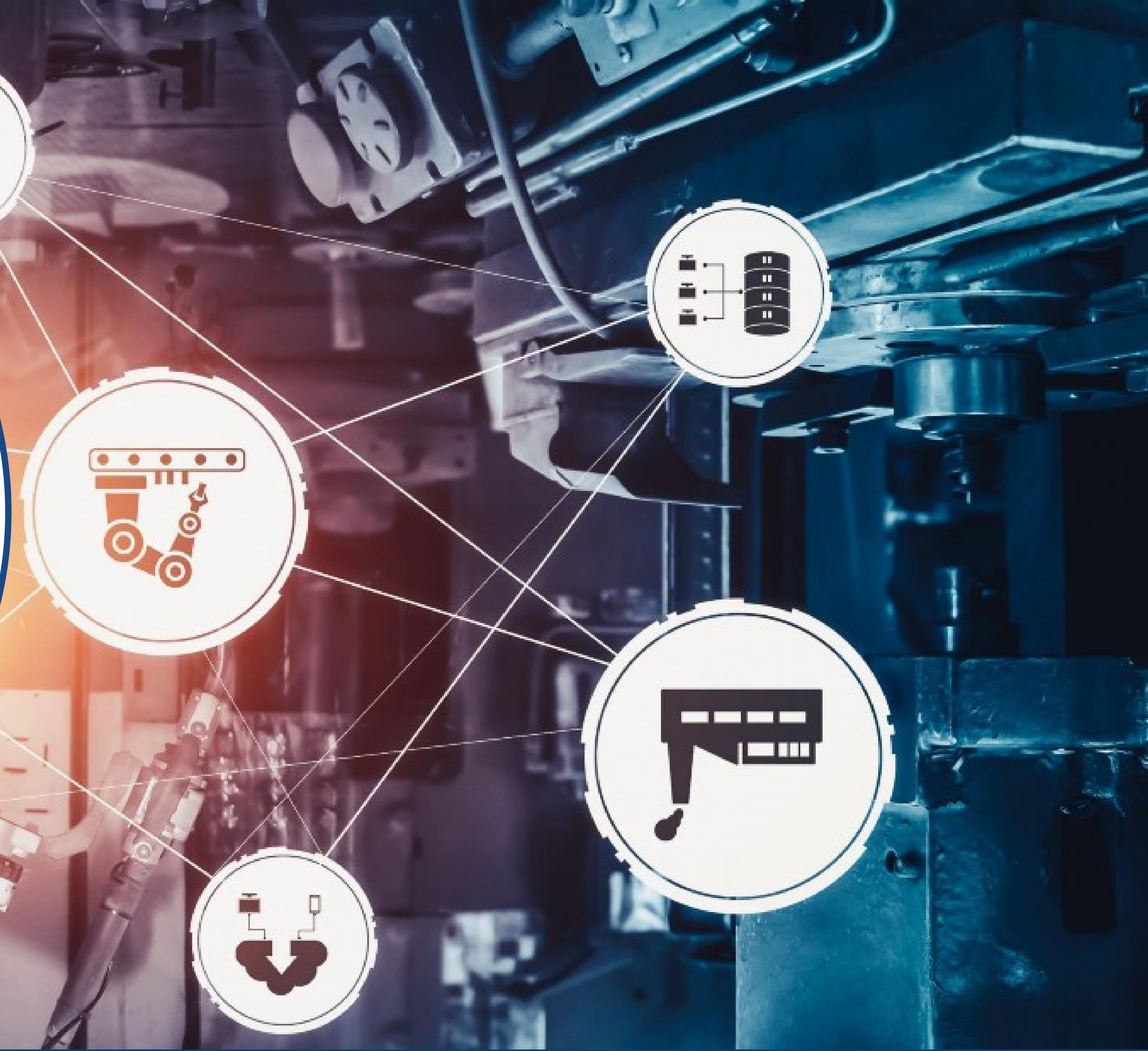

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Engineering Transformation

Internship Final Report
Arjun Yeleshwarapu

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Agenda

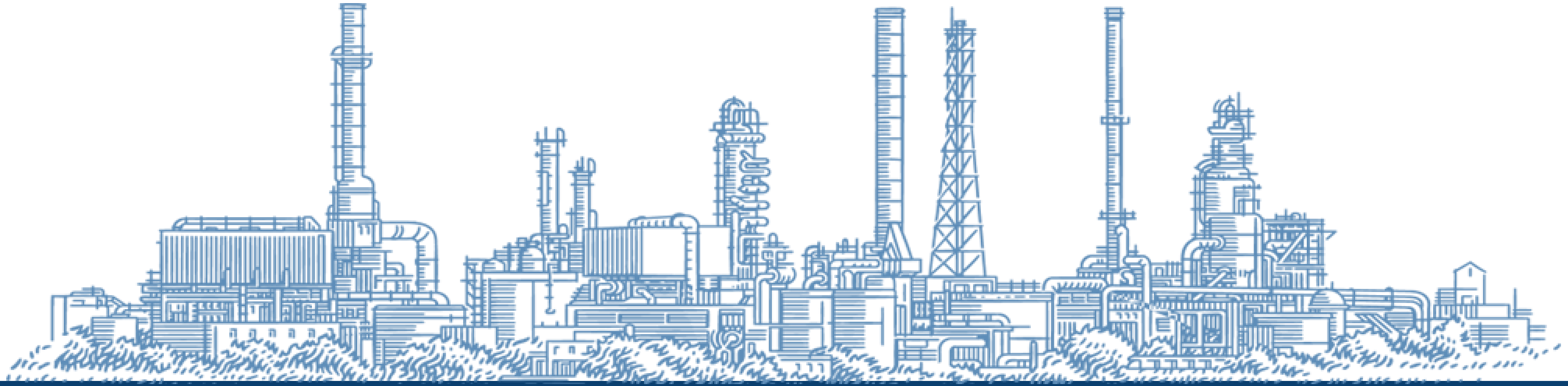
- Introduction and APM Overview
- Walkthrough of Common Industrial Assets
- Failure Modes and Effects Analysis (FMEA)
- Customer Requirement Sheet (CRS) and KPI Overview
- Pump Health Classification Project
- Pump Interpolator Tool

[redacted]

- Enclosure Design and Material Selection
- Thermal Analysis of PCB Enclosure

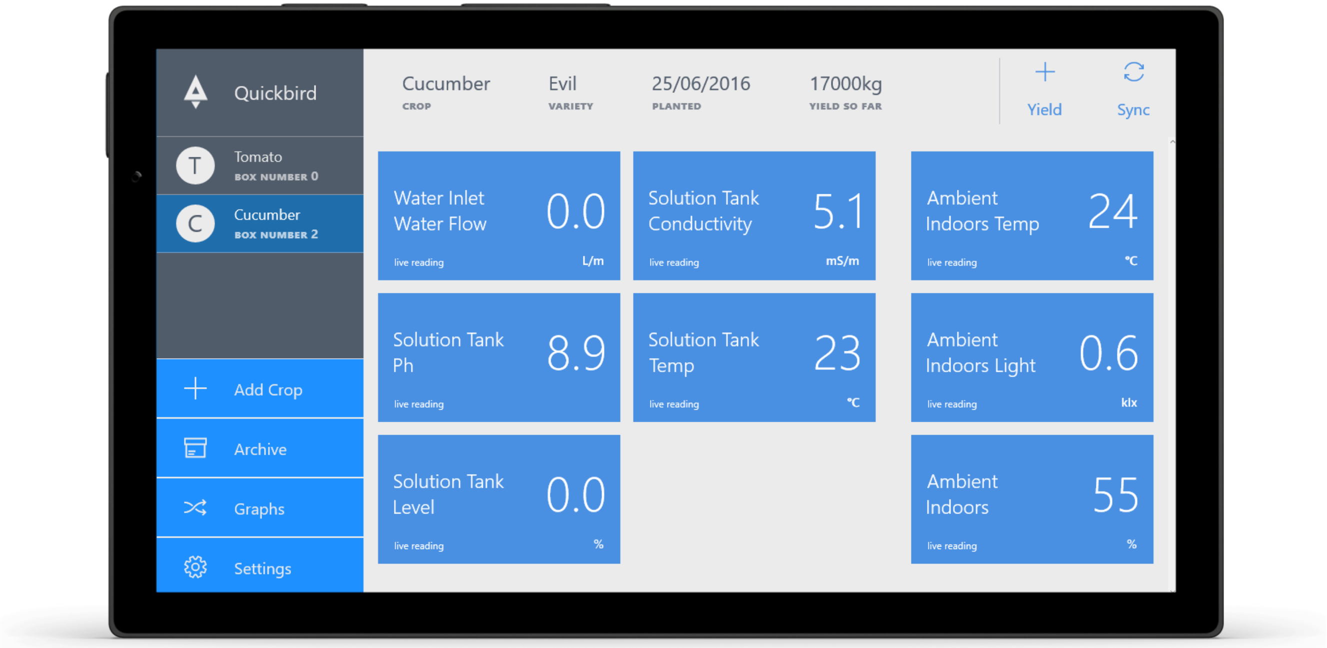
[redacted]

- Closing Thank You



Asset Performance Management Overview

- Systematic approach to track, analyze, and improve the reliability, efficiency, and health of industrial assets
  - Combines real-time sensor data, performance models, and historical maintenance logs
  - Used to reduce unplanned downtime, extend asset life, and optimize maintenance schedules
  - Monitors parameters like vibration, temperature, pressure, flow rate, power consumption
- Real-time information
  - Dashboards display key performance indicators and health scores for each asset
  - Predictive analytics used to flag potential failures before they occur
  - Integrates with CMMS (Computerized Maintenance Management Systems) and SCADA systems
- Often deployed in process industries, utilities, oil and gas, and smart buildings



Walkthrough of Assets

- Centrifugal pumps
  - Used for fluid transport
  - Sensitive to cavitation, vibration, and wear
- Electric motors
  - Key drivers in rotating equipment, monitored for current, heat, alignment
- Heat exchangers
  - Manage thermal transfer, monitored for fouling, pressure drop, efficiency loss
- Valves and actuators
  - Control flow and pressure, monitored for response time and leakage
- Compressors
  - Critical in gas systems, monitored for discharge temp, vibration, efficiency
- Flow meters and pressure sensors
  - Provide real-time process feedback and alarms
- Each asset has specific failure modes and requires tailored monitoring logic
- Asset registry includes metadata like model, age, location, service history, criticality

[redacted]

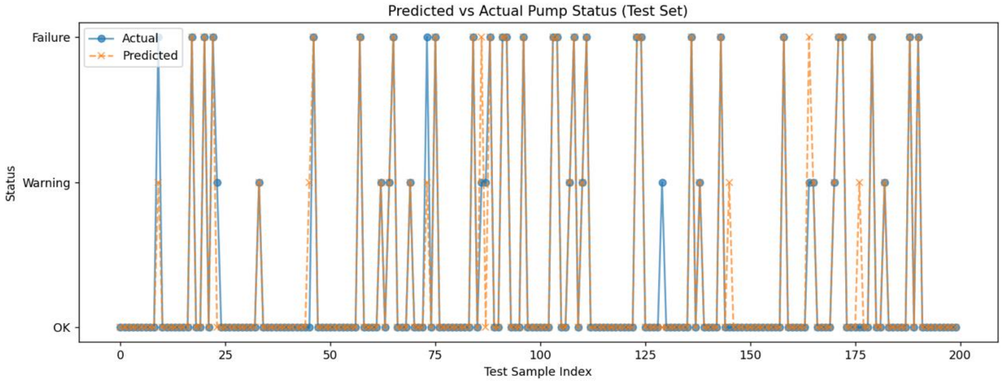
Understanding of FMEA

- Structured approach to identify and prioritize potential failure modes in a system
- Failure mode how a component could fail
    - e.g. bearing wear, seal leakage
- Effect
    - impact of that failure on system performance or safety
- Causes
    - Root triggers for the failure (e.g. misalignment, corrosion, overload)
- Detection
    - how and when the issue can be noticed (e.g. sensor alert, manual inspection)
- Importance of FMEA
    - Each mode scored for severity, occurrence, and detectability to calculate risk priority number (RPN)
    - Used in design phase and during operational monitoring to guide preventive actions
    - Helps teams focus on high-risk components and develop mitigation strategies
    - Integrated into APM systems for automated health classification and alert generation

Severity Probability	1	2	3	4	5
1	Low	Low	Low	Low	Moderate
2	Low	Low	Low	Moderate	High
3	Low	Low	Moderate	Moderate	High
4	Low	Moderate	Moderate	High	Unacceptable
5	Moderate	Moderate	High	Unacceptable	Unacceptable

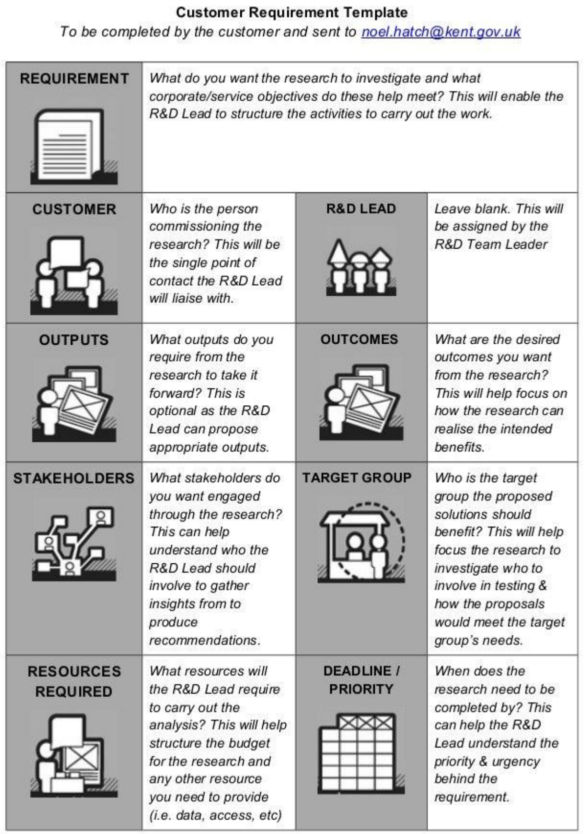
Pump Failure Predictor Project

- Use case focused on early detection of pump anomalies to reduce unplanned downtime and improve asset reliability
    - Simulates a real-world Asset Performance Management (APM) workflow using synthetic sensor data
        - If using real data, more than one year of data needed
- Project goal was to classify pump health as OK, Warning, or Failure based on operating conditions
    - Input features included vibration, bearing temperature, seal pressure, and leak status
    - Trained and compared Decision Tree and Logistic Regression models for classification
    - Evaluated using precision, recall, F1-score, and confusion matrix
- Achieved 96% overall accuracy with strong performance on OK and Failure classes
- Feature importance analysis showed bearing temperature and vibration as top indicators
- Project structured with separate folders for data, notebooks, plots, and scripts
- Concepts used include supervised learning, multi-class classification, confusion matrix, and model interpretability
- Future extensions include real-time scoring, dashboard integration, and expansion to other rotating assets



Walkthrough of CRS

- Document capturing technical and business expectations from the client or end-user
  - Includes description of use case, expected outputs, and operating conditions
  - Defines system scope, asset types, sensor types, data frequency, and UI requirements
  - Lists key performance indicators, such as energy savings, uptime targets, temperature thresholds
  - Captures industry-specific constraints like compliance
    - (e.g. ISO, IEC), environmental limits
- General Importance for Teams
  - Helps engineering teams align deliverables with client expectations from day one
  - Guides design decisions for dashboards, data models, and alert logic
- Updated iteratively based on feedback during validation, testing, and deployment



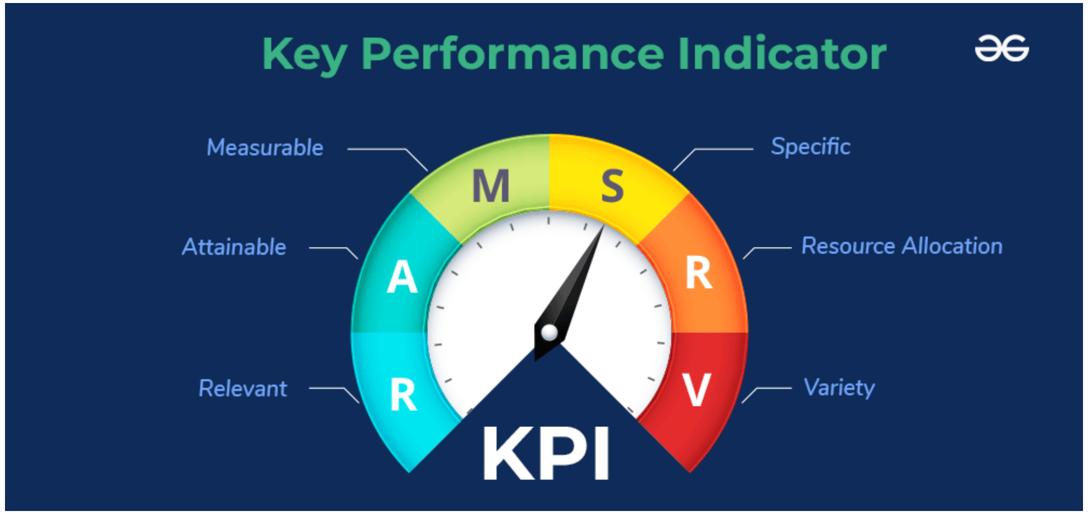
Customer Requirement Template

To be completed by the customer and sent to noel.hatch@kent.gov.uk

REQUIREMENT	*What do you want the research to investigate and what corporate/service objectives do these help meet? This will enable the R&D Lead to structure the activities to carry out the work.*		
CUSTOMER	*Who is the person commissioning the research? This will be the single point of contact the R&D Lead will liaise with.*	R&D LEAD	*Leave blank. This will be assigned by the R&D Team Leader*
OUTPUTS	*What outputs do you require from the research to take it forward? This is optional as the R&D Lead can propose appropriate outputs.*	OUTCOMES	*What are the desired outcomes you want from the research? This will help focus on how the research can realise the intended benefits.*
STAKEHOLDERS	*What stakeholders do you want engaged through the research? This can help understand who the R&D Lead should involve to gather insights from to produce recommendations.*	TARGET GROUP	*Who is the target group the proposed solutions should benefit? This will help focus the research to investigate who to involve in testing & how the proposals would meet the target group's needs.*
RESOURCES REQUIRED	*What resources will the R&D Lead require to carry out the analysis? This will help structure the budget for the research and any other resource you need to provide (i.e. data, access, etc)*	DEADLINE / PRIORITY	*When does the research need to be completed by? This can help the R&D Lead understand the priority & urgency behind the requirement.*

Key Performance Indicators

- Quantifiable metrics used to track asset condition, efficiency, and reliability
- Allow engineers and operators to monitor performance in real time and take corrective action
- Common KPI categories include operational efficiency, asset health, energy usage, and downtime
- Examples of KPIs:
  - Mean Time Between Failures (MTBF)
    - measures reliability of an asset
  - Mean Time to Repair (MTTR)
    - measures maintainability and service responsiveness
  - Overall Equipment Effectiveness (OEE)
    - combines availability, performance, and quality
  - Energy Consumption per Unit Output
    - tracks efficiency of energy-intensive assets
  - Vibration Levels
    - early indicator of mechanical degradation in rotating equipment
  - Thermal Efficiency
    - used in heat exchangers or HVAC systems to detect fouling
  - Asset Health Score
    - aggregate metric combining sensor trends and historical data
- KPI thresholds can trigger alerts, shutdowns, or preventive maintenance
- Used in dashboards, reports, and FMEA prioritization to drive decisions



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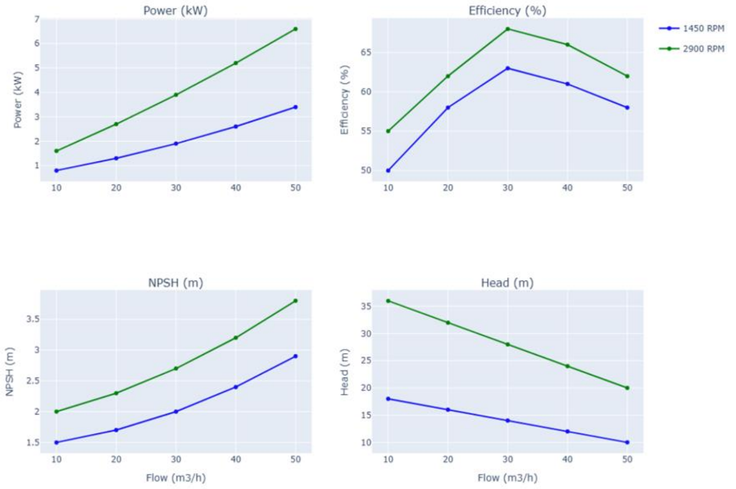
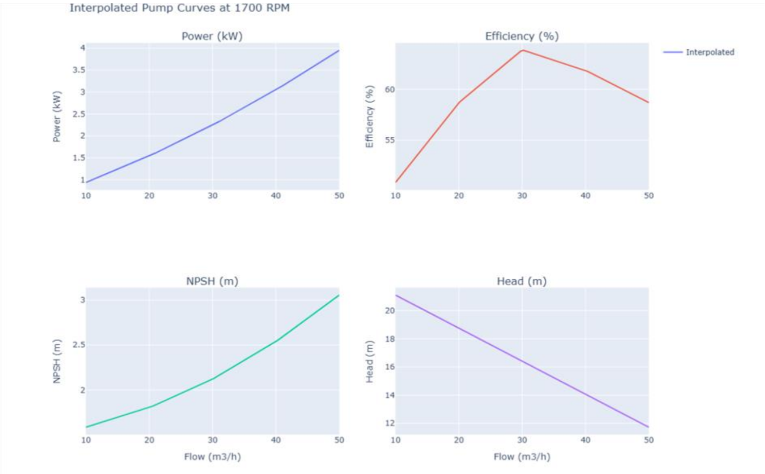
Pump Interpolator Project

- Built a reusable Python tool to interpolate and visualize centrifugal pump performance curves across any speed and flow range
    - Solves the need for flexible pump data lookup and visualization in APM and process engineering use cases
    - Uses 2D interpolation to estimate head, power, efficiency, and NPSH values at arbitrary flow and RPM
    - Supports JSON-based input format for easy updates from pump spec sheets
    - Includes a CLI interface for fast querying, as well as modular scripts for integration into other tools
    - Visual outputs created using interactive Plotly graphs to explore pump behavior
- Code structured into separate folders for core interpolation logic, visualization, interface, and data
    - Demonstrated querying from CLI and Python modules for real-time exploration of pump performance
    - Concepts used include parametric modeling, 2D interpolation, modular Python design, and data-driven engineering tools
- Designed to scale with new parameters like impeller diameter or temperature as needed





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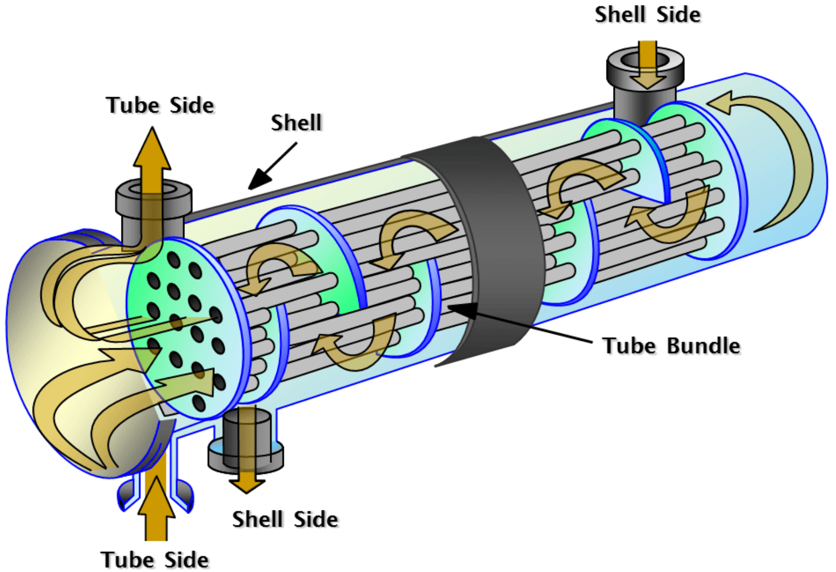
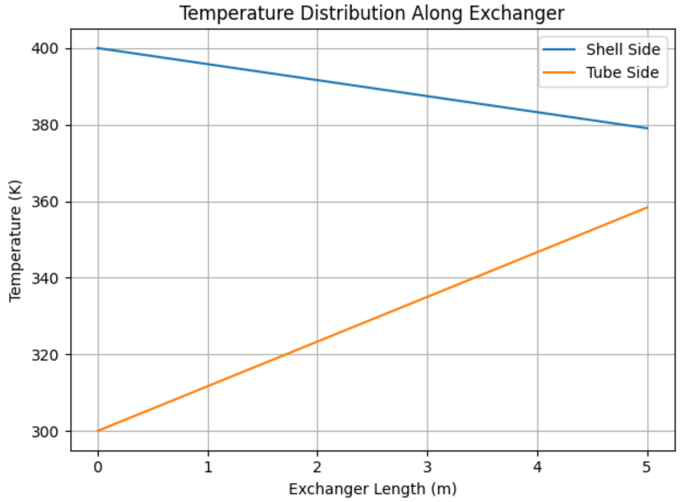
Shell and Tube Heat Exchanger Project

- Developed a Python application to size and evaluate shell-and-tube heat exchangers for industrial APM use cases
  - Supports both LMTD and epsilon-NTU methods for sizing based on user configuration
  - Handles both counterflow and parallel flow arrangements using editable config files
  - Reads flow rates, inlet temperatures, and geometry parameters from config.yaml
  - Loads fluid properties such as density, viscosity, and specific heat from fluids.csv
  - Calculates required heat transfer area, number of tubes, pressure drops, outlet temperatures, and effectiveness
  - Generates visual plots showing temperature distribution and NTU-effectiveness relationship
- Designed to support rapid design iterations and future integration into APM dashboards or APIs
  - Codebase structured for modularity and extensibility, with separate files for core logic, utilities, and I/O
- Concepts used include thermal energy balance, heat exchanger design equations, pressure drop correlations, and performance visualization





Energy Analysis Overview

- Why Is Energy Analysis needed
  - Determine usage of loads to determine if they are performing correctly
- Types of Loads
  - HVAC, pumps, compressors, lighting
- Data Collection Methods
  - Analog in brownfield sites
    - Must visit plant and bring measurement tools for things like power, temp, flow, pressure
  - Digital
    - IIoT devices/sensors can log data of temp, flow, pressure, to calculate things like pump head
- By collecting data, calculations can be run by comparing rated values vs. Actual
  - If the difference is too much, there can be recommendations given for actions

Power Grid Essentials

- Coal, water, wind, thermal energy, etc
  - Produce AC current
  - Three phase power to handle large loads efficiently (RYB)
- Transmission
  - Voltage stepped up using transformers
- Distribution
  - 3 phase electricity is stepped down at substations and delivered via poles or underground cables to
    - Homes
    - Businesses
- Why is AC used
  - Easier to transform voltages
  - More efficient for long-distance

[redacted]

Safety in Power Grid

- Critical safety layers
  - Fuses
  - Grounding
  - Surge protection devices
- Backup power systems
  - Uninterruptible Power Supply
    - Kicks in immediately when grid fails
    - Supports load for 5-30 minutes
    - Power conditioning filters out sags, surges, noise, frequency shifts
  - Diesel Generator
    - Long term outages
      - Takes 5-20 seconds to start so UPS fills the gap
    - Diesel engine runs alternator

Building Management System

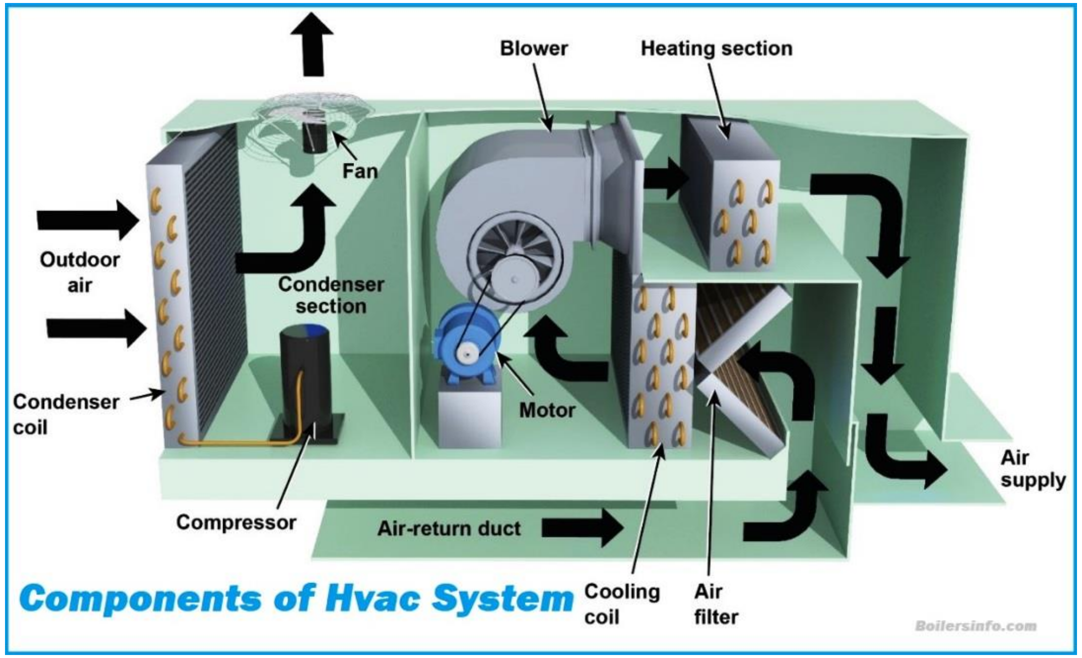
- Centralized control system to monitor, manage, and optimize key building functions for comfort, efficiency, safety, and cost savings
  - Computer based system that connects, monitors, and controls various building services such as
    - HVAC, lighting, power distribution, fire alarms, elevators, generators, energy metering
  - Sensors measure temp, humidity, current, etc
  - Controllers collect data and commands based on logic
    - Protocols like BACnet, Modbus, or KNX are used
  - BMS Server & Software
    - Central server with UI/dashboard
    - Engineers can view system performance, control settings, get alerts

Python Home Energy Dashboard

- Developed a modular simulation and dashboard for modeling energy use and cost in a 3-bedroom home across all seasons
  - Simulates key systems like HVAC, kitchen, lighting, EV charging, and solar PV with realistic daily schedules
  - Season-specific changes in temperature, solar hours, lighting needs, and electricity cost
- Interactive dashboard built using Dash and Plotly with sliders for HVAC setpoint and chiller power
  - Outputs include peak load, subsystem shares, solar offset, total energy, and cost
  - Includes actionable recommendations based on usage, season, and energy source
  - Supports energy source selection with dynamic pricing and context-aware tips
- Designed for extensibility with modular code and customizable config files

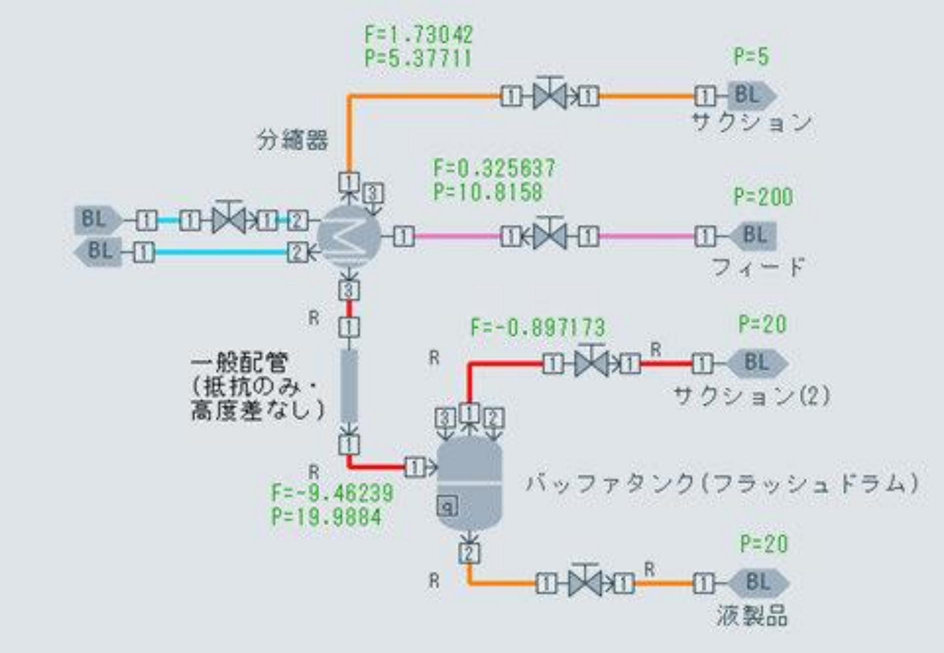
HVAC

- Learned fundamentals of HVAC function
  - Went into discussion of components of HVAC such as chiller, AHU, condensers, evaporators
  - Difference between heating and cooling discussed
- Components
  - AHU
    - Moves and conditions air
  - Chiller
    - Cools water using refrigeration cycle
  - Boiler
    - Heats water (~60-80C) for space heating
  - Cooling Tower
    - Rejects heat from chiller to atmosphere using evaporative cooling
  - Pumps & Ducts
    - Pumps move water between equipment
    - Ducts distribute air to/from occupied spaces



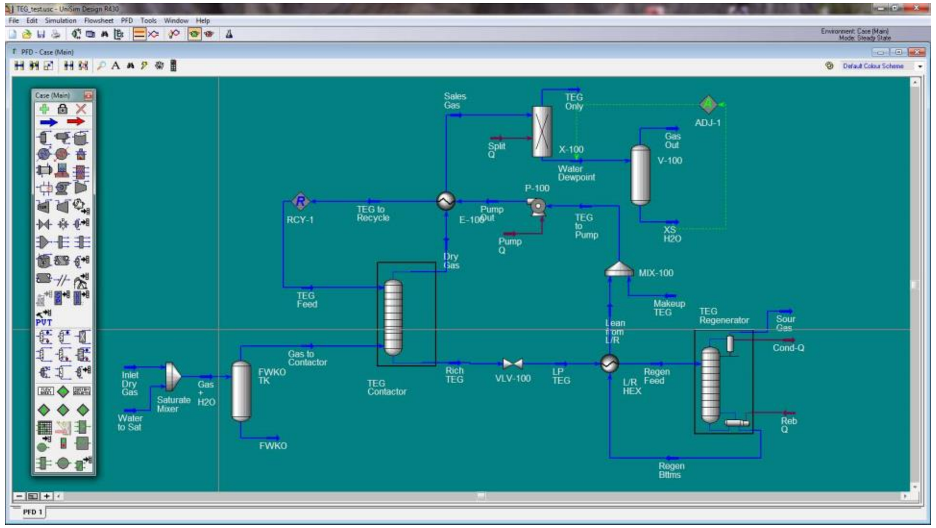
Process Enginering & Simulation Overview

- Design, optimization, and control of industrial plants
  - Translate PFD and P&ID into real-world systems
- Use software such as Unisim, Omegaland, Aspen
  - Simulate steady-state vs. dynamic state
  - Simulate failure events
  - Improve control logic using PID, MPC, or logic gates
- Simulation Process
  - Small-scale sim developed to show client before taking on the full project
  - Once client approves, full sim is developed based on PFD/P&ID



Software Types

- Aspen, Omegaland, and Unisim are the main softwares used for simulation
  - Aspen developed by Aspen Technologies
    - Chemical process modeling (batch & continuous)
    - Heat/mass balances, reaction engineering
    - Steady-state & dynamic simulation
    - Design of distillation columns, reactors, heat exchangers
  - Omegaland is developed by Yokogawa
    - Real-time dynamic simulation of industrial plants
    - Operator training simulators (OTS)
    - DCS testing and logic validation (especially Yokogawa CENTUM systems)
  - Unisim developed by Honeywell
    - Process simulation for oil & gas, refining, petrochemicals
    - Steady-state and dynamic simulations
    - Integrated with Honeywell Experion DCS systems



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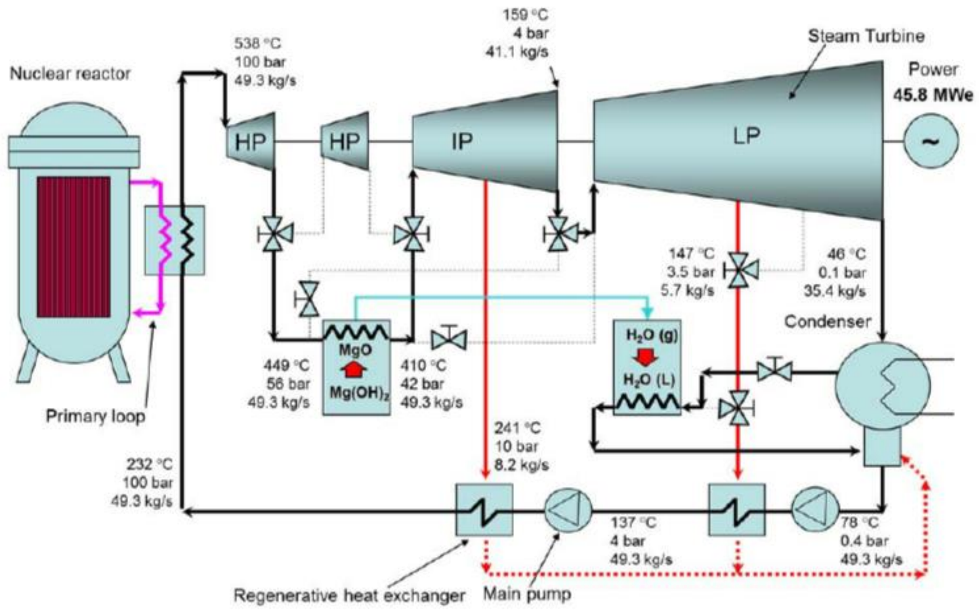
HMB Overview

- Heat and mass balance
- Mass Balance
  - Tracks mass in/out
  - Individual components (mole fractions)
  - Vapor/Liquid Phase
- Heat Balance
  - Tracks energy in/out
  - $Q = \dot{m} \cdot Cp \cdot \Delta T$
    - Mass flow rate
    - Specific heat
    - Temperature delta
- Important for tracking what is moving and how hot it is
  - Helps size equipment
  - Optimize loops

Heat storage mode (low demand of electricity for 60 min)



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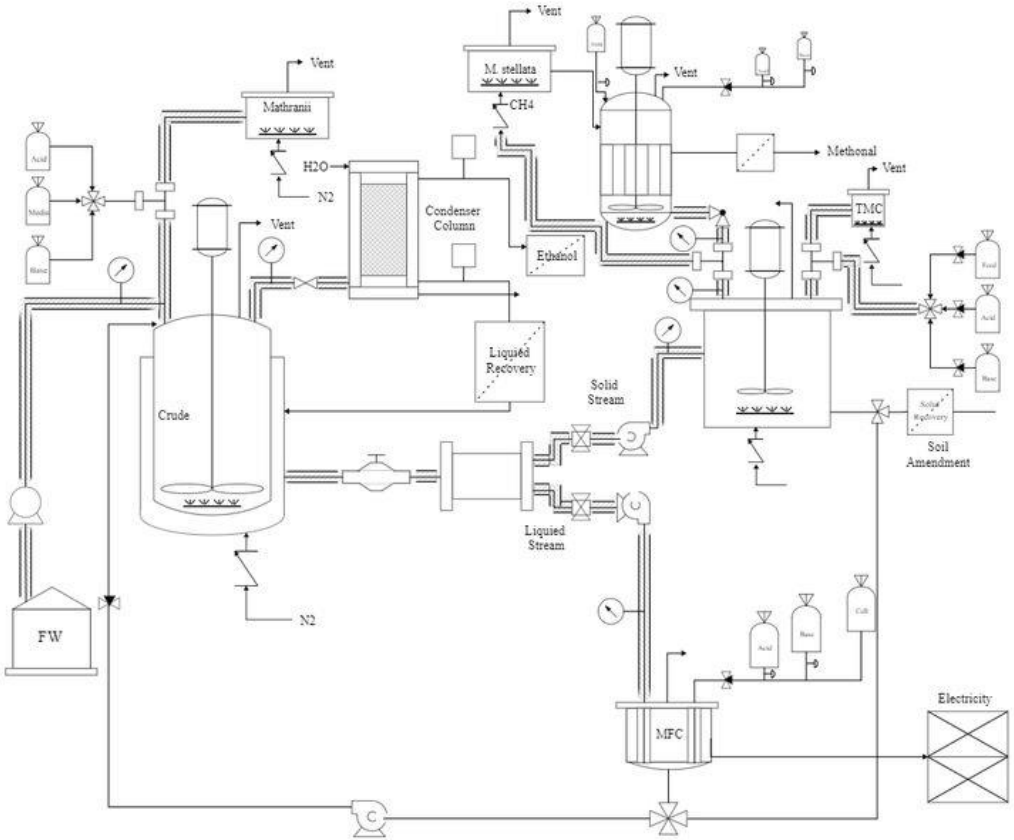
PFD & P&ID

- A PFD (Process Flow Diagram) provides a high-level overview of material and energy flow in a system
  - It includes major equipment like pumps, heat exchangers, and reactors, as well as key process streams, basic operating conditions, and utility inputs
  - PFDs are used for conceptual design, mass and energy balances, and system understanding during early stages of process development.
- A P&ID (Piping and Instrumentation Diagram) is a detailed engineering drawing that includes all pipes, valves, instruments, sensors, controllers, and control logic.
  - It shows how the system is constructed and controlled, including safety interlocks, shutdown systems, and loop diagrams.
    - P&IDs are essential for instrumentation, automation, fabrication, and safety reviews



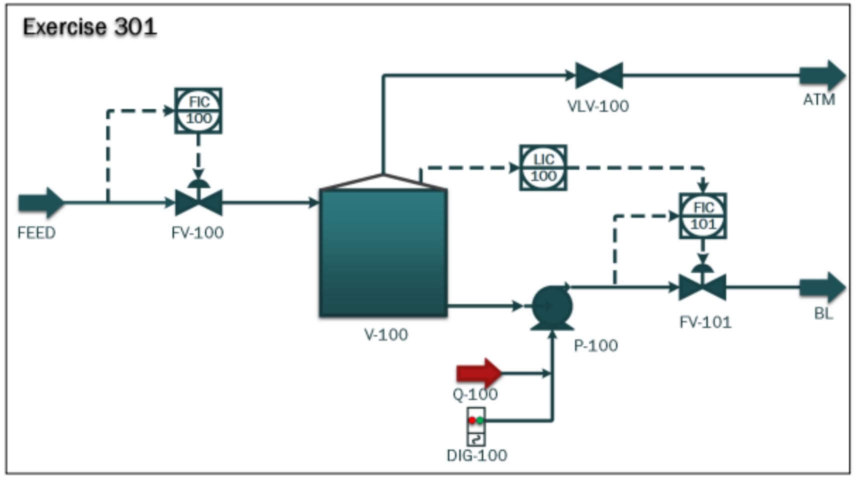
Training Documents

- After simulation is done, a training document can be made
  - consolidates the key process knowledge, operating procedures, and control strategies explored during simulation.
  - After a simulation is completed, such a document serves as a practical reference for plant operators to understand how each unit operates under normal and upset conditions.
    - It outlines the purpose of each actuator, pump, valve, and controller, helping operators interpret trends, alarms, and responses in real-time.
    - It also defines cold-start conditions, sequence of operations, and control setpoints, ensuring consistent and safe plant startup and operation.
    - By bridging the gap between simulation and field application, this document supports better decision-making, operator readiness, and reduced risk during commissioning and routine operations.

Exercise 301

Process Description

The feed enters the process at ambient temperature and 251 kPa pressure. The mass flow rate of the feed is controlled at 35000 kg/h with the help of a flow valve-actuator assembly. On entering the vessel, the mixture separates into a vapor phase and a liquid phase. The vapor phase is vented to the atmosphere, and the liquid phase is pumped downstream using a centrifugal pump – flow valve assembly. The liquid percent level in the tank is maintained at 50% of the total volume by throttling the discharge flow from the pump. Moreover, the actuators, one to detect the liquid percent level and one to measure the discharge flow rate from the pump, are cascaded to ensure optimum operating conditions.



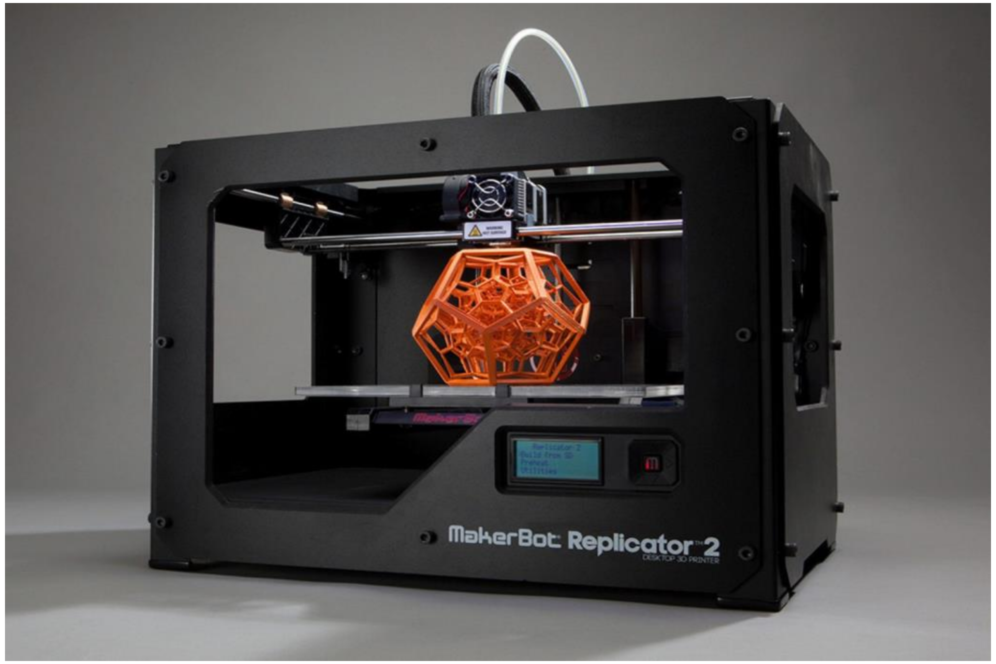
Enclosure Design

- Purpose of an Enclosure:
  - Protects internal electronics (PCBs, connectors, wiring) from dust, heat, moisture, and mechanical damage
  - Facilitates safe operation and user interaction
  - Enables modularity, serviceability, and compliance
- Design Considerations:
  - Mechanical fit: clearance, tolerances, fastening methods (screws, standoffs, snaps)
  - Thermal management: passive/active cooling via material choice or ventilation
  - Accessibility: cutouts, mounting holes, labeling
  - Manufacturability: suitable for 3D printing, injection molding, or sheet metal fabrication
  - Standards like IP65 or UL94 V-0 often guide material and feature choices
- Why It's Important:
  - Ensures reliability in harsh environments
  - Aligns with industry standards (e.g. IP ratings, UL, IEC)
  - Critical to cost, serviceability, and product safety

 [redacted]

Material Choice

- Plastics Overview
  - PLA
    - Easy to print, biodegradable, low heat resistance, brittle under stress
    - Best for prototypes and low-stress applications
    - Cheapest material
  - PETG
    - Stronger and more flexible than PLA,
    - good chemical resistance
    - moderate heat resistance
    - Suitable for functional parts needing slight flexibility
    - Mid-range
  - ABS
    - Durable and impact –resistant
    - higher temperature tolerance
    - good for enclosures but requires ventilation during printing
    - Most expensive



Material Choice

- Sheet Metal Overview
  - Mild steel
    - Strong and inexpensive
    - Prone to corrosion unless coated
    - Inexpensive
  - Stainless steel
    - Corrosion-resistant
    - Strong, used in rugged or outdoor environments
    - Significantly more expensive
  - Aluminum
    - Lightweight
    - Corrosion-resistant
    - Good thermal conductivity
    - Easier to machine
    - Mid-range cost

HART Simulator Enclosure

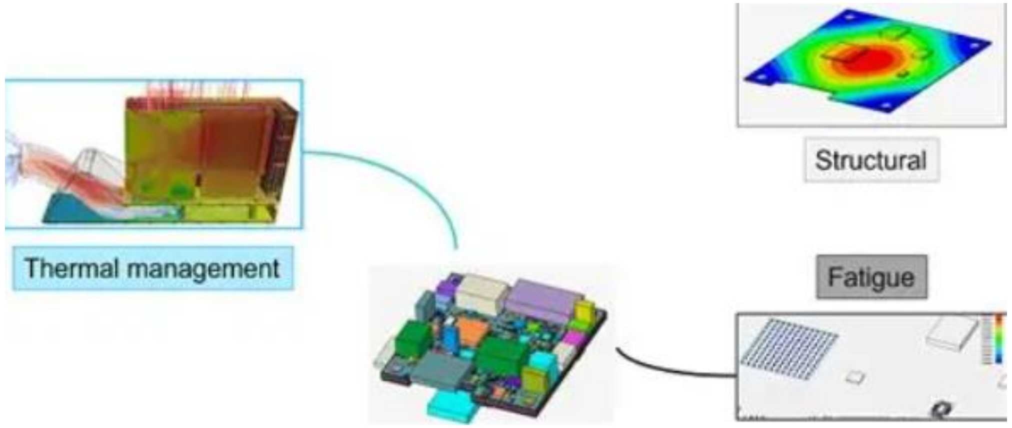
[redacted]

- For the enclosure, sheet metal is used as it is much cheaper and easier to mass-manufacture than plastics
  - Simply bend a sheet of metal with holes in correct position
- Passively cooled, no fans
- Not necessary to do IP waterproofing for this design

[redacted]

PCB Thermal Analysis

- Performed thermal analysis of ECU that takes in 400A of current
  - Split through five MOSFETs
- Necessary to perform thermal analysis in Altair Simlab to determine
  - Whether more MOSFETs are needed
  - Whether additional copper can be used to help distribute heat away from PCB
- The PCB enclosure will have no vents or fans, so it is necessary for materials to be used to effectively regulate temperature
  - Too many MOSFET's or copper is additional cost
    - Therefore, optimization is needed through simulation to inform embedded team the best course of action for development



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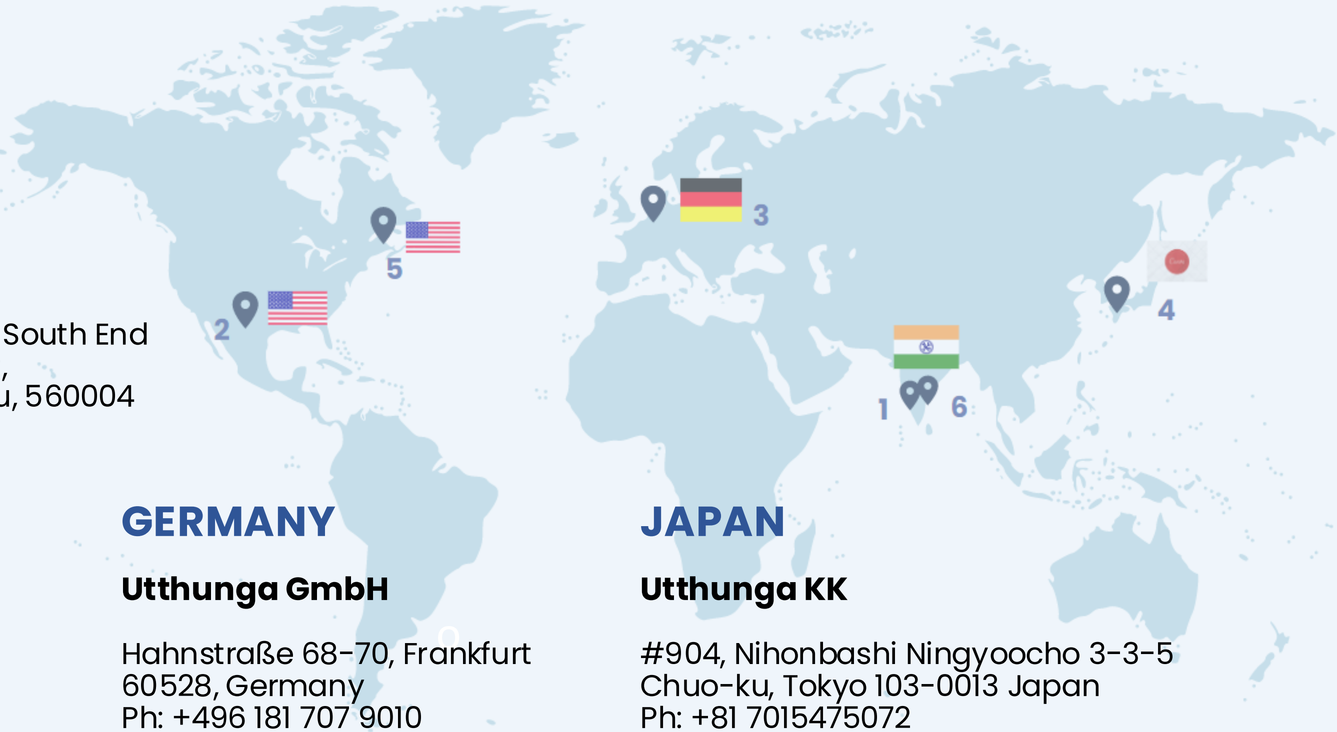

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