

PHASE 3:Implementation Of Project

Title: Root Cause Analysis For Equipment Failures

Objective:

To systematically identify the underlying causes of equipment failures in order to implement effective corrective and preventive actions, reduce downtime, improve equipment reliability, and enhance overall operational efficiency

1.AI Model

Development Overview

An AI model for **Root Cause Analysis (RCA)** of **equipment failures** combines sensor data, maintenance logs, domain knowledge, and machine learning (ML) techniques to identify the underlying causes of failures in industrial systems.

Implementation

Data Ingestion Layer: Build a data pipeline that collects and stores high-frequency sensor data and logs.

Data Preprocessing & Labeling: Assign known failure modes from maintenance logs (manual/automated)

Feature Engineering: Lag features for failure precursors

Outcome

An AI-based RCA system detects equipment failures early and identifies their root causes using sensor data and machine learning.

It reduces downtime, lowers maintenance costs, and improves asset reliability. The system offers explainable insights and supports better maintenance decisions.

2. IoT Sensor Deployment:

Overview

IoT sensors collect real-time data (vibration, temperature, pressure, current, etc.) from equipment to monitor health, performance, and detect anomalies. They enable continuous condition monitoring essential for predictive maintenance and root cause analysis.

Implementation

Sensor Selection: Based on parameters (e.g., vibration sensors for motors, temperature for boilers).

Connectivity Setup: Use protocols like **LoRaWAN**, **Wi-Fi**, or **Ethernet**; data is transmitted to the cloud or local gateway.

Integration: Connect with a **data platform** (e.g., Azure IoT, AWS IoT Core) to store, analyze, and visualize data.

Edge Devices (optional): Preprocess data at the edge before sending to the cloud.

Outcomes

Enables **real-time monitoring** and **early anomaly detection**. Reduces **manual inspections**, improves **safety** and **equipment uptime**. Forms the data backbone for AI-based diagnostics and RCA.

3. Digital Twin For Failure Simulation:

Overview

A **Digital Twin** is a virtual replica of a physical asset (like a machine or system) that simulates its behavior using real-time sensor data and historical models. For failure simulation, it predicts how equipment will behave under different stress conditions, usage patterns, or faults—helping anticipate and prevent failures.

Implementation

Model Creation: Build a 3D or system-level virtual model using CAD, physics-based simulations, or machine learning. Integrate real sensor data from IoT devices for dynamic updates.

Simulation Setup: Inject faults or vary parameters (e.g., temperature, load) to simulate failures. Use tools like **ANSYS Twin Builder**, **Siemens Mindsphere**, or custom models in **MATLAB/Simulink**, **Unity**, or **Python**.

Integration with AI: Combine with ML models to predict failures and test what-if scenarios. Link with dashboards for visualization and decision-making.

Outcome

Simulates **failure scenarios without physical testing**, reducing risk and cost. Improves design, maintenance planning, and operational reliability. Enables **continuous learning** and optimization of equipment through real-time feedback loops.

4. Blockchain-Based Maintenance Logs:

Overview

Blockchain-based maintenance logs use **decentralized ledgers** to store and track equipment maintenance records securely and immutably.

They ensure **tamper-proof**, transparent histories of servicing, inspections, part replacements, and failures—especially valuable in regulated or multi-party environments.

Implementation

Blockchain Platform: Use platforms like **Hyperledger Fabric**, **Ethereum**, or **Multichain** for permissioned or public access.

Smart Contracts: Define logic for logging events (e.g., `logMaintenance(equipmentID, technicianID, timestamp, actionTaken)`).

Integration:

Connect IoT devices or CMMS (Computerized Maintenance Management Systems) to trigger smart contracts automatically.

Use APIs or middleware for secure data input.

Outcome

Ensures **trust, traceability, and compliance** in maintenance records. Reduces disputes and fraud in high-value or safety-critical systems (e.g., aerospace, manufacturing). Facilitates **audits, warranty tracking, and regulatory reporting**.

5. Testing and Feedback:

Overview

Testing and feedback are critical for ensuring the accuracy and efficiency of AI or IoT systems. Testing ensures the system performs as expected, while feedback loops help improve it over time. This involves collecting data on the system's performance, validating it, and iterating based on user and system feedback.

Implementation

Testing:

Unit Testing: Test individual components or algorithms.

Integration Testing: Ensure smooth interaction between sensors, IoT devices, and AI models.

Performance Testing: Check for latency, throughput, and accuracy under various conditions.

Simulated Testing: Use synthetic data or simulated failure scenarios (e.g., in digital twin models) to verify behavior.

Feedback Mechanism:

Data Collection: Continuously collect feedback from users, sensors, or system outputs.

Model Retraining: Use feedback to retrain AI models, adjust thresholds, or optimize performance.

User Feedback: Create channels (e.g., surveys, dashboards) for users to report issues or suggest improvements.

Outcome

Continuous testing and feedback ensure the system adapts to real-world conditions and maintains reliability. Identifying bugs or inefficiencies early leads to faster problem resolution. Feedback loops allow users to contribute to system improvements, fostering better trust and engagement.

Challenges and Solutions:

Data Quality and Availability

- **Challenge:** Testing and feedback rely heavily on accurate, real-time data. Missing, noisy, or incomplete data can lead to false conclusions and poor model performance.
- **Solution:**
 - Implement **data cleaning and preprocessing** techniques (e.g., outlier detection, interpolation).
 - Use **redundant sensors** or **multi-sensor fusion** to ensure reliability.
 - Deploy **edge computing** to preprocess data before sending it to the cloud, reducing delays and data gaps.

Scalability of Testing

- **Challenge:** IoT systems generate vast amounts of data, and testing all components at scale is complex. Running tests on every possible scenario is time-consuming.
- **Solution:**
 - Use **automated testing frameworks** to simulate various scenarios at scale.
 - Leverage **cloud-based testing environments** for parallel processing and faster testing.
 - Employ **A/B testing** or **canary releases** to test new features in production with a small group before full deployment.

Model Drift & Performance Degradation

- **Challenge:** AI models can degrade over time as they encounter new, unseen data or environmental changes (model drift).
- **Solution:**
 - Implement **continuous monitoring** and **model drift detection** techniques (e.g., monitoring performance metrics like accuracy and precision).
 - **Retrain models periodically** using fresh data and integrate **feedback loops** to improve predictions.
 - Use **online learning** techniques to update models in real-time with new data.

Outcomes of Phase 3:

1.Improved System Performance

- **Outcome:** Continuous testing and feedback help to **fine-tune algorithms** and ensure they adapt to real-world scenarios, resulting in **better accuracy, reliability, and efficiency** of the system.

2. Faster Time-to-Market

- **Outcome:** Automated testing and rapid feedback loops enable **quicker identification of bugs, performance issues**, and areas for improvement,

speeding up the development process and shortening time-to-market for new features.

3. Increased User Satisfaction

- **Outcome:** Real-time feedback and continuous improvement create a **better user experience**. Users feel more engaged when they see that their feedback directly influences system upgrades.

Next Steps For Phase 4:

Define Clear Objectives and KPIs

- **Next Step:** Set measurable goals for testing and feedback. Define **Key Performance Indicators (KPIs)** such as accuracy, response time, uptime, and user satisfaction to track the success of the system.
- **Action:** Create a KPI dashboard that updates in real time to monitor system performance.

2. Implement Automated Testing Frameworks

- **Next Step:** Automate the testing process to scale and cover a broader range of scenarios. Include unit tests, integration tests, and stress tests.
- **Action:** Use tools like **Selenium** (for UI testing), **pytest** (for Python code), **Jenkins** or **GitLab CI/CD** to automate testing pipelines.

3. Set Up Real-Time Feedback Collection Mechanisms

- **Next Step:** Build feedback loops to collect user input on system performance. This can be through in-app surveys, direct reporting, or system logs.
- **Action:** Integrate feedback mechanisms within your UI (e.g., feedback buttons, bug reporting forms) or through automated monitoring systems that flag issues.

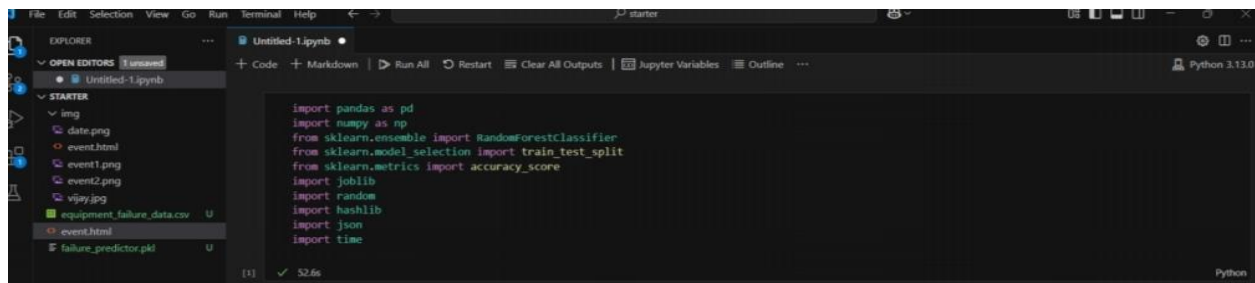
4. Monitor and Detect Model Drift

- **Next Step:** Continuously monitor AI models for drift. As real-world data changes, models may lose accuracy.
- **Action:** Implement drift detection tools like **Alibi Detect** or **EvidentlyAI** to alert teams when retraining or adjustments are needed.

SCREENSHOTS OF CODE AND PROCESS:

CODE:

CELL 1: Import libraries

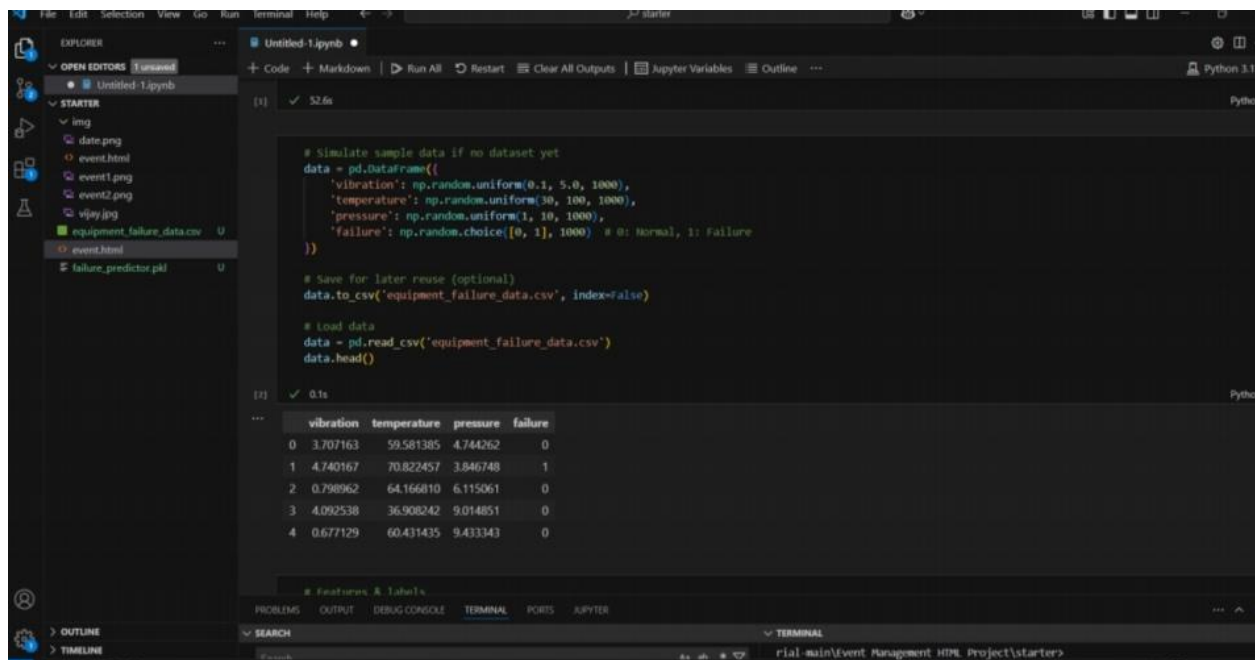


The screenshot shows a Jupyter Notebook interface with a file explorer on the left and a code editor on the right. The code editor contains the following Python code:

```
import pandas as pd
import numpy as np
from sklearn.ensemble import RandomForestClassifier
from sklearn.model_selection import train_test_split
from sklearn.metrics import accuracy_score
import joblib
import random
import hashlib
import json
import time
```

The code is executed, and the output shows a success message: [1] ✓ 52.6s.

CELL 2: Load and prepare data



The screenshot shows a Jupyter Notebook interface with a file explorer on the left and a code editor on the right. The code editor contains the following Python code:

```
# simulate sample data if no dataset yet
data = pd.DataFrame({
    'vibration': np.random.uniform(0.1, 5.0, 1000),
    'temperature': np.random.uniform(30, 100, 1000),
    'pressure': np.random.uniform(1, 10, 1000),
    'failure': np.random.choice([0, 1], 1000) # 0: Normal, 1: Failure
})

# Save for later reuse (optional)
data.to_csv('equipment_failure_data.csv', index=False)

# load data
data = pd.read_csv('equipment_failure_data.csv')
data.head()
```

The code is executed, and the output shows a success message: [2] ✓ 0.1s. Below the message, a table of the first five rows of the data is displayed:

	vibration	temperature	pressure	failure
0	3.707163	59.581385	4.744262	0
1	4.740167	70.822457	3.846748	1
2	0.798962	64.166810	6.115061	0
3	4.092538	36.908242	9.014851	0
4	0.677129	60.431435	9.433343	0

The code is also executed again, and the output shows a success message: [2] ✓ 0.1s.

CELL 3: Train AI model


```
File Edit Selection View Go Run Terminal Help
starter
Python 3.11.0

EXPLORER
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  + STARTER
    + img
    + date.png
    + event.html
    + event1.png
    + event2.png
    + vibey.jpg
    + equipment_failure_data.csv
    + event.html
    + failure_predictor.pkl

+ Code + Markdown Run All Restart Clear All Outputs Jupyter Variables Outline
2 0.798962 64.166810 6.115061 0
3 4.092538 36.908242 9.014851 0
4 0.677129 60.431435 9.433343 0

# Features & labels
x = data[['vibration', 'temperature', 'pressure']]
y = data['failure']

# Split data
X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.2, random_state=42)

# Train model
model = RandomForestClassifier(n_estimators=100, random_state=42)
model.fit(X_train, y_train)

# Evaluate
preds = model.predict(X_test)
accuracy = accuracy_score(y_test, preds)
print(f"Model accuracy: {accuracy:.2%}")

# Save model
joblib.dump(model, 'failure_predictor.pkl')

[1] ✓ 0.3s Python
... Model accuracy: 44.56%
... ['failure_predictor.pkl']

PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL PORTS JUPYTER
SEARCH
r:\main\Event Management HTML Project\starter>
```

CELL 4:Simulate sensor data in notebook

```
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starter
Python 3.11.0

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    + vibey.jpg
    + equipment_failure_data.csv
    + event.html
    + failure_predictor.pkl

+ Code + Markdown Run All Restart Clear All Outputs Jupyter Variables Outline
# Simulate and test a single data point
def generate_sensor_data():
    return {
        'vibration': round(random.uniform(0.1, 5.0), 2),
        'temperature': round(random.uniform(30, 100), 2),
        'pressure': round(random.uniform(1, 10), 2)
    }

# Simulate 5 readings & check prediction
for _ in range(5):
    sensor_data = generate_sensor_data()
    print(f"Sensor data: {sensor_data}") # <-- fixed: removed extra quote
    features = np.array([sensor_data['vibration'], sensor_data['temperature'], sensor_data['pressure']])
    prediction = model.predict(features)[0]
    if prediction == 1:
        print("⚠ Alert: Failure predicted!\n")
    else:
        print("✅ All normal.\n")

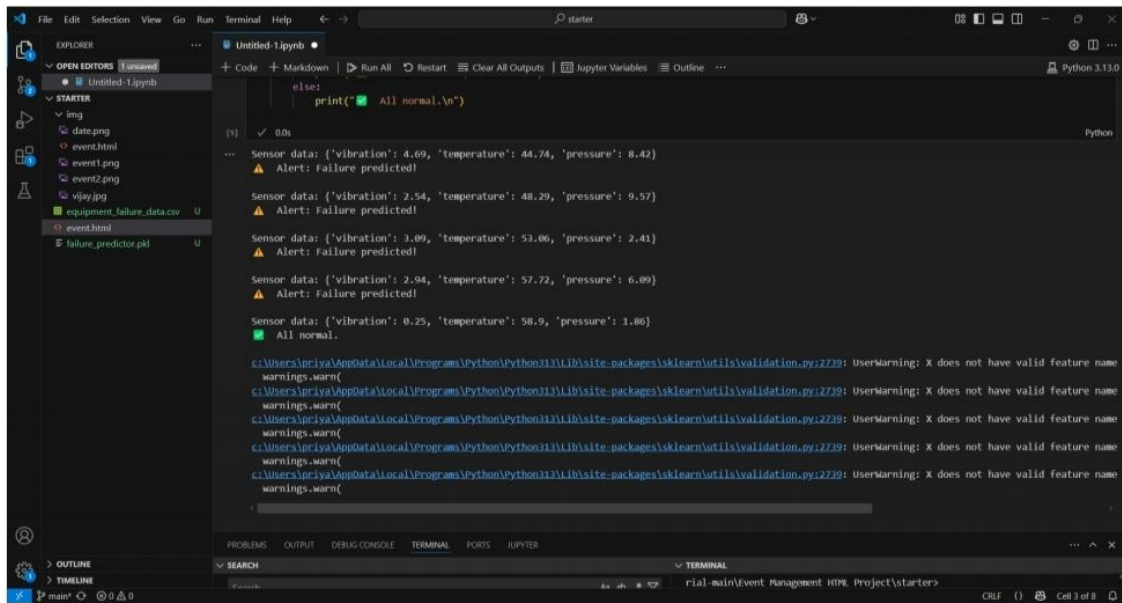
[1] ✓ 0.0s Python
... Sensor data: {'vibration': 4.69, 'temperature': 44.74, 'pressure': 8.42}
  ⚠ Alert: Failure predicted!

Sensor data: {'vibration': 2.54, 'temperature': 48.29, 'pressure': 9.57}
  ⚠ Alert: Failure predicted!

Sensor data: {'vibration': 3.09, 'temperature': 53.06, 'pressure': 2.41}
  ⚠ Alert: Failure predicted!

Sensor data: {'vibration': 2.94, 'temperature': 57.72, 'pressure': 6.09}

PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL PORTS JUPYTER
SEARCH
r:\main\Event Management HTML Project\starter>
```



```
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Python 3.13.0

else:
    print(" All normal.\n")

[1] ✓ 0.0s
Python

Sensor data: {'vibration': 4.69, 'temperature': 44.74, 'pressure': 8.42}
Alert: Failure predicted!

Sensor data: {'vibration': 2.54, 'temperature': 48.29, 'pressure': 9.57}
Alert: Failure predicted!

Sensor data: {'vibration': 3.09, 'temperature': 53.06, 'pressure': 2.41}
Alert: Failure predicted!

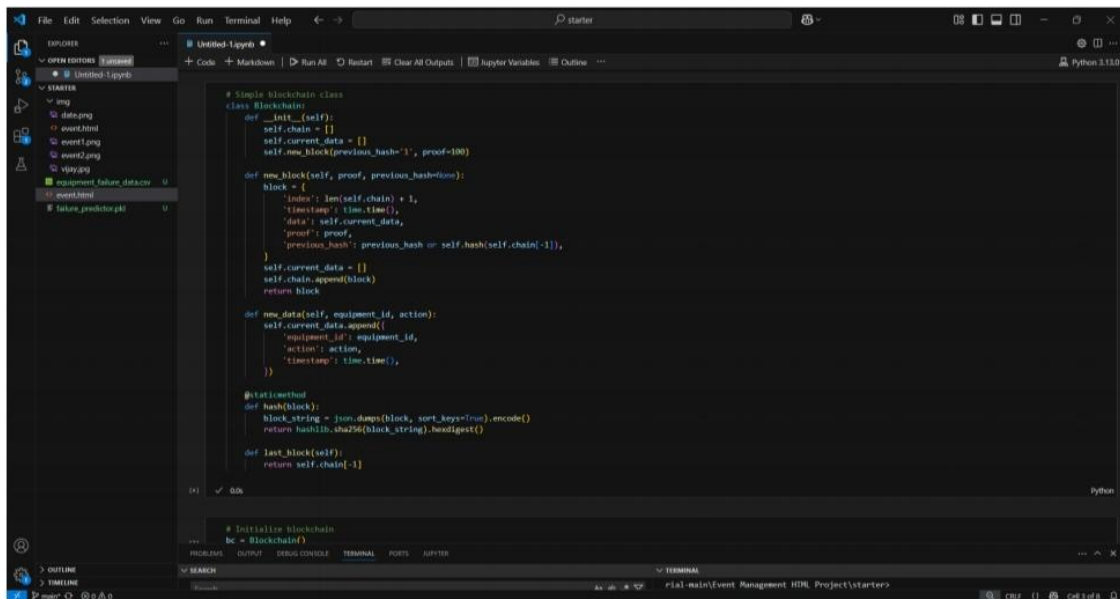
Sensor data: {'vibration': 2.94, 'temperature': 57.72, 'pressure': 6.09}
Alert: Failure predicted!

Sensor data: {'vibration': 0.25, 'temperature': 58.9, 'pressure': 1.86}
All normal.

c:\Users\priva\AppData\Local\Programs\Python\Python313\lib\site-packages\sklearn\utils\validation.py:2739: UserWarning: X does not have valid feature name
warnings.warn(
c:\Users\priva\AppData\Local\Programs\Python\Python313\lib\site-packages\sklearn\utils\validation.py:2739: UserWarning: X does not have valid feature name
warnings.warn(
c:\Users\priva\AppData\Local\Programs\Python\Python313\lib\site-packages\sklearn\utils\validation.py:2739: UserWarning: X does not have valid feature name
warnings.warn(
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warnings.warn(
c:\Users\priva\AppData\Local\Programs\Python\Python313\lib\site-packages\sklearn\utils\validation.py:2739: UserWarning: X does not have valid feature name
warnings.warn(

PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL PORTS JUPYTER
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trial-main\Event Management HTML Project\starters
Cell 7 of 8
```

CELL 5: Blockchain Logger



```
File Edit Selection View Go Run Terminal Help
Untitled-1.ipynb
+ Code + Markdown + Run All + Restart + Clear All Outputs + Jupyter Variables + Outline ...
Python 3.13.0

# Simple blockchain class
class Blockchain:
    def __init__(self):
        self.chain = []
        self.current_data = []
        self.new_block(previous_hash='1', proof=100)

    def new_block(self, proof, previous_hash=None):
        block = {
            'index': len(self.chain) + 1,
            'timestamp': time.time(),
            'data': self.current_data,
            'proof': proof,
            'previous_hash': previous_hash or self.hash(self.chain[-1]),
        }
        self.current_data = []
        self.chain.append(block)
        return block

    def new_data(self, equipment_id, action):
        self.current_data.append({
            'equipment_id': equipment_id,
            'action': action,
            'timestamp': time.time(),
        })

    @staticmethod
    def hash(block):
        block_string = json.dumps(block, sort_keys=True).encode()
        return hashlib.sha256(block_string).hexdigest()

    def last_block(self):
        return self.chain[-1]

[1] ✓ 0.0s
Python

# Initialize blockchain
bc = Blockchain()

PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL PORTS JUPYTER
SEARCH
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Cell 8 of 8
```

CELL 6: Test blockchain logging

