Course Presentation

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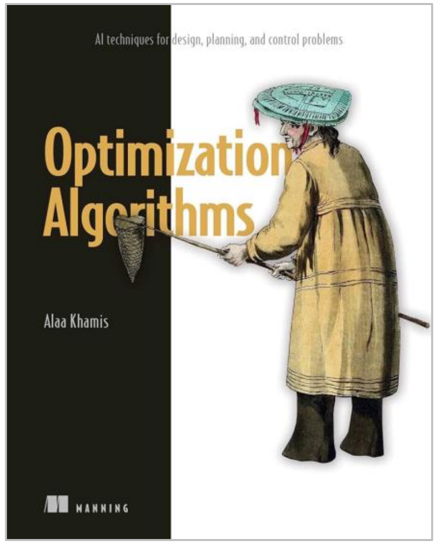
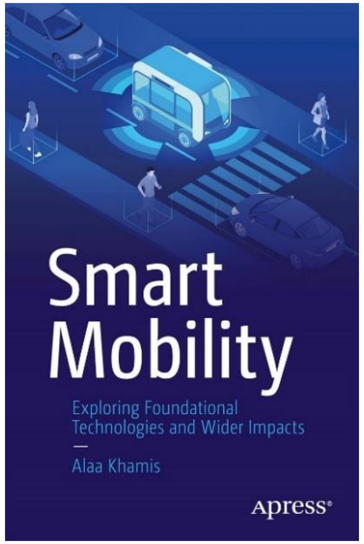
Associate Professor and Director of AI for Smart Mobility Lab

Lecture 1 – Monday August 25, 2025

About Me

- Associate Professor in ISE Department at KFUPM
- Director of AI for Smart Mobility Lab
- Affiliated with IRC for Smart mobility and Logistics
- Former AI & Smart Mobility Technical Leader at General Motors
- Adjunct Faculty at University of Toronto and Ontario Tech University, Canada.





About You

- Your name?
- Where do you work?
- What sparked your interest in taking this course?

Outline

- Course Description
- Course Topics
- Course Outline
- Grading
- Course Project
- Resources

Outline

- **Course Description**
- Course Topics
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Course Description

This course provides a comprehensive overview of **data analytics** techniques that improve asset **reliability and maintenance** performance in an Industry 4.0 setting.

Topics cover the complete **analytics pipeline**: data ingestion and cleansing, feature engineering, descriptive, diagnostic analysis, predictive modeling, prescriptive optimization, and system observability. Lectures combine theory with hands-on exercises drawn from Industry 4.0 contexts, culminating in a team project that applies multiple analytic techniques to a real or simulated maintenance problem.

Course Description

Data

Data Analysis

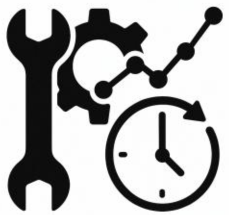
- Descriptive Analytics
- Diagnostic Analytics
- Predictive Analytics
- Prescriptive Analytics

Reliability

- Reliability Modelling (parametric and non- parametric)
- Reliability indices & Failure Analysis
- Reliability Testing

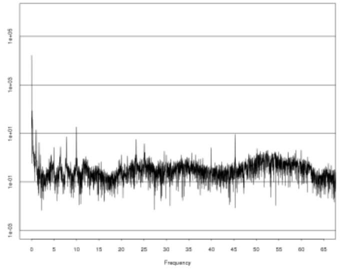
Maintenance

- Improvement (reliability-driven)
- Corrective (event-driven)
- Preventive (Equipment-driven, time-driven and predictive)



Course Description

- **Data**

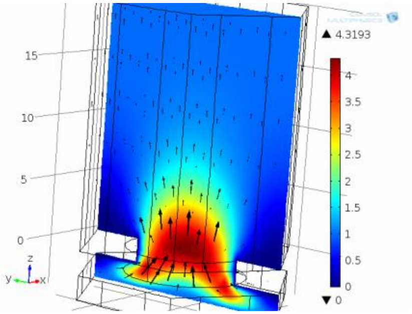


Time-series

(vibration, temperature, pressure)

Audio

(leak detection, abnormal machine sounds)

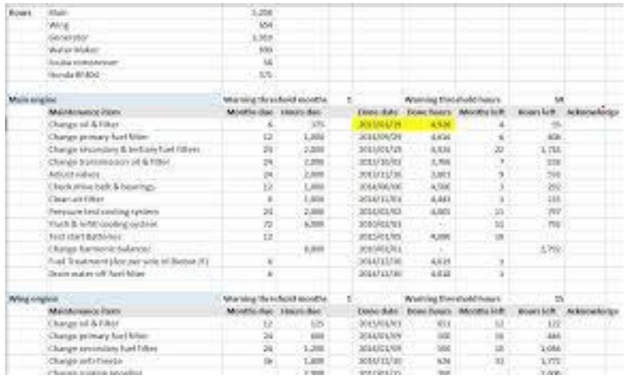


Image

(thermal/hyperspectral scans, surface inspection)

Video

(continuous monitoring of operations)

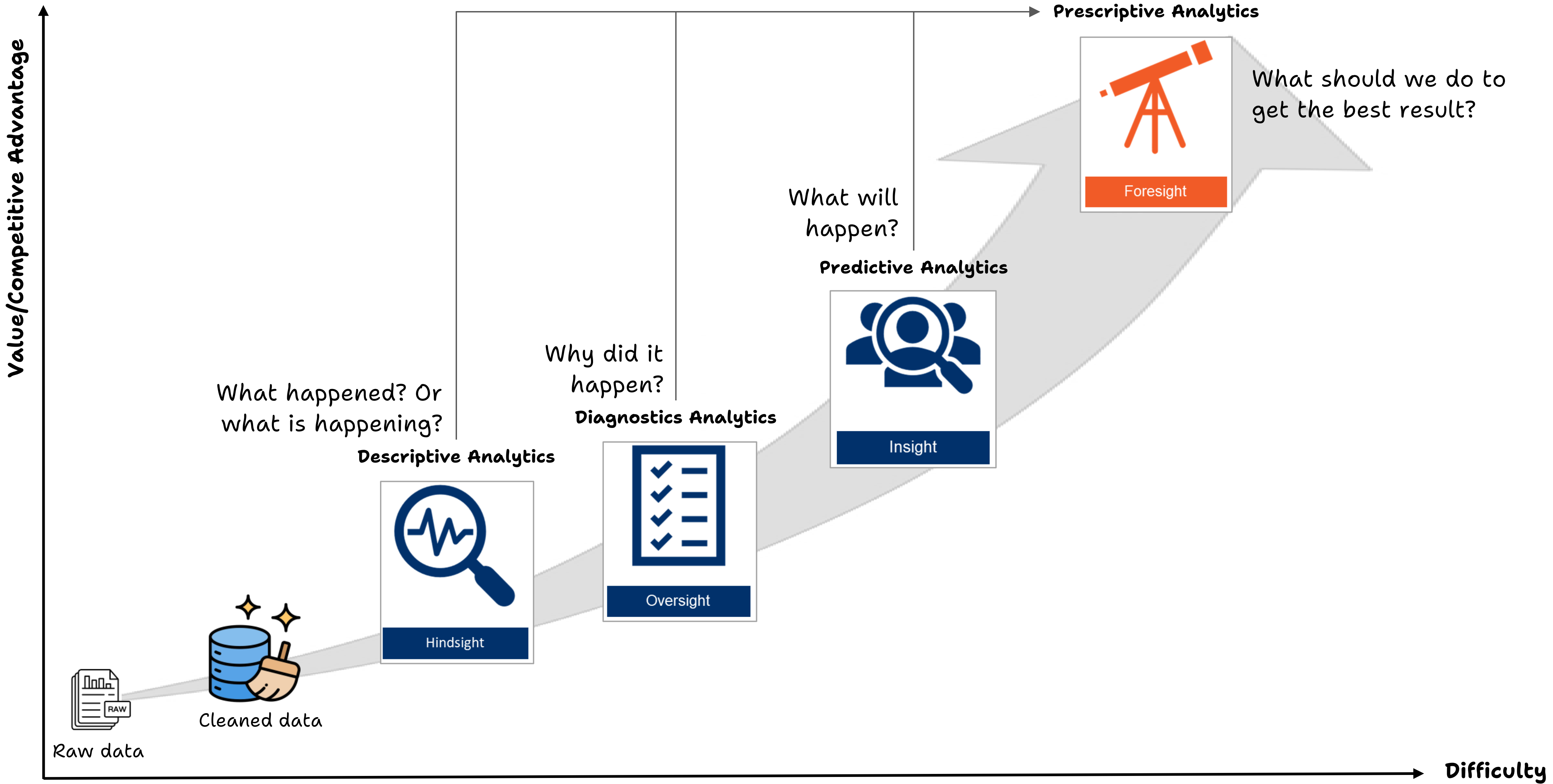


Text

(maintenance logs, incident reports)

Course Description

- Data Analytics



Course Description

- **Data Analytics: Conveyor Belt Example**

Value/Competitive Advantage

Raw data

Cleaned data → Monthly reports or CMMS logs

What happened? Or what is happening?

Descriptive Analytics

Hindsight → The conveyor experienced 12 micro-stoppages averaging 90 seconds each, always preceded by a spike in motor current above 15 A.

Why did it happen?

Diagnostics Analytics

Oversight → Analysis links each current spike to misaligned guide rails that pushed bottles off center, creating extra friction and overloading the drive motor.

What will happen?

Predictive Analytics

Insight → A predictive model estimates a 70 % chance that the motor current will exceed 15 A within the next three production shifts, triggering another micro-stoppage if alignment is not corrected.

Prescriptive Analytics

What should we do to get the best result?

Foresight → A recommendation engine advises realigning the guide rails during the next 10-minute changeover and implementing a weekly alignment check, projecting a 40 % reduction in unplanned downtime and saving two hours of line capacity per month.

Difficulty

Course Description

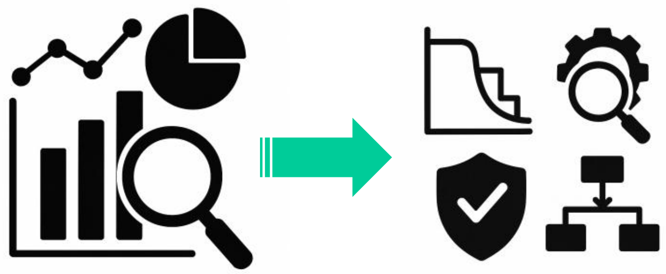
- **Reliability**

Reliability is the probability that a product or system will operate as intended, under specified operating conditions for a specific period.

Reliability is consistent quality over a specified period.

Course Description

- **Data Analysis for Reliability**



Sensory data

- Motor current
- Thermography
- Vibration
- Acoustics

Low-voltage motor

Data Analysis for Reliability

Descriptive Analytics

- Failure rate trends
- Mean Time Between Failure (MTBF) and availability metrics
- Historical reliability summaries

Diagnostic Analytics

- Root cause identification
- Failure mode classification
- Insights for design or process improvement

Predictive Analytics

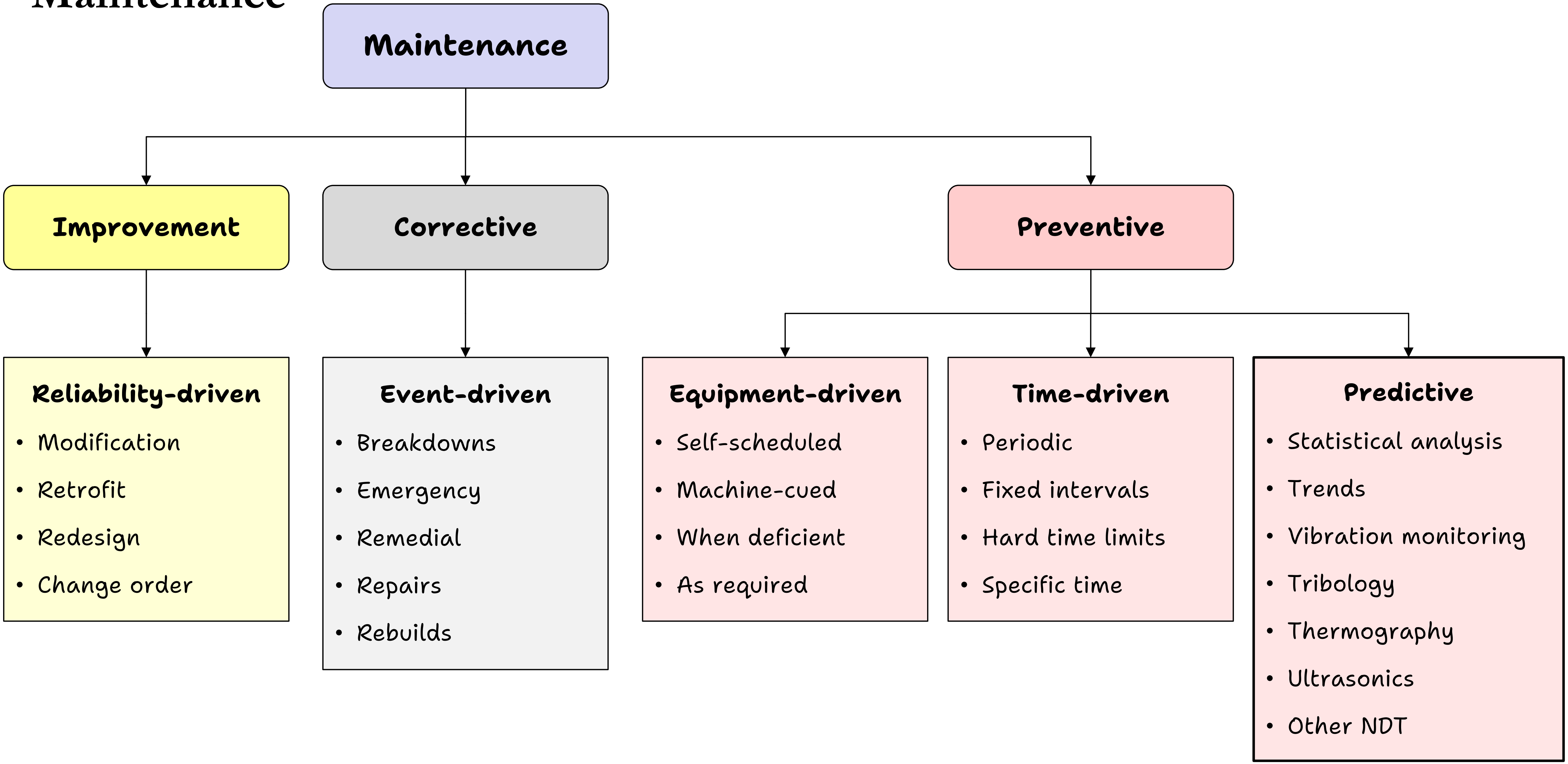
- Estimating failure probability over time
- Forecasting expected lifetime
- Modeling degradation patterns (e.g., wear, corrosion, thermal stress)
- Fitting life distributions (e.g., Weibull, Lognormal) using machine learning or statistical models

Prescriptive Analytics

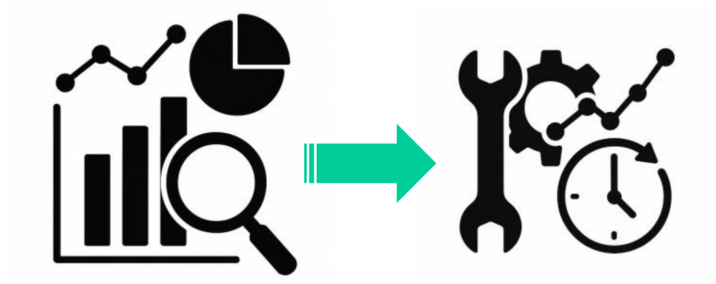
- Recommend design changes to address predicted failure risks
- Propose optimal system configurations to meet reliability targets
- Optimize testing strategies (e.g., test types, durations, sample sizes)
- Prioritize risk mitigation actions based on predicted failure impact

Course Description

- Maintenance



- Data Analysis for Reliability



Sensory data

- Motor current
- Thermography
- Vibration
- Acoustics

Low-voltage motor

Data Analysis for Maintenance

Descriptive Analytics

- Detects abnormal trends (e.g., rising temperature or vibration)
- Summarizes operating history and performance
- Establishes normal operating baselines

Diagnostic Analytics

- Identifies causes of anomalies or failures
- Correlates sensor patterns with known faults
- Classifies failure types (e.g., misalignment, wear)

Predictive Analytics

- Forecasts future failures or degradation
- Estimates remaining useful life (RUL)
- Triggers condition-based maintenance actions

Prescriptive Analytics

- Optimized maintenance schedules
- Recommended repair or replacement actions
- Efficient spare parts and resource planning
- Targeted failure risk mitigation
- Real-time adaptive maintenance strategies
- Minimized lifecycle maintenance costs

Course Description

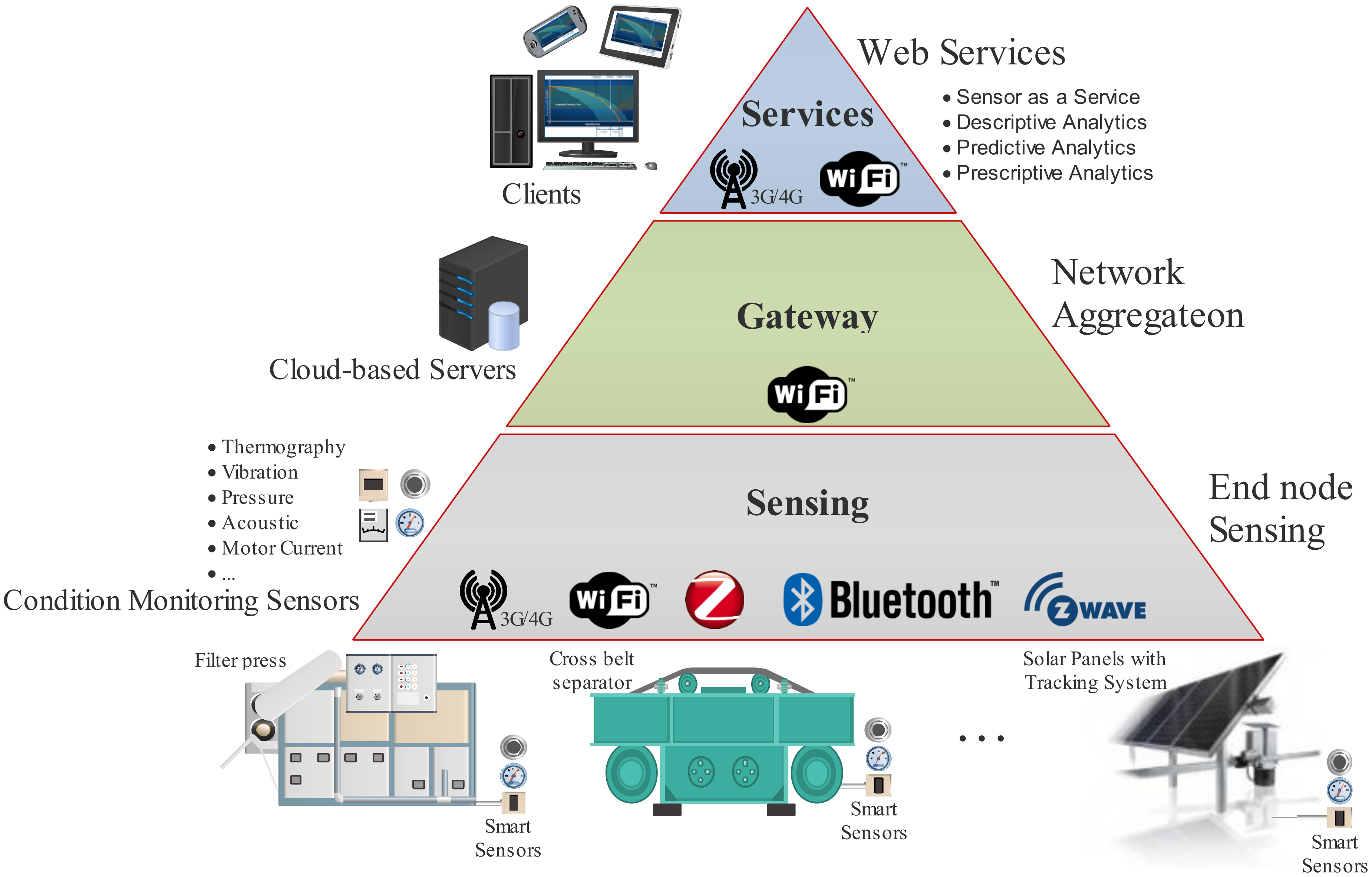
- **Data Analysis for Maintenance**

https://www.youtube.com/watch?v=Ewnr-lS58eE

Alaa Khamis. Cognitive IoT-based Predictive Maintenance System. US, 62819700, 2019.

Course Description

- **Data Analysis for Maintenance**



Alaa Khamis. Cognitive IoT-based Predictive Maintenance System. US, 62819700, 2019.

Course Description

1. Foundations

- Python Refresher
- Reliability & Maintenance 4.0 Overview
- Introduction to Data analytics

2. Data Acquisition and Preparation

- Data Sources in Maintenance Systems
- Data Imperfection Aspects
- Data Cleansing
- Feature Extraction & Engineering

3. Descriptive Analytics

- Data summarization
- Visualization Techniques
- Clustering
- Association Rules
- Anomaly Detection

4. Diagnostic Analytics

- Correlation Analysis
- Root Cause Analysis

5. Predictive Analytics

- Time-series forecasting
- ML for predictive maintenance
- Remaining Useful Life (RUL) Prediction

6. Prescriptive Analytics

- Optimization models
- Recommender systems

7. Observability

- Telemetry Data: Metrics, logs, traces
- OpenTelemetry
- Grafana

Course Description

- **Course Objectives**

  By the end of the course, participants will be able to

  - Collect, cleanse, and engineer features from maintenance data sources.
  - Summarize and visualize reliability data, perform clustering, discover association rules, and detect anomalies.
  - Diagnose failure causes using correlation analysis and structured root-cause methods.
  - Build models that forecast failures, predict remaining useful life, and support predictive maintenance.
  - Recommend optimal maintenance actions through optimization models and recommender systems.
  - Implement observability pipelines with metrics, logs, traces, and dashboards

Outline

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- **Course Topics**
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- Grading
- Course Project
- Resources

Course Topics

- Reliability and Maintenance 4.0 fundamentals and key KPIs
- Overview of descriptive, diagnostic, predictive, and prescriptive analytics
- Maintenance data sources from sensors, IoT devices, CMMS logs, and traces
- Data imperfections such as missing values, outliers, noise, sparsity, and drift
- Data cleansing, standardization, imputation, and outlier mitigation
- Feature extraction, selection, dimensionality reduction, and encoding
- Descriptive analytics: summarization, visualization, clustering, association rules, and anomaly detection
- Diagnostic analytics: correlation analysis and structured root-cause methods
- Predictive analytics: regression & classification, time-series forecasting, and RUL prediction
- Prescriptive analytics: optimization, and recommender systems
- Observability with telemetry data collection: OpenTelemetry instrumentation, and Grafana

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Course Outline

Week	Date	Lectures	Assignments
1	Monday August 25, 2025	Course Presentation	
1	Wednesday August 27, 2025	Python Refresher-I	
2	Monday September 01, 2025	Python Refresher-II	
2	Wednesday September 03, 2025	Introduction to Reliability & Maintenance	
3	Monday September 08, 2025	Introduction to Data Analytics	
3	Wednesday September 10, 2025	Data Sources	
4	Monday September 15, 2025	Data Imperfection Aspects	
4	Wednesday September 17, 2025	Data Preparation I	Team Formation Deadline
5	Monday September 22, 2025	Data Preparation II	
5	Wednesday September 24, 2025	Feature Engineering I	
6	Monday September 29, 2025	Feature Engineering II	
6	Wednesday October 01, 2025	Descriptive Analytics I	
7	Monday October 06, 2025	Descriptive Analytics II	Assignment-1 Problem Characterization
7	Wednesday October 08, 2025	Descriptive Analytics III	
8	Monday October 13, 2025	Descriptive Analytics IV	
8	Wednesday October 15, 2025	Diagnostic Analytics I	
9	Monday October 20, 2025	Diagnostic Analytics II	
9	Wednesday October 22, 2025	Midterm Exam	
10	October 26-30, 2025	Midterm Break	
11	Monday November 03, 2025	Predictive Analytics I	
11	Wednesday November 05, 2025	Predictive Analytics II	
12	Monday November 10, 2025	Predictive Analytics III	
12	Wednesday November 12, 2025	Predictive Analytics IV	
13	Monday November 17, 2025	Prescriptive Analytics I	Assignment-2 Related Work
13	Wednesday November 19, 2025	Prescriptive Analytics II	
14	Monday November 24, 2025	Observability for Reliability and Maintenance Monitoring I	
14	Wednesday November 26, 2025	Observability for Reliability and Maintenance Monitoring II	
15	Monday December 01, 2025	Observability for Reliability and Maintenance Monitoring III	
15	Wednesday December 03, 2025	Observability for Reliability and Maintenance Monitoring IV	Final Report Submission
16	Monday December 08, 2025	Final Project Presentations I	
16	Wednesday December 10, 2025	Final Project Presentations II	
17	Dec. 15-27, 2025	Final examinations	

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Grading

Evaluation Method	Weight
Assignments	20%
Attendance	5%
In-class participation	5%
Midterm Exam	25%
Course Project	45%
Total	100%

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- Grading
- **Term Project**
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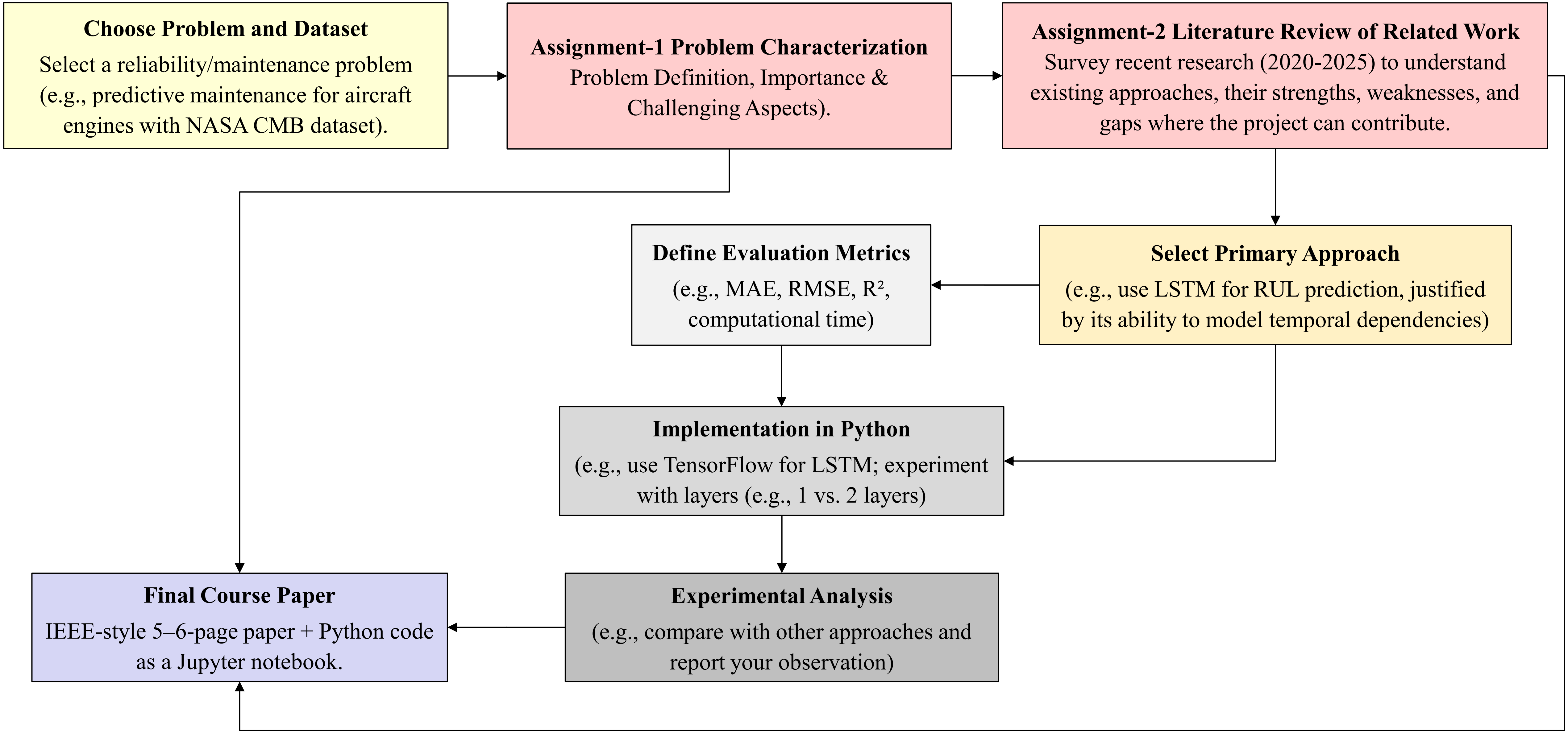
Course Project

- Projects MUST be done in a group of **2 students**.
- Students explore the applicability of the different techniques studied in the course to handle a selected reliability/maintenance problem.
- Students choose a data analytics approach to handle this problem and justify their choice.
- Students establish a set of **evaluation metrics** and **analyze experimentally** the performance of the implemented technique in Python with different parameters. Students must identify the pros and cons of the implemented approach and how this solution differs or extends the related approaches reported in the recent literature .
- Students conduct a **comparative study** between the selected approach and other potential approach to quantitatively and qualitatively evaluate these approaches in terms of a number of well-defined evaluation metrics and using the problem data as a benchmark dataset.

Course Project

- **Example Project Workflow**



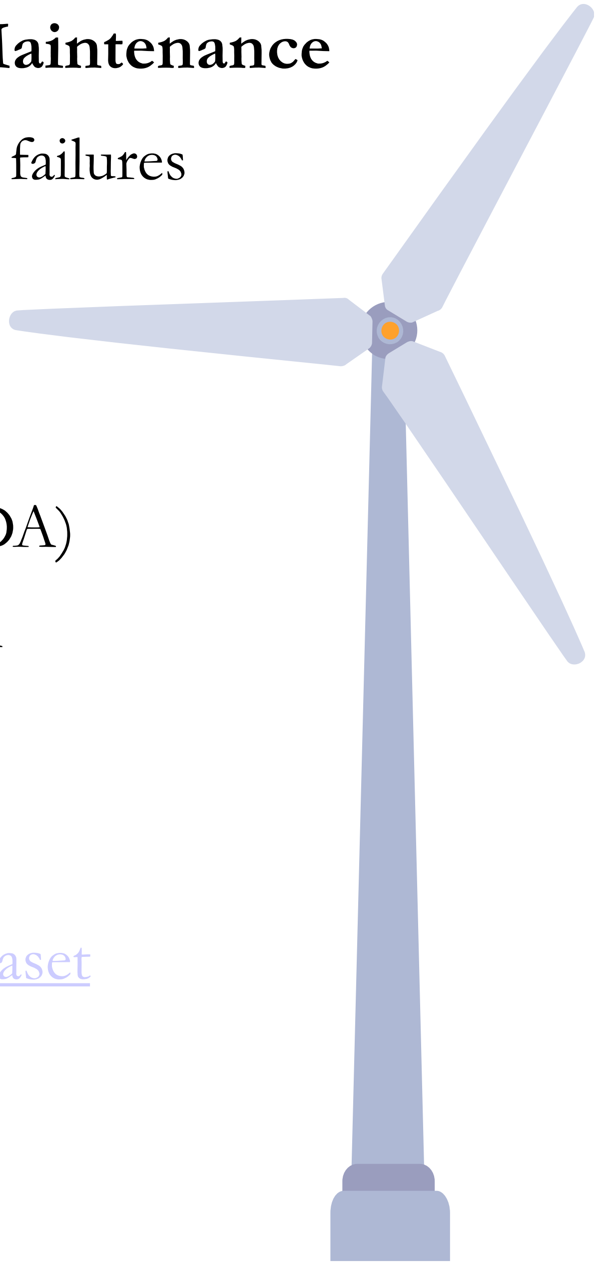
- **Suggested Project Ideas: Anomaly Detection in Wind Turbine Maintenance**

Problem: Detect anomalies in wind turbine sensor data to identify potential failures early, reducing downtime in renewable energy systems.

Dataset: Wind Turbine SCADA Dataset.

- Description: Contains supervisory control and data acquisition (SCADA) data, including power output, wind speed, and component status, with labeled anomalies.
- Source: Available via Kaggle at https://www.kaggle.com/datasets/berkerisen/wind-turbine-scada-dataset

  https://zenodo.org/records/14958989



Course Project

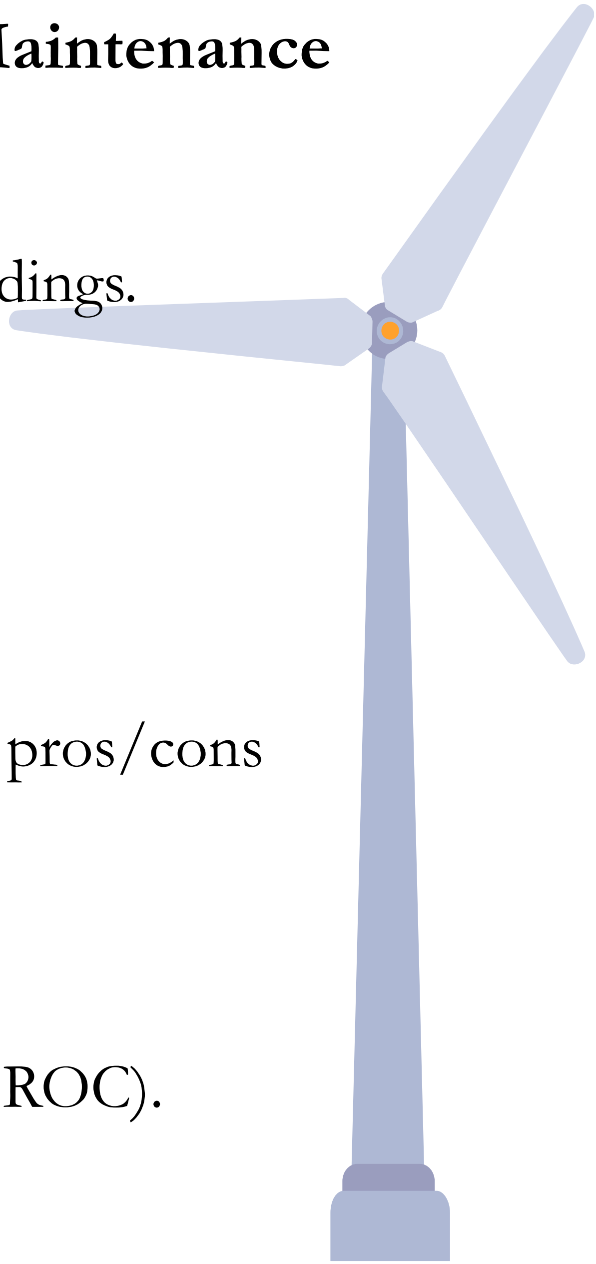
- **Suggested Project Ideas: Anomaly Detection in Wind Turbine Maintenance**

Tasks:

- Implement an isolation forest model to detect anomalies in sensor readings.
- Compare with an autoencoder-based approach, evaluating metrics like precision, recall, and F1-score.
- Experiment with different model parameters.
- Review recent literature on wind turbine anomaly detection to discuss pros/cons and innovations.

Evaluation Metrics:

- Quantitative: Precision, recall, F1-score, area under ROC curve (AUC-ROC).
- Qualitative: ease of integration with existing systems.



- **Suggested Project Ideas: Others**

Dataset Library

Dataset	Domain / Type	Applications	Highlights
🔧 Machine Predictive Maintenance Classification (Kaggle)	Industrial machines (synthetic)	Failure classification	Includes machine operating parameters and failure types
⏱ Predictive Maintenance Dataset AI4I 2020 (Kaggle)	Synthetic industrial machines	Classification, regression	Well-known UCI dataset republished on Kaggle
⚙ Machine Failure Prediction (Kaggle)	Industrial sensor data (synthetic)	Failure event prediction	Includes temperature, pressure, vibration, humidity, power consumption
💾 Hard Drive Reliability Data Set (Kaggle)	Storage hardware	Failure prediction	Real-world drive health data from Backblaze
🤖 Preventive-to-Predictive Maintenance (Kaggle)	Industrial scenarios	Prognostics & diagnostics	Created by Bosch for real-world maintenance benchmarking
🛠 Engine Failure Detection (Kaggle)	Engine sensor data	Predictive maintenance	Includes sensor readings and fault conditions
✈ C-MAPSS (Turbofan Engine Simulation)	Simulated aircraft engines	RUL prediction, degradation modeling	Benchmark dataset in prognostics research with multiple scenarios
🚇 MetroPT-3 (Air Compressor)	Metro train compressor	Predictive maintenance, anomaly detection	Real sensor data (15 signals at 1 Hz) with failure events
📊 NASA Prognostics Data Repository	Run-to-failure experiments	Reliability & prognostics across components	Includes bearings, composites, milling, batteries, turbofan, etc.
📈 MetroPT (Zenodo/Nature)	Train APU with GPS	Predictive maintenance, anomaly benchmarking	Multimodal sensor data with labeled anomalies

https://github.com/Dr-AlaaKhamis/ISE518/tree/main/datasets

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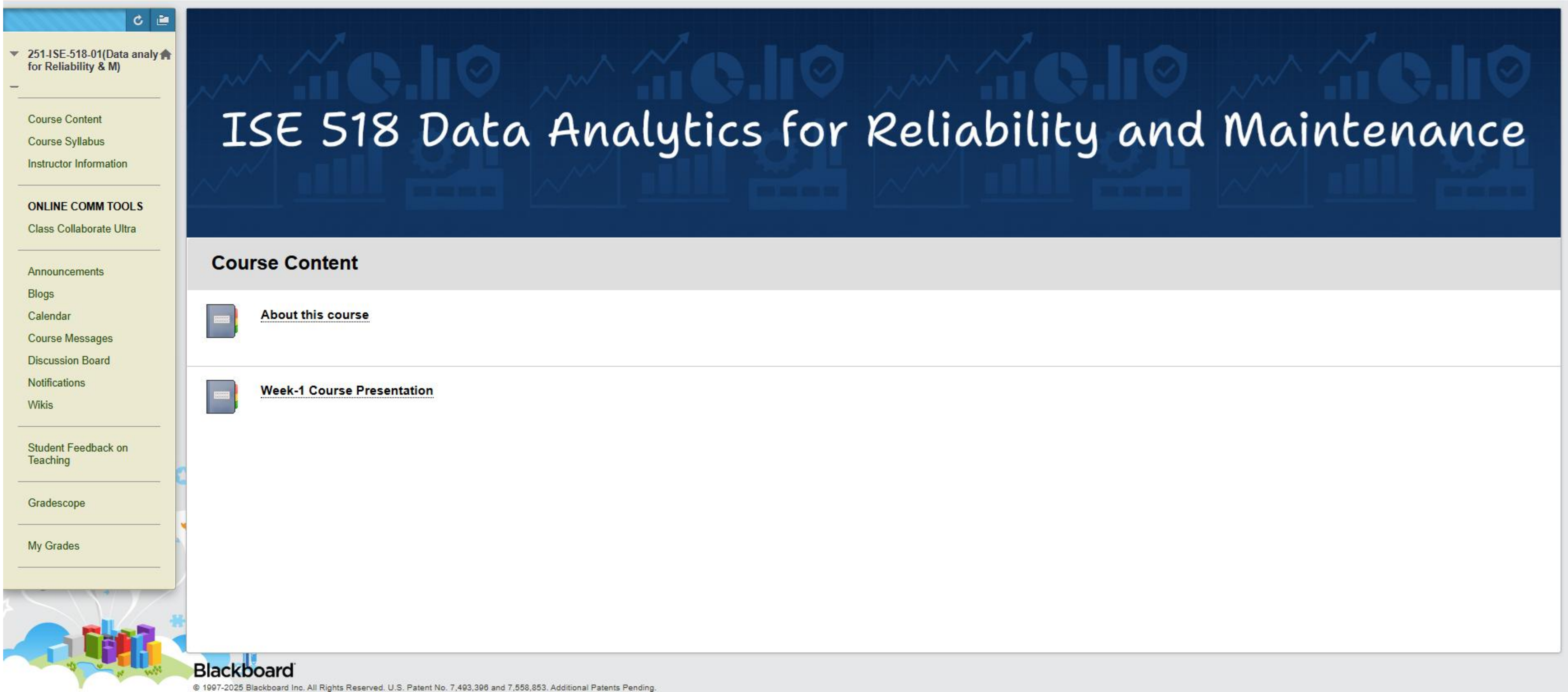
- Assignments
- Course Project
- **Resources**

Resources

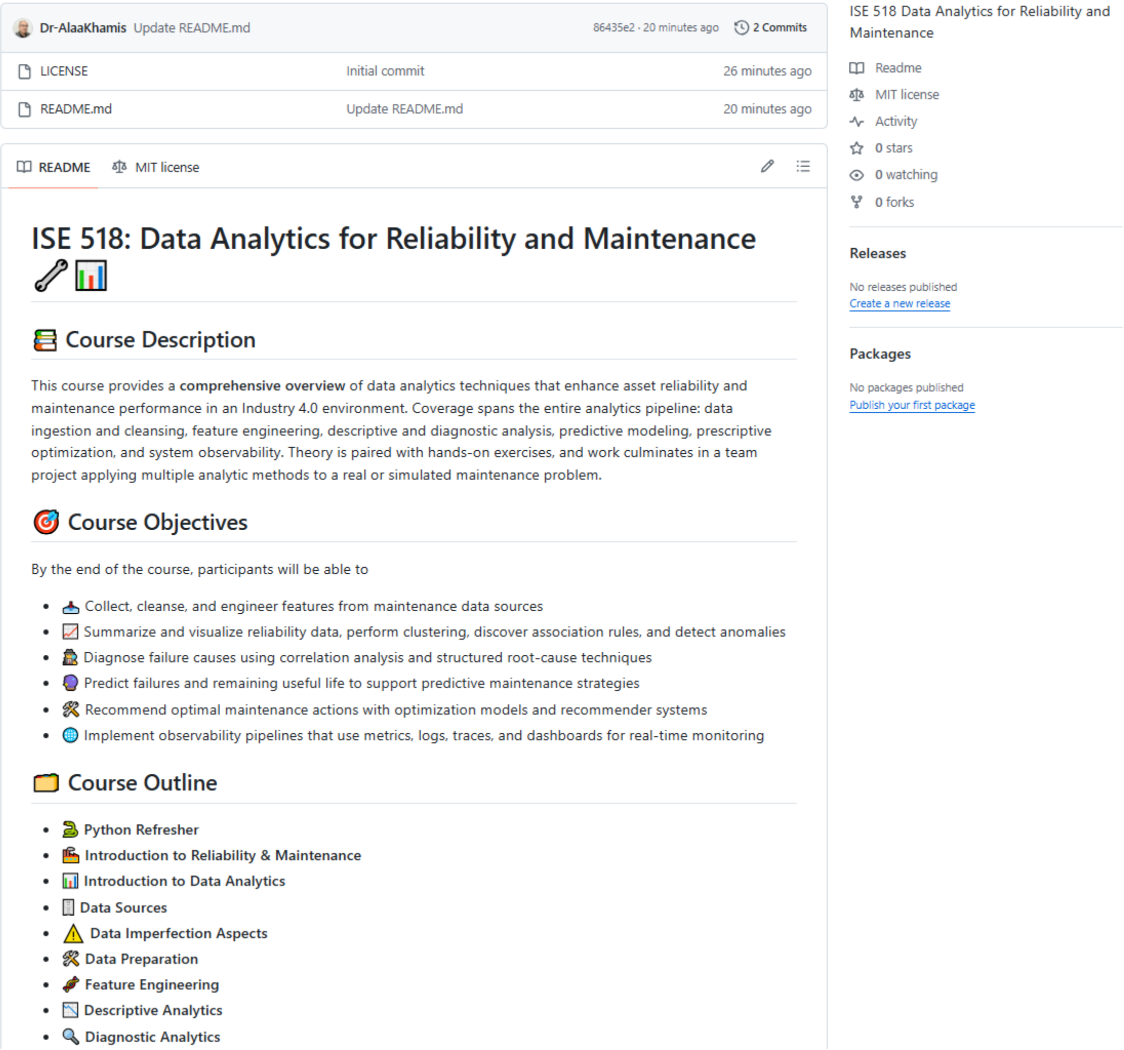
- **Course Website**

  Lecture slides and reading materials will be posted on Blackboard



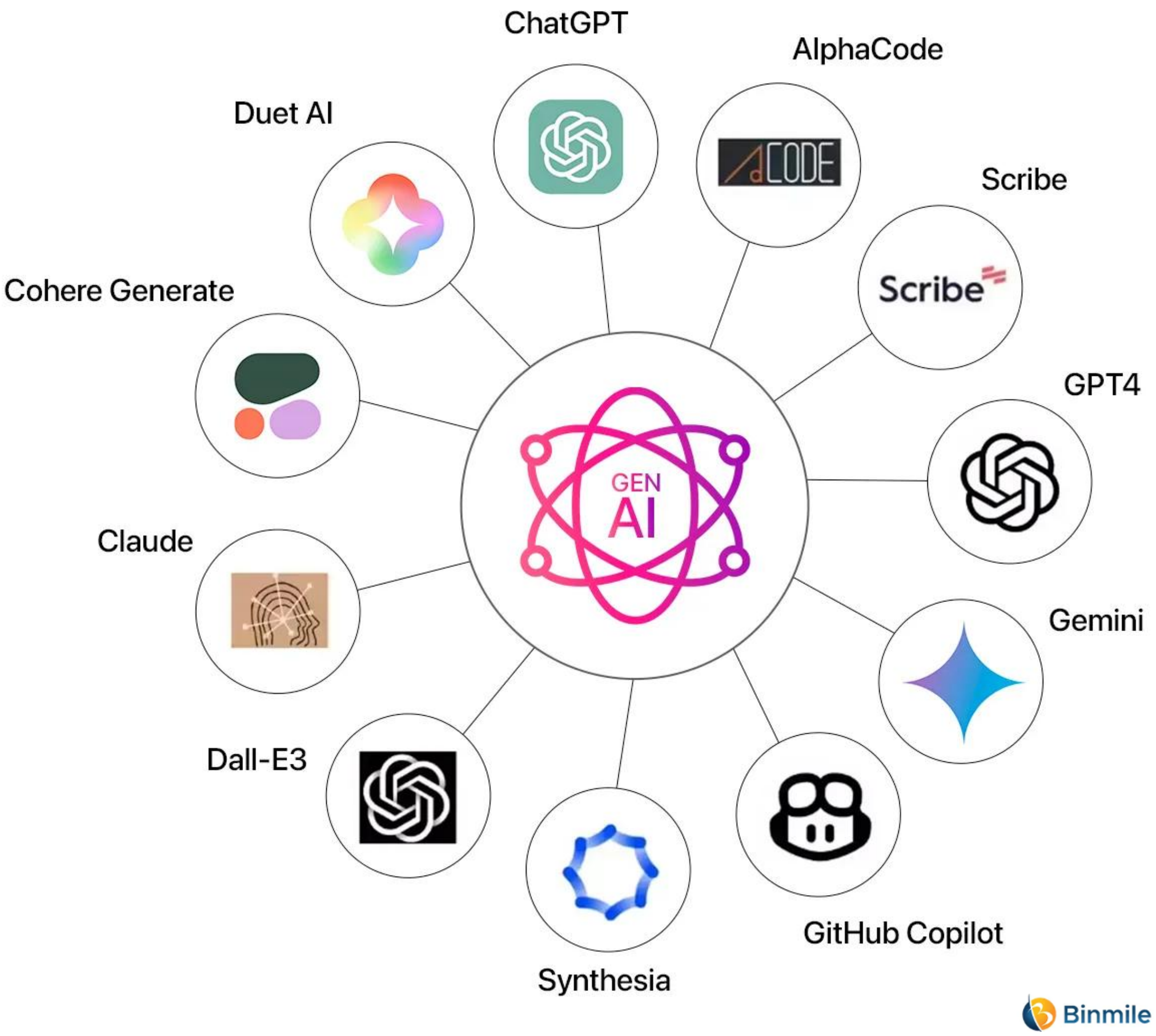
Resources

- **Open-source sample codes and data**
  - Course GitHub repo: https://github.com/Dr-AlaaKhamis/ISE518



Resources

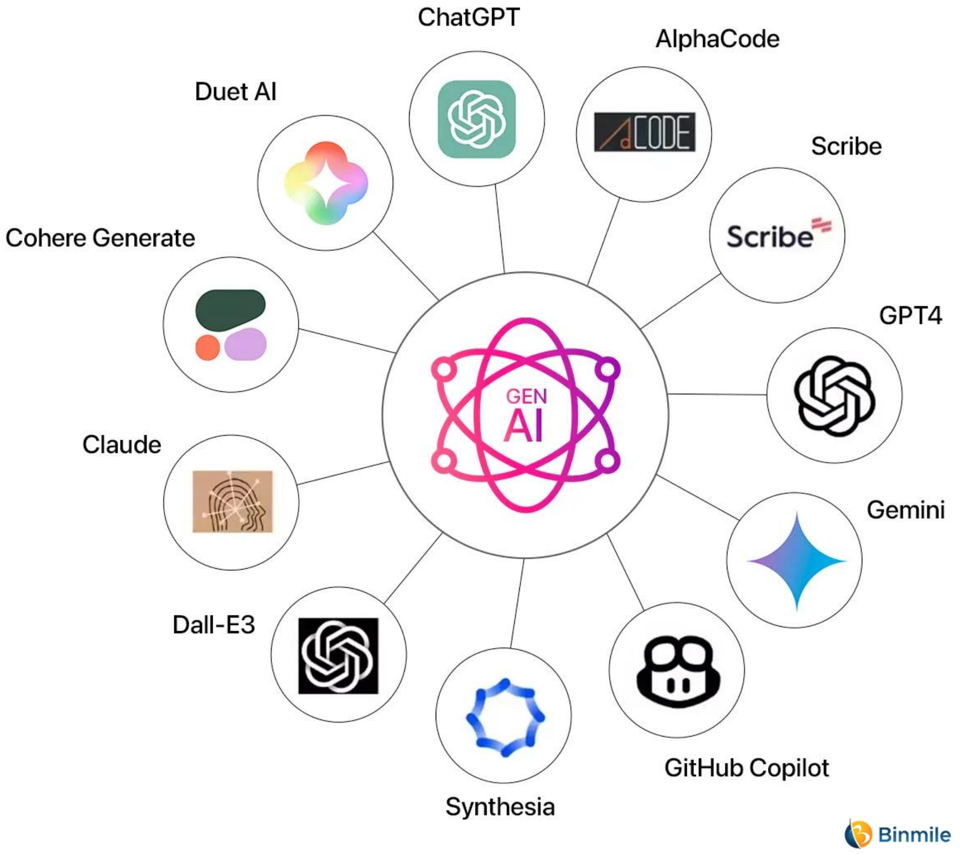

Generate by Gemini


ChatGPT
AlphaCode
Duet AI
Scribe
Cohere Generate
GPT4
GEN AI
Claude
Gemini
Dall-E3
GitHub Copilot
Synthesia
Binmile

Resources

- **GenAI Dos and Don'ts**

  - ☑ Do use GenAI tools responsibly and ethically to enhance learning and research
  - ☑ Do use GenAI for brainstorming and proofreading
  - ☑ Do cite any AI assistance
  - ☒ Don't blindly trust GenAI without fact-checking
  - ☒ Don't use GenAI as the only source of information
  - ☒ Don't use GenAI to complete entire assignments
  - ☒ Don't overuse GenAI to avoid cognitive offloading



Resources

- **GenAI Dos and Don'ts**

Over-reliance on AI

Cognitive offloading

Memory retention ('Google effect')

Fragmentation of attention

Reduced problem-solving ability

Loss of critical thinking

Engineer – Critical Thinking = Unengineer

Questions?