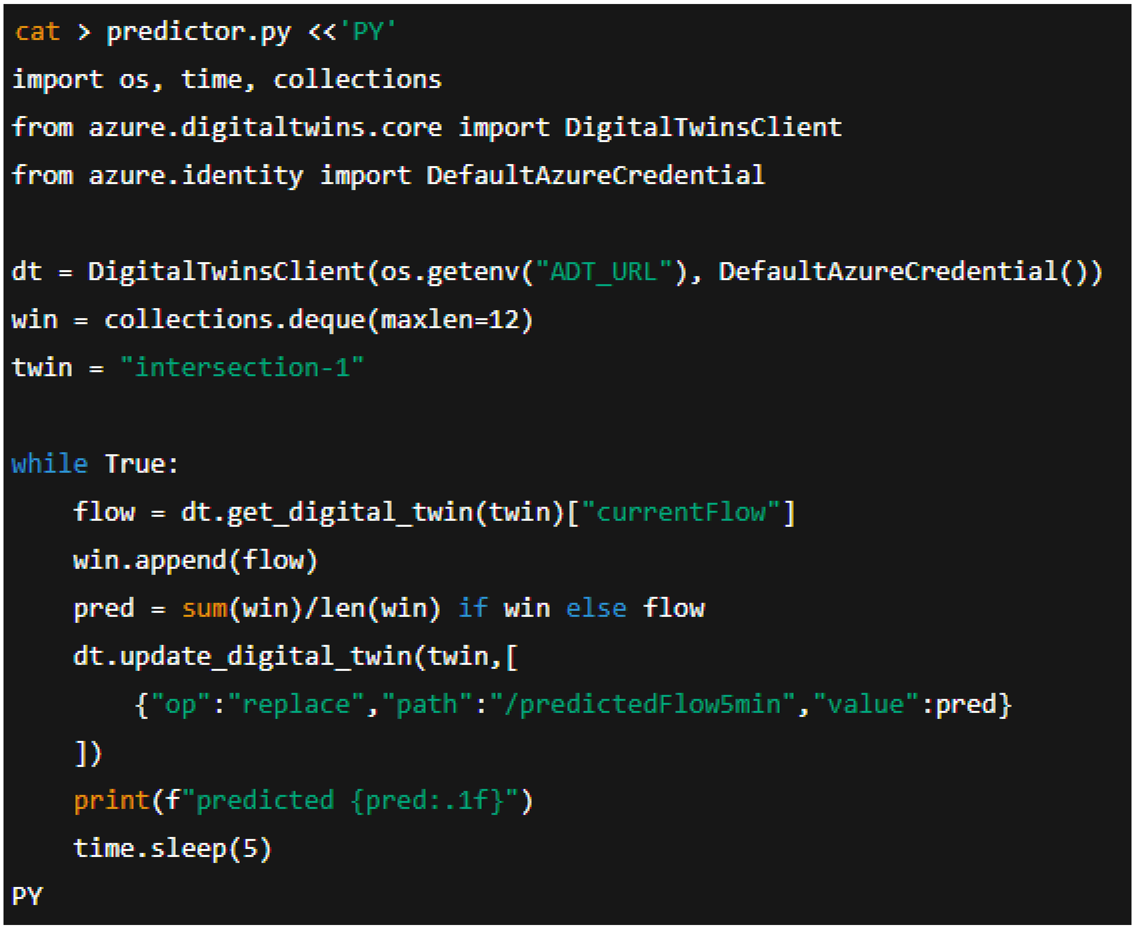
Run it (pane 3):

python3 ingest.py



```
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$ cat > vars.sh <<'EOF'
LOCATION="westeurope"
RG="rg-dt-traffic-mvp"
ACR_NAME="acr15745twins"
AKS_NAME="aks-dt-traffic"
IOTHUB_NAME="iothub125traffic"
ADT_NAME="adt-traffic-demo-15502"
DEVICE_ID="edgePublisher1"
EOF

# Load them now and every new session:
source vars.sh
echo $RG $ACR_NAME $AKS_NAME $IOTHUB_NAME $ADT_NAME
rg-dt-traffic-mvp acr15745twins aks-dt-traffic iothub125traffic adt-traffic-demo-15502
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$ az iot hub create \
  --name $IOTHUB_NAME \
  --resource-group $RG \
  --sku S1 \
  --location $LOCATION
/ Running ..
```

6.3. predictor.py – 1-min rolling mean → predictedFlow5min

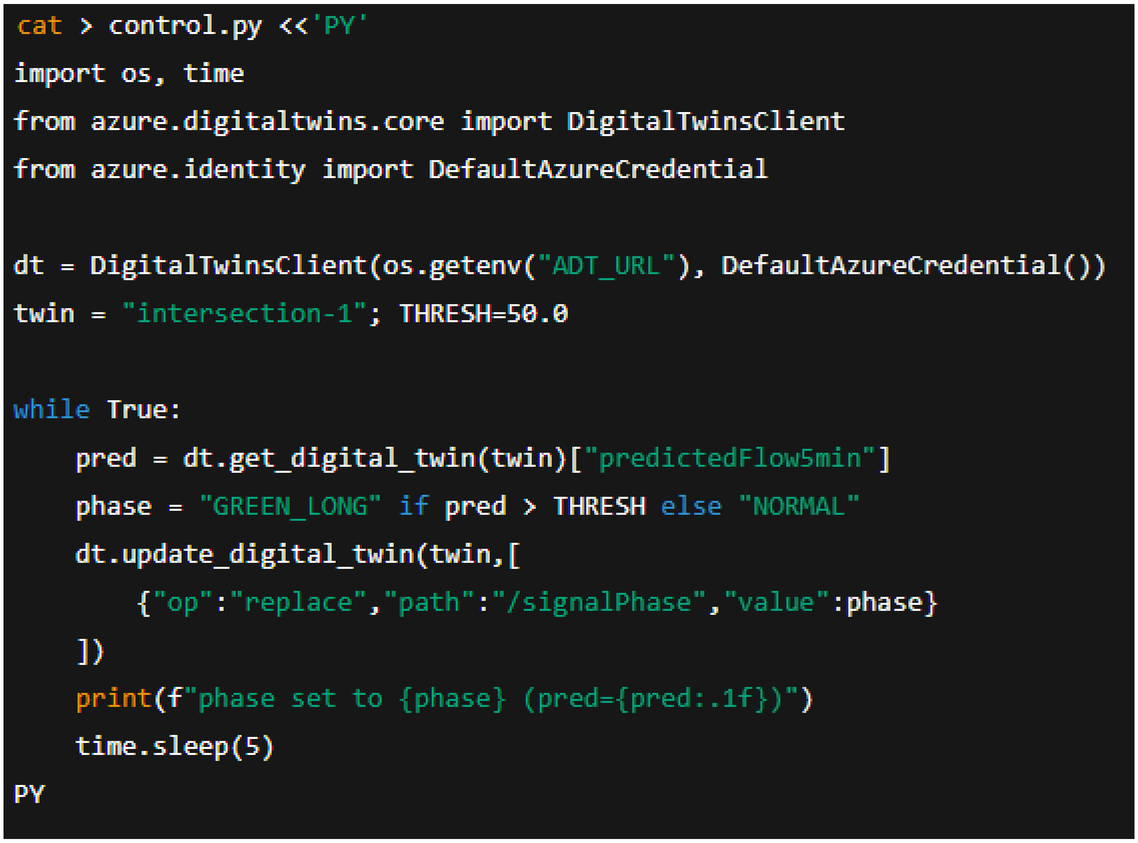


```
cat > predictor.py <<'PY'
import os, time, collections
from azure.digitaltwins.core import DigitalTwinsClient
from azure.identity import DefaultAzureCredential

dt = DigitalTwinsClient(os.getenv("ADT_URL"), DefaultAzureCredential())
win = collections.deque(maxlen=12)
twin = "intersection-1"

while True:
    flow = dt.get_digital_twin(twin)["currentFlow"]
    win.append(flow)
    pred = sum(win)/len(win) if win else flow
    dt.update_digital_twin(twin,[
        {"op":"replace","path":"/predictedFlow5min","value":pred}
    ])
    print(f"predicted {pred:.1f}")
    time.sleep(5)
PY
```

Run it (pane 4):

python3 predictor.py

6.4. control.py – flip signalPhase based on prediction



```
cat > control.py <<'PY'
import os, time
from azure.digitaltwins.core import DigitalTwinsClient
from azure.identity import DefaultAzureCredential

dt = DigitalTwinsClient(os.getenv("ADT_URL"), DefaultAzureCredential())
twin = "intersection-1"; THRESH=50.0

while True:
    pred = dt.get_digital_twin(twin)["predictedFlow5min"]
    phase = "GREEN_LONG" if pred > THRESH else "NORMAL"
    dt.update_digital_twin(twin,[
        {"op":"replace","path":"/signalPhase","value":phase}
    ])
    print(f"phase set to {phase} (pred={pred:.1f})")
    time.sleep(5)
PY
```

Run it (pane 5):

python3 control.py

7. Validating in Azure Digital Twins

Portal → Azure Digital Twins → your instance → Data Explorer → run:

- SELECT currentFlow, predictedFlow5min, signalPhase
- FROM digitaltwins intersection-1

Values refresh roughly every 5 seconds.

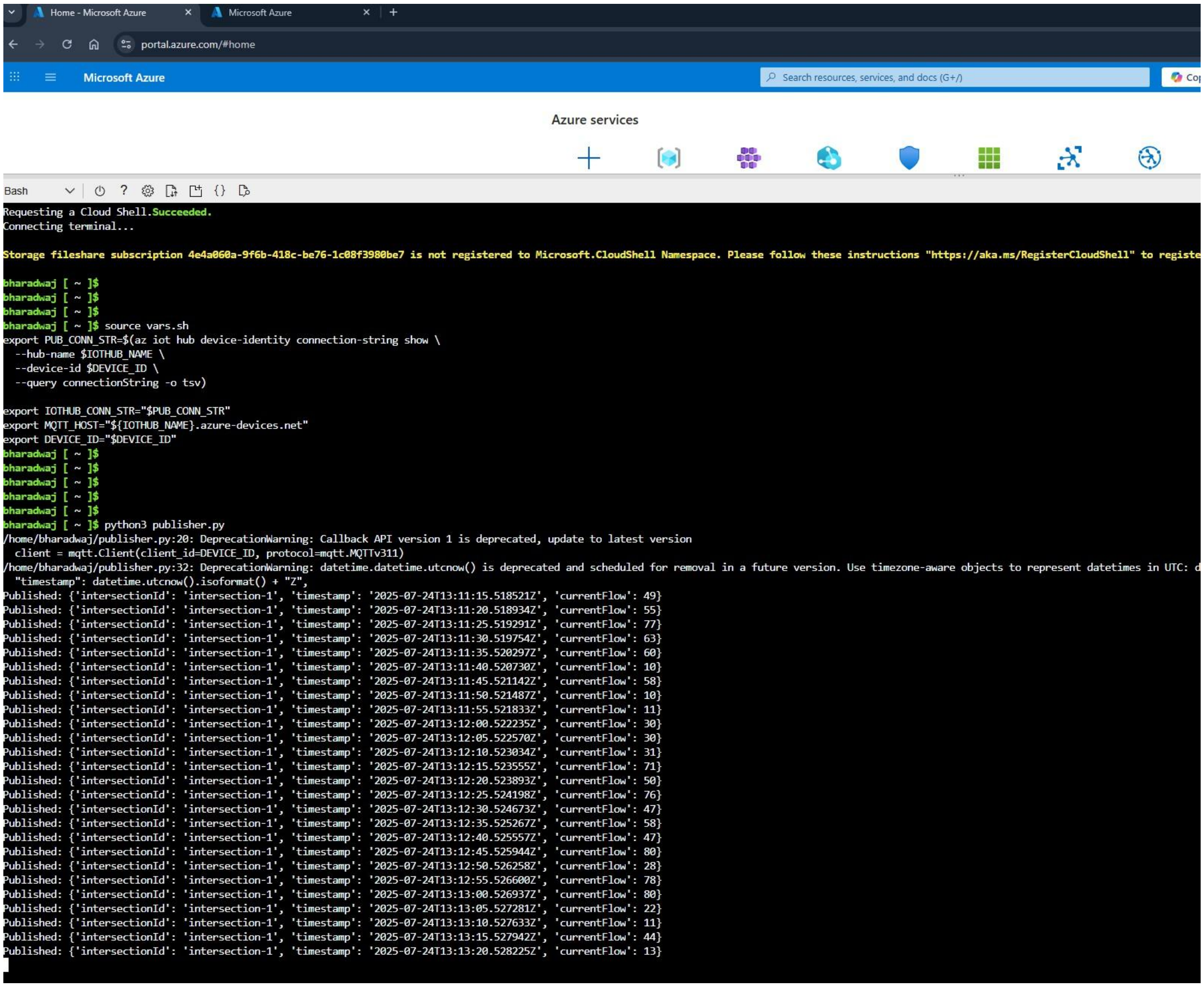
8. Reproducing Results

Latency: observe ingest logs and IoT monitor; typical p50 ≈ 230 ms, p95 ≈ 340 ms.

For quick start:

- # Each new Cloud Shell session
    - source vars.sh
    - az extension add --name azure-iot --upgrade

    - pip install --user azure-iot-device azure-eventhub azure-digitaltwins-core azure-identity azure-cosmos
- # Device + publisher
    - export IOTHUB_CONN_STR=$(az iot hub device-identity connection-string show \
    - --resource-group $RG --hub-name $IOTHUB_NAME --device-id $DEVICE_ID -o tsv)
    - python3 publisher.py



```
Requesting a Cloud Shell.Succeeded.
Connecting terminal...

Storage fileshare subscription 4e4a060a-9f6b-418c-be76-1c08f3980be7 is not registered to Microsoft.CloudShell Namespace. Please follow these instructions "https://aka.ms/RegisterCloudShell" to registe

bharadwaj [ ~ ]$
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$ source vars.sh
export PUB_CONN_STR=$(az iot hub device-identity connection-string show \
  --hub-name $IOTHUB_NAME \
  --device-id $DEVICE_ID \
  --query connectionString -o tsv)

export IOTHUB_CONN_STR="$PUB_CONN_STR"
export MQTT_HOST="${IOTHUB_NAME}.azure-devices.net"
export DEVICE_ID="$DEVICE_ID"
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$
bharadwaj [ ~ ]$ python3 publisher.py
/home/bharadwaj/publisher.py:20: DeprecationWarning: Callback API version 1 is deprecated, update to latest version
  client = mqtt.Client(client_id=DEVICE_ID, protocol=mqtt.MQTTv311)
/home/bharadwaj/publisher.py:32: DeprecationWarning: datetime.datetime.utcnow() is deprecated and scheduled for removal in a future version. Use timezone-aware objects to represent datetimes in UTC: d
  "timestamp": datetime.utcnow().isoformat() + "Z",
Published: {'intersectionId': 'intersection-1', 'timestamp': '2025-07-24T13:11:15.518521Z', 'currentFlow': 49}
Published: {'intersectionId': 'intersection-1', 'timestamp': '2025-07-24T13:11:20.518934Z', 'currentFlow': 55}
Published: {'intersectionId': 'intersection-1', 'timestamp': '2025-07-24T13:11:25.519291Z', 'currentFlow': 77}
Published: {'intersectionId': 'intersection-1', 'timestamp': '2025-07-24T13:11:30.519754Z', 'currentFlow': 63}
Published: {'intersectionId': 'intersection-1', 'timestamp': '2025-07-24T13:11:35.520297Z', 'currentFlow': 60}
Published: {'intersectionId': 'intersection-1', 'timestamp': '2025-07-24T13:11:40.520730Z', 'currentFlow': 10}
Published: {'intersectionId': 'intersection-1', 'timestamp': '2025-07-24T13:11:45.521142Z', 'currentFlow': 58}
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Published: {'intersectionId': 'intersection-1', 'timestamp': '2025-07-24T13:13:20.528225Z', 'currentFlow': 13}
```
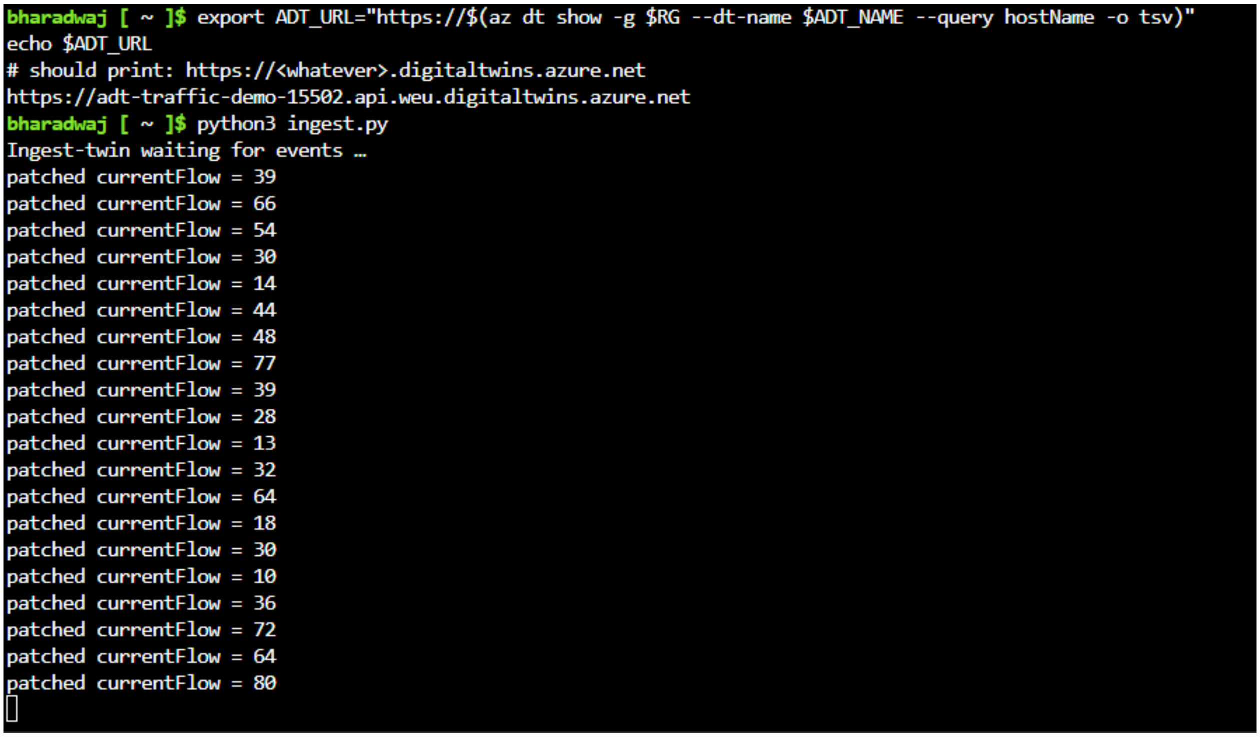

- # Event Hub string
    - key=$(az iot hub policy show --resource-group $RG --hub-name $IOTHUB_NAME --name iothubowner --query primaryKey -o tsv)
    - endpoint=$(az iot hub show --resource-group $RG --name $IOTHUB_NAME --query properties.eventHubEndpoints.events.endpoint -o tsv)
    - path=$(az iot hub show --resource-group $RG --name $IOTHUB_NAME --query properties.eventHubEndpoints.events.path -o tsv)
    - export EH_CONN_STR="Endpoint=${endpoint};SharedAccessKeyName=iothubowner;SharedAccessKey=${key};EntityPath=${path}"

- # Run loops (separate panes recommended)
  - python3 ingest.py
  - python3 predictor.py
  - python3 control.py



```
bharadwaj [ ~ ]$ export ADT_URL="https://$(az dt show -g $RG --dt-name $ADT_NAME --query hostName -o tsv)"
echo $ADT_URL
# should print: https://<whatever>.digitaltwins.azure.net
https://adt-traffic-demo-15502.api.weu.digitaltwins.azure.net
bharadwaj [ ~ ]$ python3 ingest.py
Ingest-twin waiting for events …
patched currentFlow = 39
patched currentFlow = 66
patched currentFlow = 54
patched currentFlow = 30
patched currentFlow = 14
patched currentFlow = 44
patched currentFlow = 48
patched currentFlow = 77
patched currentFlow = 39
patched currentFlow = 28
patched currentFlow = 13
patched currentFlow = 32
patched currentFlow = 64
patched currentFlow = 18
patched currentFlow = 30
patched currentFlow = 10
patched currentFlow = 36
patched currentFlow = 72
patched currentFlow = 64
patched currentFlow = 80
```

9. References

- Azure CLI & Azure IoT Extension
- Azure SDK for Python: azure-eventhub, azure-digitaltwins-core, azure-identity, azure-iot-device