PREDICTIVE MAINTENANCE ANALYTICS FOR SMART MANUFACTURING
Use Case Proposal & Business Understanding

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1. Industry & Organization Context

Industry:
Industrial Manufacturing / CNC Milling Operations

Organization (Fictional Scenario):
A medium-sized smart factory operating multiple sensor-equipped CNC milling machines producing three product variants (L, M, H). Machines log operational parameters such as air temperature, process temperature, rotational speed, torque, and tool wear during production cycles, generating timestamped event data.

2. Business Problem Statement

The organization currently faces the following challenges:

- Frequent unplanned machine failures causing production downtime and delayed customer orders
- A reactive maintenance approach, where interventions occur after failures rather than proactively
- Limited visibility into which machines, product types, or operating conditions correlate with failures
- Absence of data-driven decision support, with maintenance planning relying on fixed schedules or experience rather than analytics
- High emergency repair costs, as reactive maintenance is significantly more expensive than planned interventions

Root Cause:
Although machine sensor data exists, it remains fragmented and unanalyzed, with no centralized BI platform to transform raw logs into actionable maintenance intelligence.

3. Proposed Solution Objectives

This Business Intelligence (BI) project aims to:

1. Establish machine reliability monitoring through standardized KPIs tracking failure rates, downtime, and maintenance intervals
2. Identify high-risk operational patterns by analyzing correlations between product types, machines, and operating conditions with failure events
3. Enable predictive maintenance strategies by developing dashboards that shift maintenance from reactive to proactive
4. Support resource allocation decisions using objective data to prioritize critical assets
5. Define safe operating boundaries by identifying temperature and tool-wear thresholds associated with increased failure risk

4. Analytical Questions to Address

The BI solution will investigate the following ten key questions:

1. What is the overall machine failure rate, and how is it distributed across failure modes (HDF, OSF, PWF, TWF, RNF)?
2. Which product types (L, M, H) exhibit higher failure rates during production?
3. Which machines or production lines experience more frequent failures?
4. Under which operating conditions (temperature, torque, speed, tool wear) do failures tend to occur?
5. How do temperature and tool wear levels differ between failed and non-failed operations?
6. How does the failure rate trend over time (daily, monthly, by shift)?
7. Are there identifiable temperature or tool-wear thresholds where failure probability increases?
8. How do failures distribute across different shifts or working days versus weekends?
9. Which product–machine combinations represent the highest risk?
10. What production impact do failures cause, and which preventive interventions would be most effective?

5. Proposed Key Performance Indicators (KPIs)

The BI solution will implement eight core KPIs:

KPI 1: **Machine Failure Rate (%)**
Definition: Percentage of production events resulting in failure
Business Value: Primary reliability metric for system health monitoring

KPI 2: **Failure Distribution by Mode**
Definition: Breakdown of failures by type (HDF, OSF, PWF, TWF, RNF)
Business Value: Prioritizes root-cause investigation efforts

KPI 3: **Failure Rate by Product Type**
Definition: Failure percentage for each product variant
Business Value: Identifies products requiring process adjustments

KPI 4: **Failure Rate by Machine**
Definition: Failure percentage per machine or production line
Business Value: Highlights assets requiring maintenance priority

KPI 5: **Temperature Analysis**
Definition: Temperature comparison between failed and normal operations
Business Value: Establishes thermal thresholds for early alerts

KPI 6: **Tool Wear Analysis**
Definition: Tool wear comparison between failed and normal operations
Business Value: Defines optimal tool replacement intervals

KPI 7: **Temporal Failure Patterns**
Definition: Failure trends by shift, day, and month
Business Value: Reveals scheduling or operational patterns

KPI 8: **Production Impact Metric**
Definition: Percentage of production capacity lost due to failures
Business Value: Quantifies the business case for preventive maintenance

6. Data Source & Project Scope

Planned Data Source:
AI4I 2020 Predictive Maintenance Dataset
(UCI Machine Learning Repository / Kaggle)

Dataset Characteristics:

- 10,000 machine-event records from CNC milling operations
- Features include product type, air temperature, process temperature, rotational speed, torque, and tool wear
- Binary indicators for overall failure and specific failure modes

Project Scope:
The analysis will focus on identifying patterns, developing predictive insights, and creating interactive dashboards to support maintenance decision-making.

7. Expected Deliverables

The project will produce the following deliverables:

- Data Model: Star schema design including a fact table (machine events) and dimension tables (Date, Machine, Product Type)
- ETL Pipeline: Scripts for data cleaning, transformation, and loading
- Interactive Dashboards:
    - Executive Summary view with high-level KPIs
    - Deep-dive analysis for detailed patterns and correlations
    - Additional analytical views with drill-down and forecasting capabilities
- Calculated Measures: DAX formulas for aggregation, year-over-year (YoY), and month-over-month (MoM) analysis
- Insights Report: Key findings, recommendations, and an implementation roadmap

8. Expected Outcomes & Benefits

Successful implementation is expected to enable:

- A 25–35% reduction in unplanned downtime through predictive maintenance strategies
- A 20–30% decrease in maintenance costs by shifting from reactive to planned interventions
- Extended equipment lifespan through operation within safe parameter boundaries
- Improved production scheduling with enhanced machine health visibility
- A data-driven cultural shift from intuition-based to analytics-based maintenance decisions

Project Team:
Roua Smida, Rooya Jelassi, Mohamed Al Aziz Shabou, Mohamed Nidhal El Moulaa