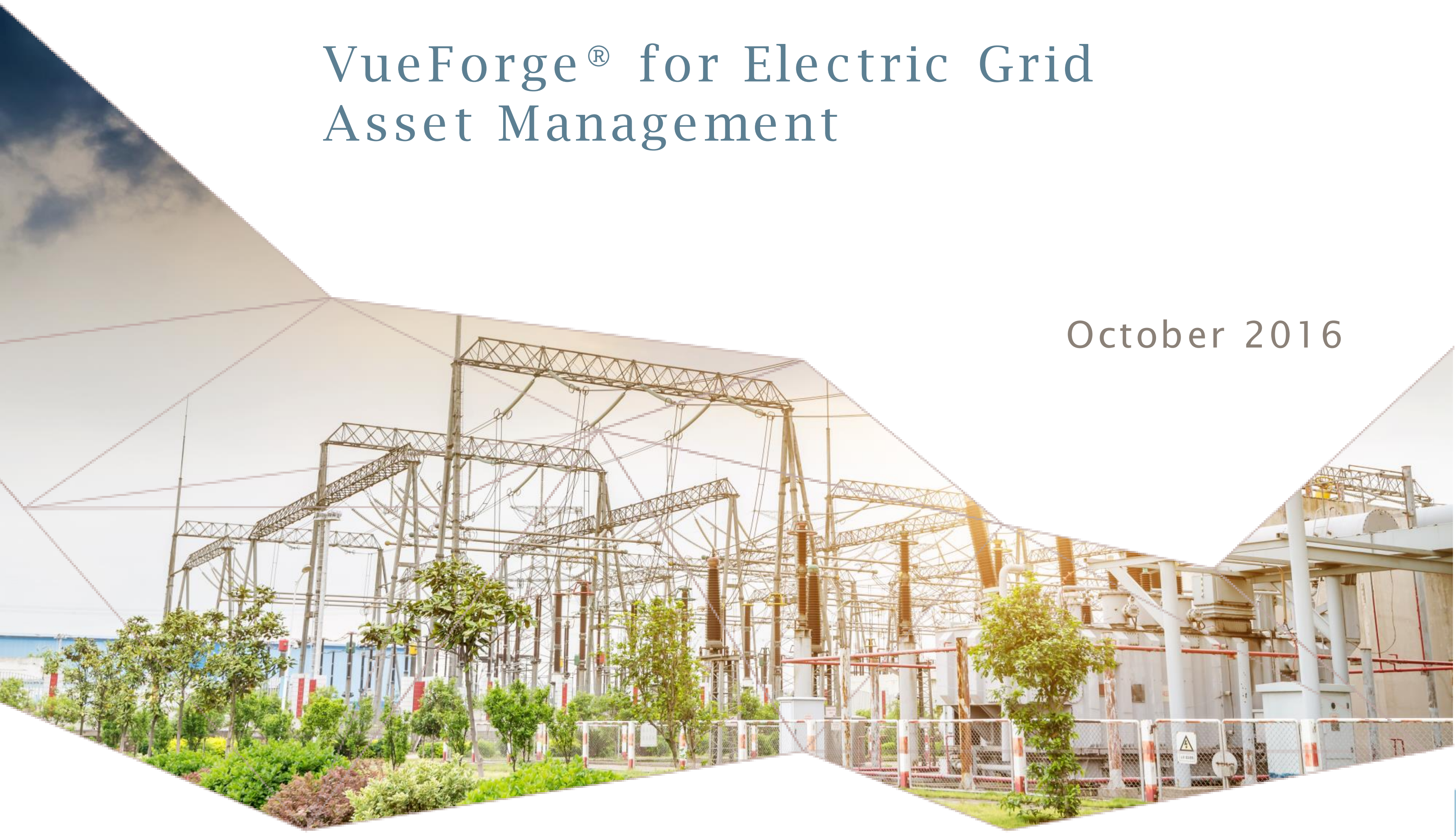
VueForge® for Electric Grid Asset Management



October 2016

SAS® FÓRUM PORTUGAL 2016

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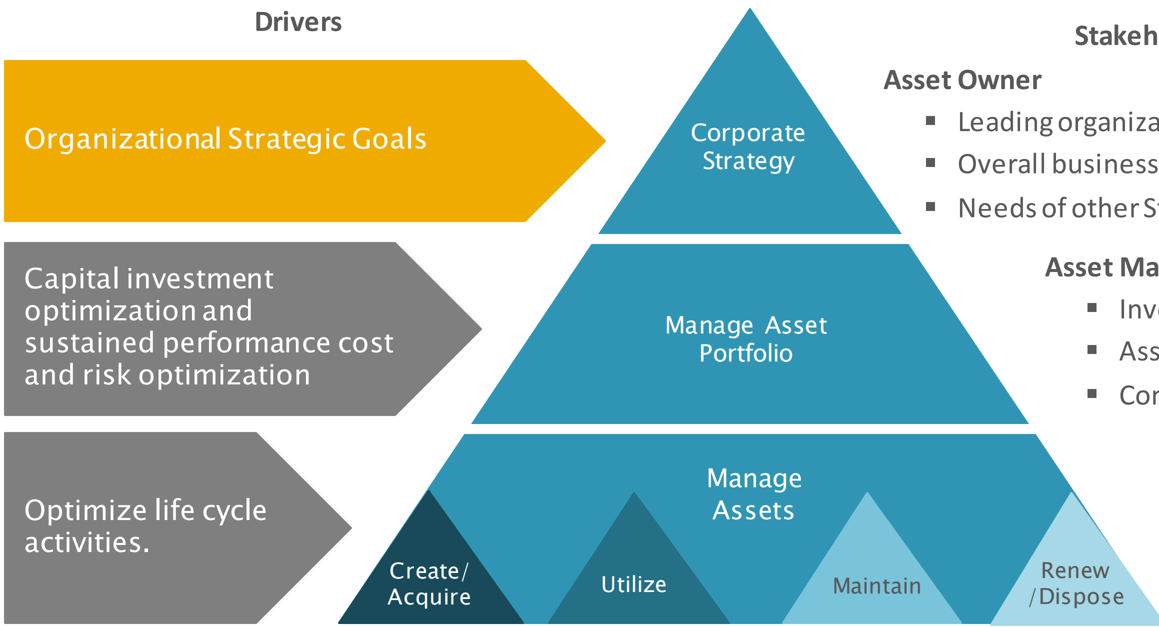
Asset Management in Electrical Utilities - Industry Challenge

Driven by the need for efficiency, risk control and transparency, electrical utilities are moving towards **Risk and Condition based asset management** in order to **defer investment and reduce O&M costs** while ensuring **high levels of reliability** and **availability** throughout the life-cycle of the assets.

Drivers



Stakeholders Responsibilities

Asset Owner

- Leading organizational objectives and policies
- Overall business strategy
- Needs of other Stakeholders (ex: regulators, customers)

Asset Manager

- Investment and maintenance strategy
- Asset health and risk analysis
- Condition monitoring plan

Asset Operator

- Engineering, construction
- O&M, asset monitoring
- Data collection and reporting

The international standards PAS55 (2004, 2008) and the newly released ISO 55000 series (2014) provide a framework for a structured Asset Management (AM) System in order to increase system performance and optimize operating cost.

VALUE PROPOSAL

What is VueForge® for Electric Grid Asset Management ?

VueForge® for Electric Grid Asset Management is a **digital platform with advanced analytics** enabling asset management optimization in electric grids.

It makes possible to **reduce Opex and defer Capex** while providing electric grid owners with:

- Comprehensive visibility of asset fleet condition and risk
- Strategic asset investment planning
- Flexible Ownership: Licensed or SaaS

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How does this platform work ?

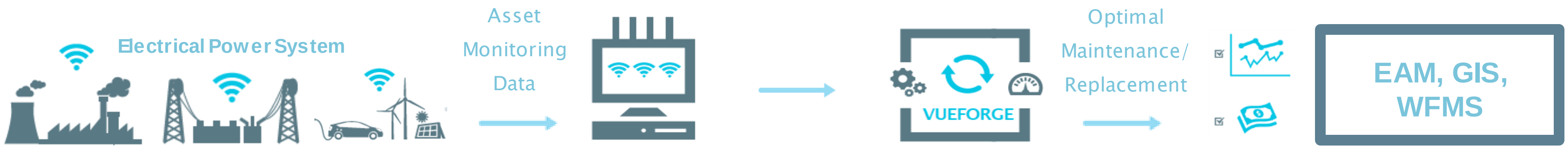
Operational Technology (OT)

Sensors and Monitoring Systems

VueForge® for Electric Grid Asset Management

Information Technology (IT)

Entreprise Management Systems



ASSET CONDITION MONITORING

IT ACCEPTS (REAL-TIME AND NON-REAL TIME) ASSET DATA FROM THOUSANDS OF ASSETS SCATTERED ACROSS GRID PROVIDING COMPREENSHIVE VISIBILITY ON THE CONDITION OF THE ASSET FLEET.

ASSET HEALTH AND RISK EVALUATION & FORECASTING

ADVANCED ANALYTICS IS USED TO EVALUATE ASSET HEALTH (CONDITION) AND RISK, REMAINING LIFE, AND ASSOCIATED RISK OF THE ASSET FLEET. GENERATION OF ALTERNATIVE MAINTENANCE PLANS

STRATEGIC INVESTMENT PLANNING

GENERATION OF ALTERNATIVE MAINTENANCE/REPLACEMENT PLANS EMBEDDING AN ECONOMIC EVALUATION (NPV AND TCO) IN ORDER TO MITIGATE THE RISK IN A COST-EFFECTIVE MANNER.

This **ASSET DATA REPOSITORY, VISUALIZATION AND ADVANCED ANALYTICS PLATFORM** :

- is an end-to-end tool offering **“a zero cost of ownership”** platform in SaaS mode combined with an Asset Management Managed Services.
- integrates existing Enterprise Asset Management Systems (EAM) and operational systems for asset data integration, **removing manual work.**
- generates **alternative asset maintenance and investment scenarios** in order to help electrical utilities mitigate risk in a cost effective manner, minimizing the life-cycle cost of the asset fleet of an electric grid.

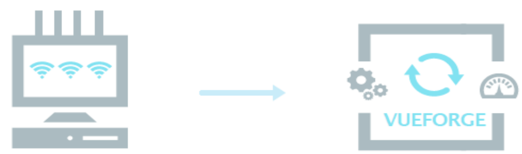
How does this platform work ?

Operational Technology (OT)

Sensors and Monitoring Systems

ASSET CONDITION MONITORING

VueForge® for Electric Grid Asset Management

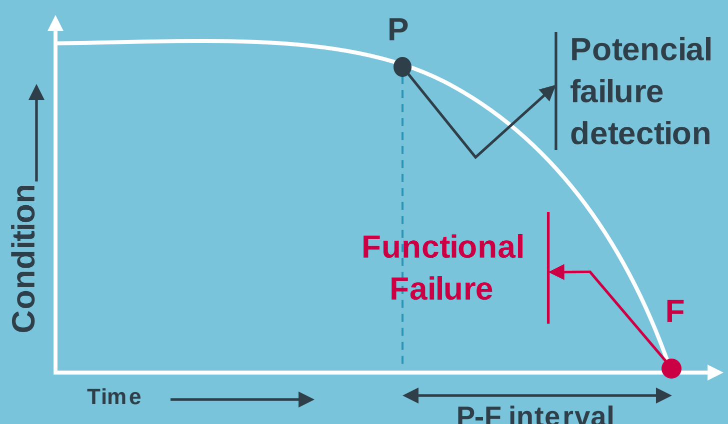


ASSET HEALTH AND RISK EVALUATION & FORECASTING

Information Technology (IT)

Entreprise Management Systems

STRATEGIC INVESTMENT PLANNING



Approach:

1. Failure mode, effect and criticality analysis in order to ensure the focus on the relevant components and failures.
2. Collect the relevant asset condition data to assess current asset condition.
3. Integration with the OT/IT systems for automatic asset data collection, cleaning and visualization.

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How does this platform work ?

Operational Technology (OT)

Sensors and Monitoring Systems

VueForge® for Electric Grid Asset Management

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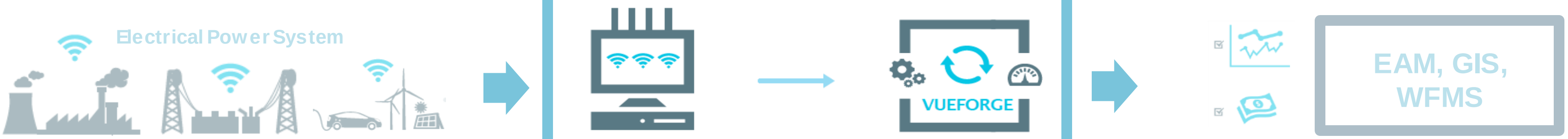
Entreprise Management Systems

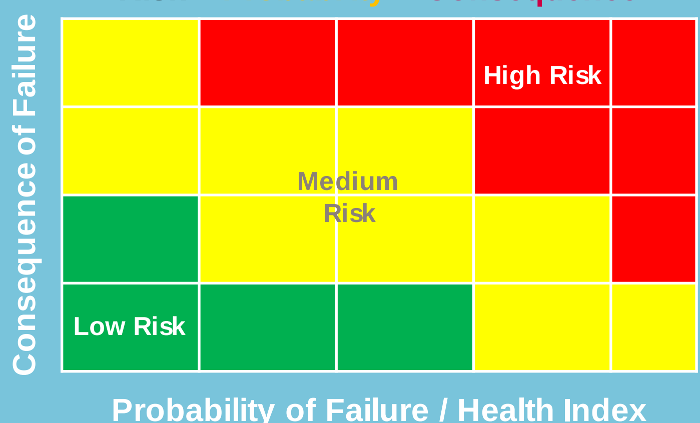


ASSET CONDITION MONITORING

ASSET HEALTH AND RISK EVALUATION & FORECASTING

STRATEGIC INVESTMENT PLANNING

Risk = Probability × Consequence



Approach:

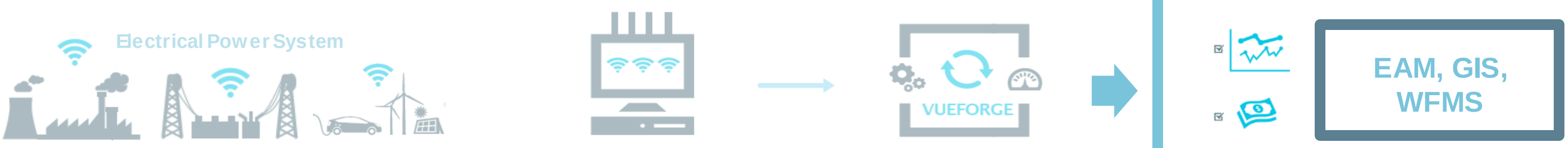
4. Condition Assessment Modelling to evaluate Asset Condition and Performance data.
5. Modelling of the Health Index and Failure Probability at the individual and fleet levels.
6. Modelling of the Risk of Failure based on the Probability of Failure and Consequences of Failure.

How does this platform work ?

Operational Technology (OT)
Sensors and Monitoring Systems

VueForge® for Electric Grid Asset Management

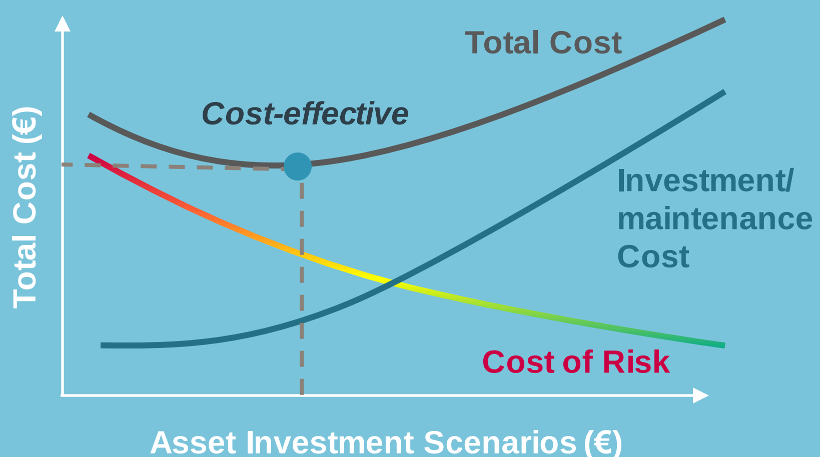
Information Technology (IT)
Entreprise Management Systems



ASSET CONDITION MONITORING

ASSET HEALTH AND RISK EVALUATION & FORECASTING

STRATEGIC INVESTMENT PLANNING



Approach:

7. Forecast of the Health Index and Cost of Risk based on past performance.
8. Generation of alternative investment scenarios to reduce Cost of Risk embedding an economic evaluation (NPV, TCO).
9. Asset Investment Optimization based on the acceptable risk level defined by the customer.

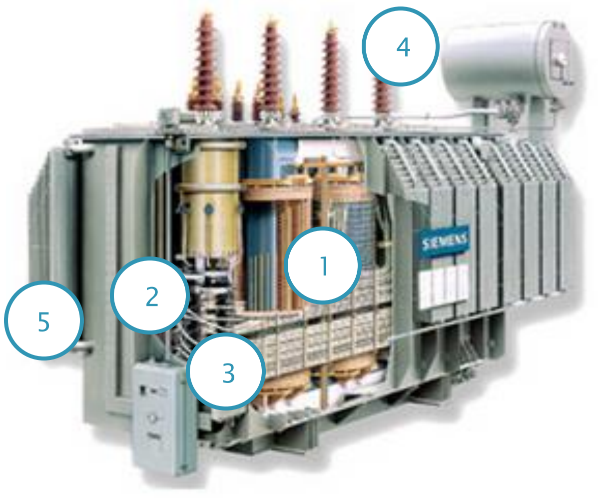
Demo
Power Transformer Use Case

DEMO

Asset Health Assessment - Power Transformer

Power transformers are built with high degrees of precision and quality due to their critical role in the operation of the electrical power system.

According to IEC Standard, a power transformer is defined as a static piece of apparatus with two or more windings which, by electromagnetic induction, transforms a system of alternating voltage and current into another system of voltage and current usually of different values and at the same frequency for the purpose of transmitting electrical power.



ID	Component	Failure Mode	Failure Cause	Monitoring Options
				• Age/Historical Maintenance
1	Core	Short circuited laminations (E) Broken ground condition (E) Unintentional ground (E)	Loss of lamination pressure (M)	Dissolved Gas Analysis (H2, O2, CH4, CO, CO2, C2H4, C2H6, C2H2).
	Winding	Deformation of winding (M) Breakdown of insulation (E) High moisture (C)	Aging of paper insulation (M/C) Loss of winding pressure (M) Carbonization of paper (T) Overheating (E/T) Copper corrosion (C) Partial discharges (E)	Loading Ambient Temperature Winding Hot-Spot Temperature Dissolved Gas Analysis (H2, O2, CH4, CO, CO2, C2H4, C2H6, C2H2).
	Oil	Formation of sludge (C) Corrosivity (C) Contamination of particles (C) Water in oil (C)	Oxidation of oil (C) High moisture (C)	Oil Analysis Maintenance Records
2	Tank	Overheating from stray flux or circulating currents (T) Leaks (M)	Aging of gaskets (C) Corrosion (C) Loss of sealing pressure (M)	Maintenance Records Dissolved Gas Analysis (H2, O2, CH4, CO, CO2, C2H4, C2H6, C2H2).
3	OLTC	Coking of contacts (E/C/T) Burnt resistor (E) Jammed mechanism (M)	Aging of oil (C) Aging of insulation (C) Wear of mechanical parts (M) Silver corrosion (C)	Tap position, Motor drive current Moisture in Oil Diverter, Selector, near Tank temperature Maintenance Records
4	Bushings	Corona and discharges (E) Loose field distributor (E/M) High resistance (E/T) Capacitive insulation (E/M) Cracks in outer coating (M) Leaks (M) Pollution of outer surcafe (C)	Partial discharges (E), Degradation of paper insulation (C) Moisture ingress (C)	Bushing capacitance Bushing oil pressure Maintenance Records
5	Cooling	Loss of gasket sealing (M) Failure of fans or pumps (M/E)	Corrosion (C) Clogging of heat exchangers (C) Clogging of water coolers (M)	Switching status Inlet/ outlet oil temperature

Legend: E=Electrical, M=Mechanical, T=Thermal, C=Chemical

Annex

VueForge® for Electric Grid Asset Management – Analytics Methodology

Risk-Based Asset Management - Overview

The methodology covers the calculation of the **Current and Future Asset Health Degradation** and **Probability of Failure (PoF)** in order to assess the **asset risk profile** and enable the **optimization of asset replacement/refurbishment/maintenance.**

1 ASSET HEALTH ASSESSMENT & FORECAST MODEL

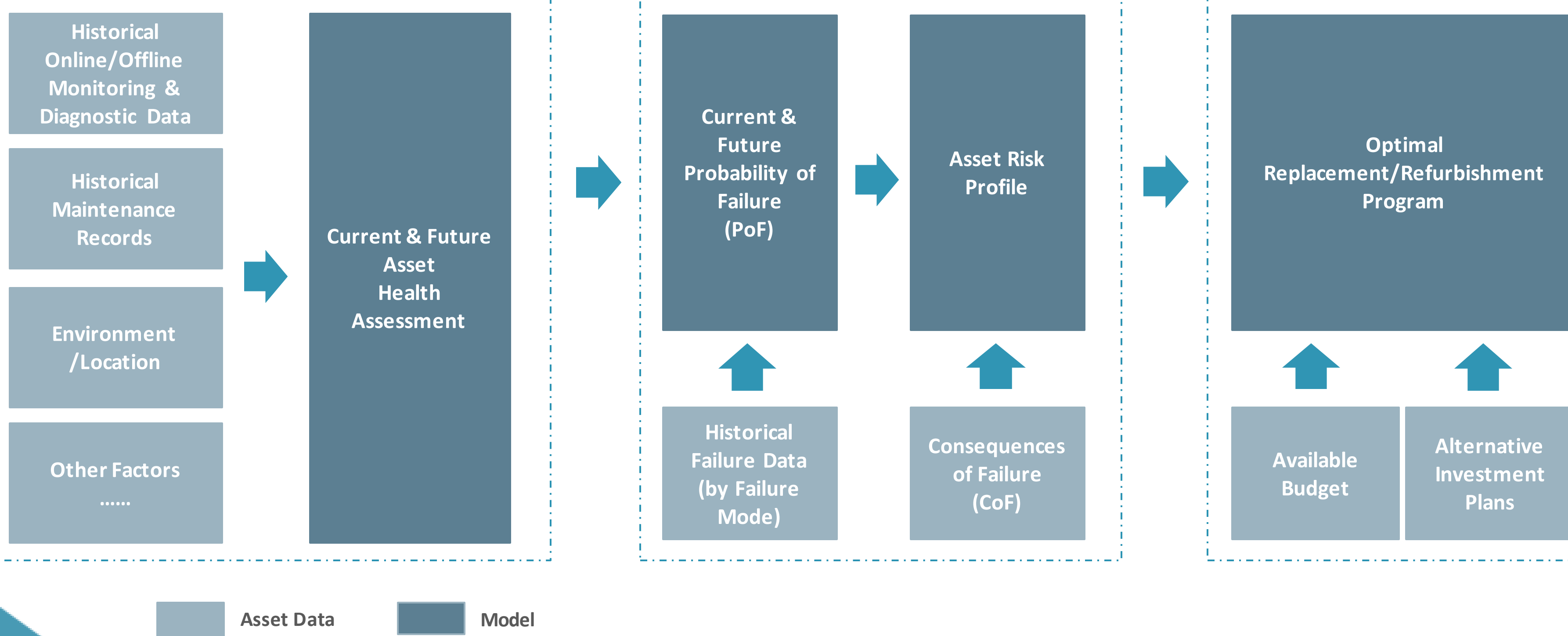
The **Asset Health Assessment Model** allows to evaluate the **current overall asset condition** and **forecast asset health degradation** based on available asset data.

2 PROBABILITY OF FAILURE/ RISK MODEL

Determines the **Asset Risk Profile** based on the **Current/Future Probability of Failure (PoF)** using **asset condition and reliability data.**

3 OPTIMAL INVESTMENT PLANNING MODEL

Determines the **optimal viable asset replacement/refurbishment plan** for the asset fleet.



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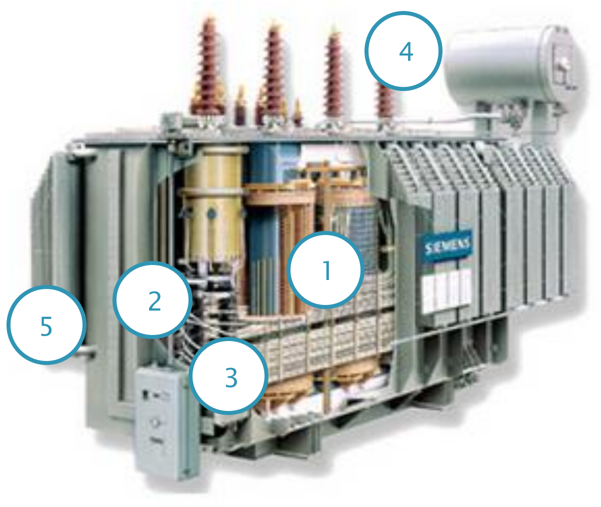

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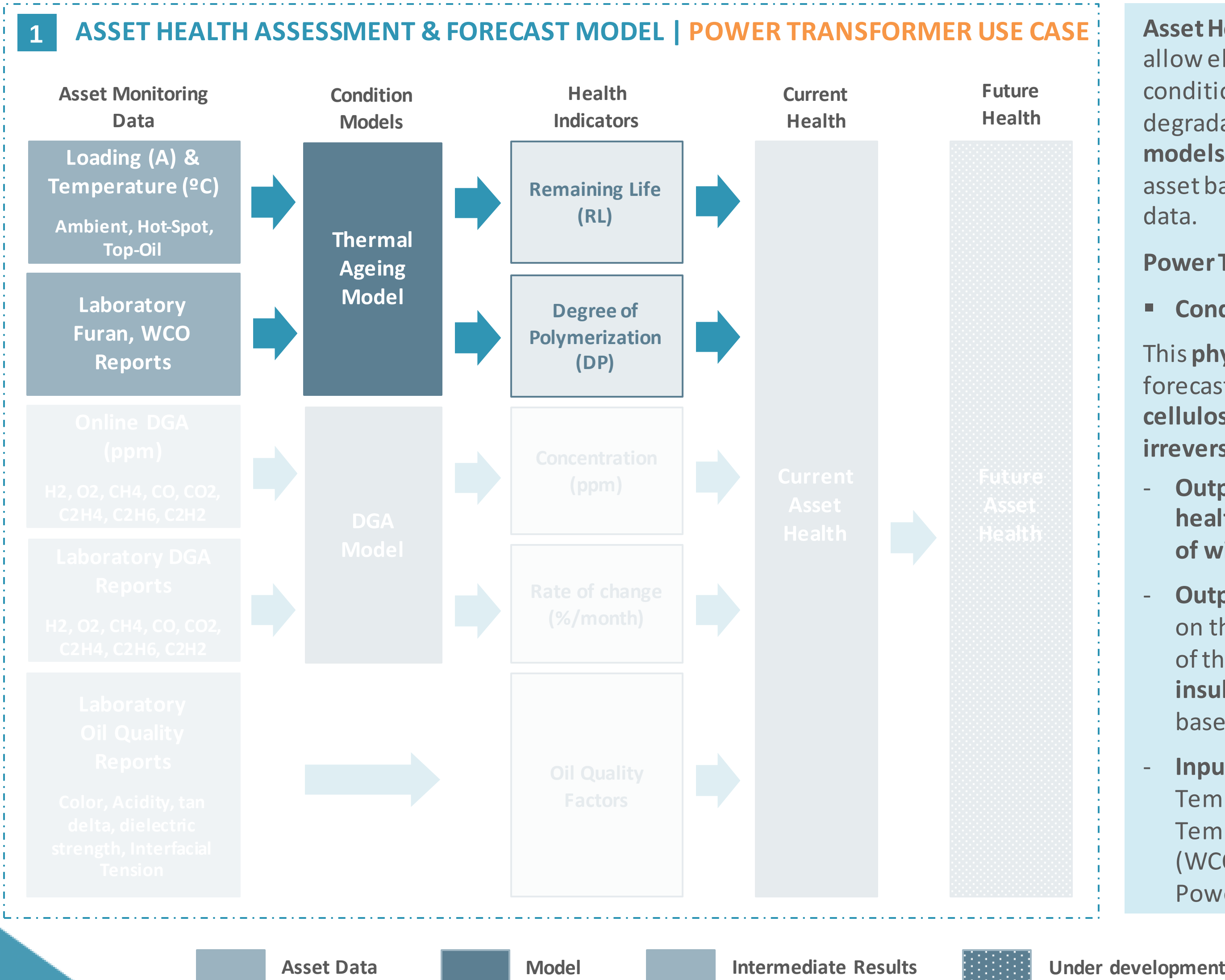
Asset Health Assessment & Forecast Model



Asset Health Assessment and Forecast Model: allow electrical utilities to evaluate the overall condition of their assets and forecast their degradation. It is composed by a set of **condition models** to assess separate subsystems of the asset based on available on-line and offline asset data.

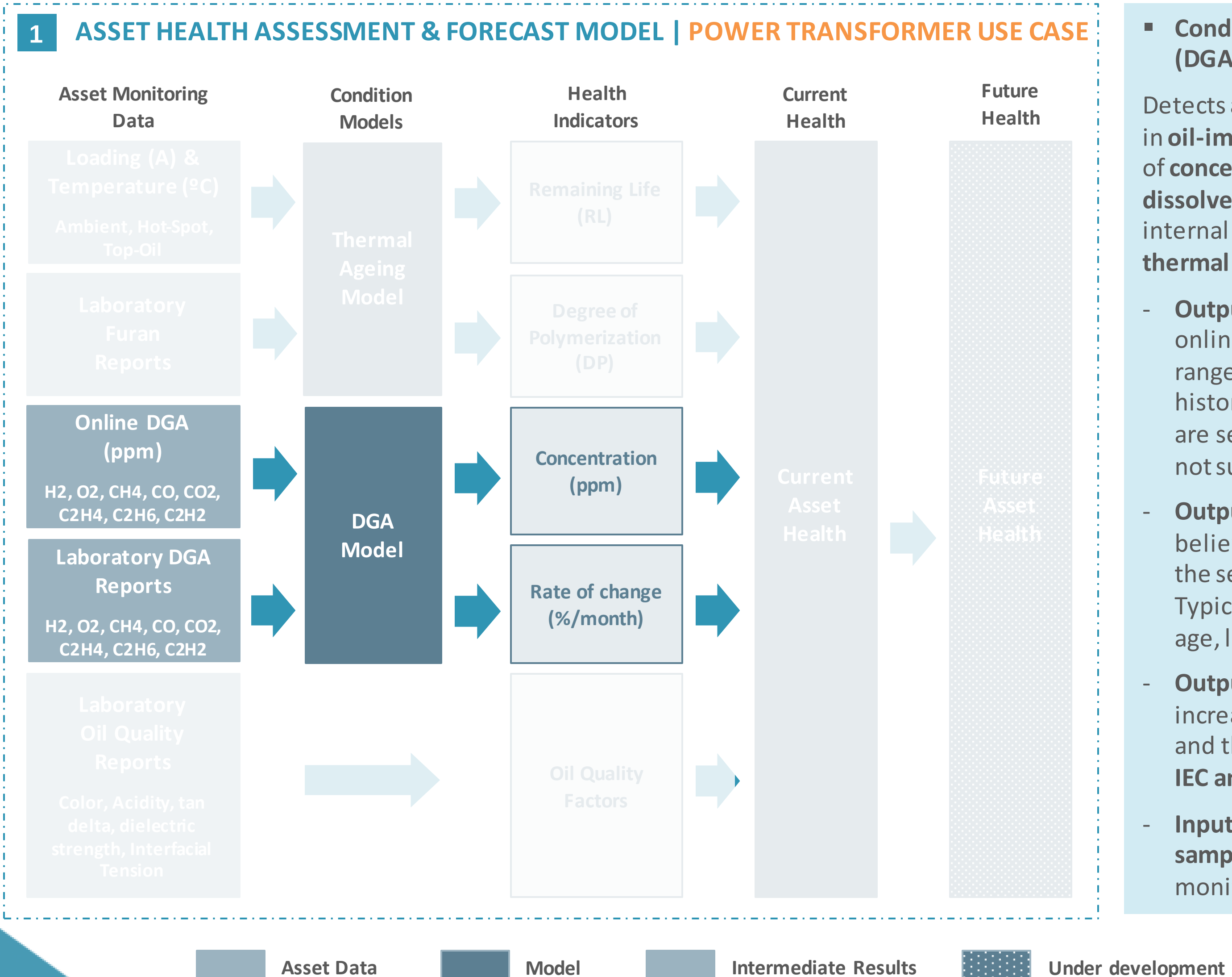
Power Transformer Use Case

- **Condition Model: Thermal Ageing**

This **physical model** intends to assess and forecast the **thermal degradation of the cellulose winding paper insulation which is an irreversible process.**

- **Output: Degree of Polymerization (DP):** is an **health indicator** of the **degree of degradation of winding insulation.**
- **Output: Remaining Life (RL):** calculated based on the **DP forecast curve** which is an indicator of the **rate of the degradation of the winding insulation** (The RL can also be calculated based on the IEC standard).
- **Inputs:** Historical load; Historical Ambient Temperature; Historical Hot-spot or Top-oil Temperatures; Furans; Water Content in Oil (WCO) and the thermal characteristics of the Power Transformer.

Asset Health Assessment & Forecast Model



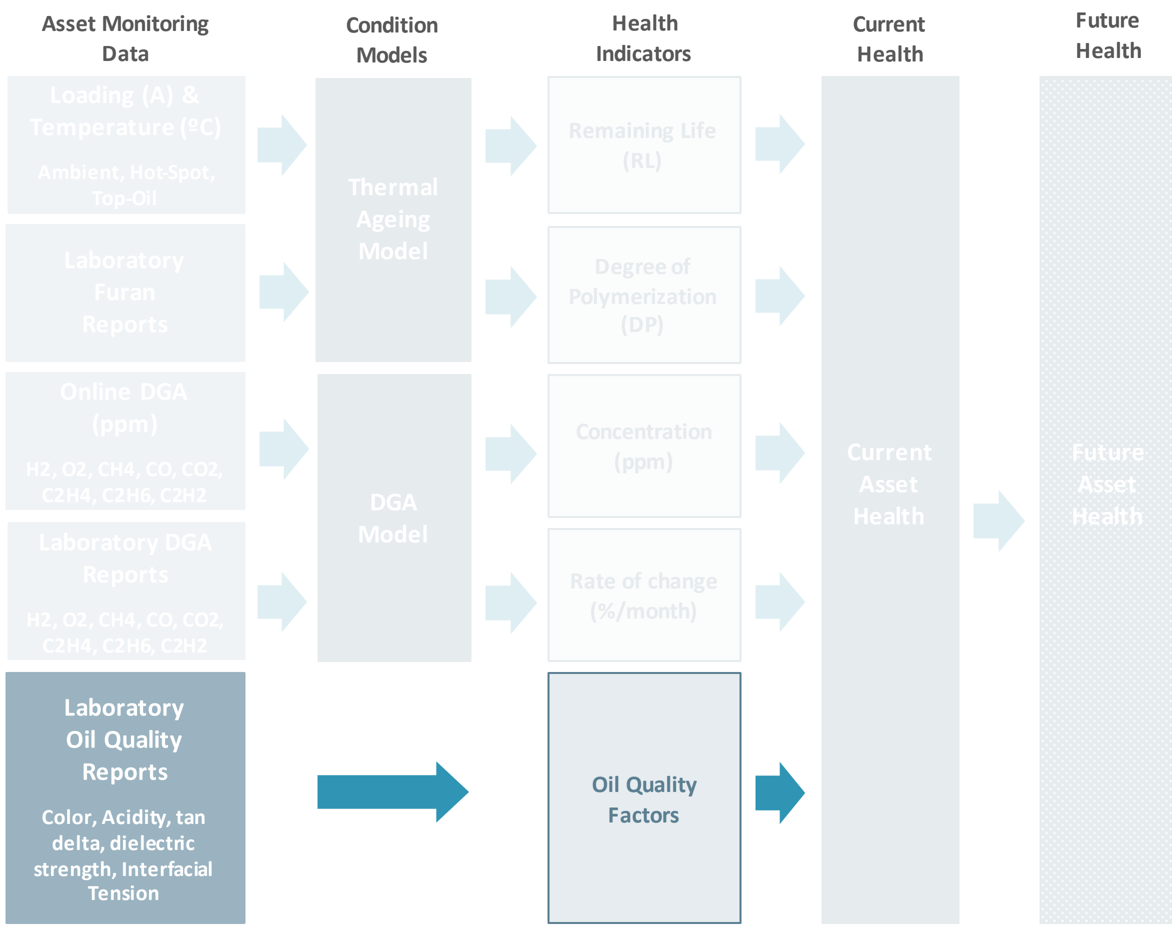
- **Condition Model: Dissolved Gas Analysis (DGA)**

Detects and evaluates **potential incipient faults** in **oil-immersed transformers** by interpretation of **concentrations and production rate of gases dissolved in the oil** of the power transformer. An internal fault generates various gases due to the **thermal degradation of the insulation.**

- **Output:** the **Gas Concentrations** measured online or offline are compared with the 90% ranges of typical values observed in in the history of the power transformers fleet which are set by the user while the platform does not support a considerable number of assets.
- **Output:** The **Rates of Gas Increase (ROC)** are believed to provide more information about the severity and size of a possible fault. Typical values depend on the equipment type, age, load patterns, etc.
- **Output:** Concentration and rates of gas increase above the limits will trigger alarms and the **fault analysis process according with IEC and Duval methods**.
- **Inputs: DGA analysis** involving **manual sampling** or **online DGA** involving continuous monitoring.

Asset Health Assessment & Forecast Model

1 ASSET HEALTH ASSESSMENT & FORECAST MODEL | POWER TRANSFORMER USE CASE



Asset Data | Model | Intermediate Results | Under development

- **Condition Model: Oil Quality**

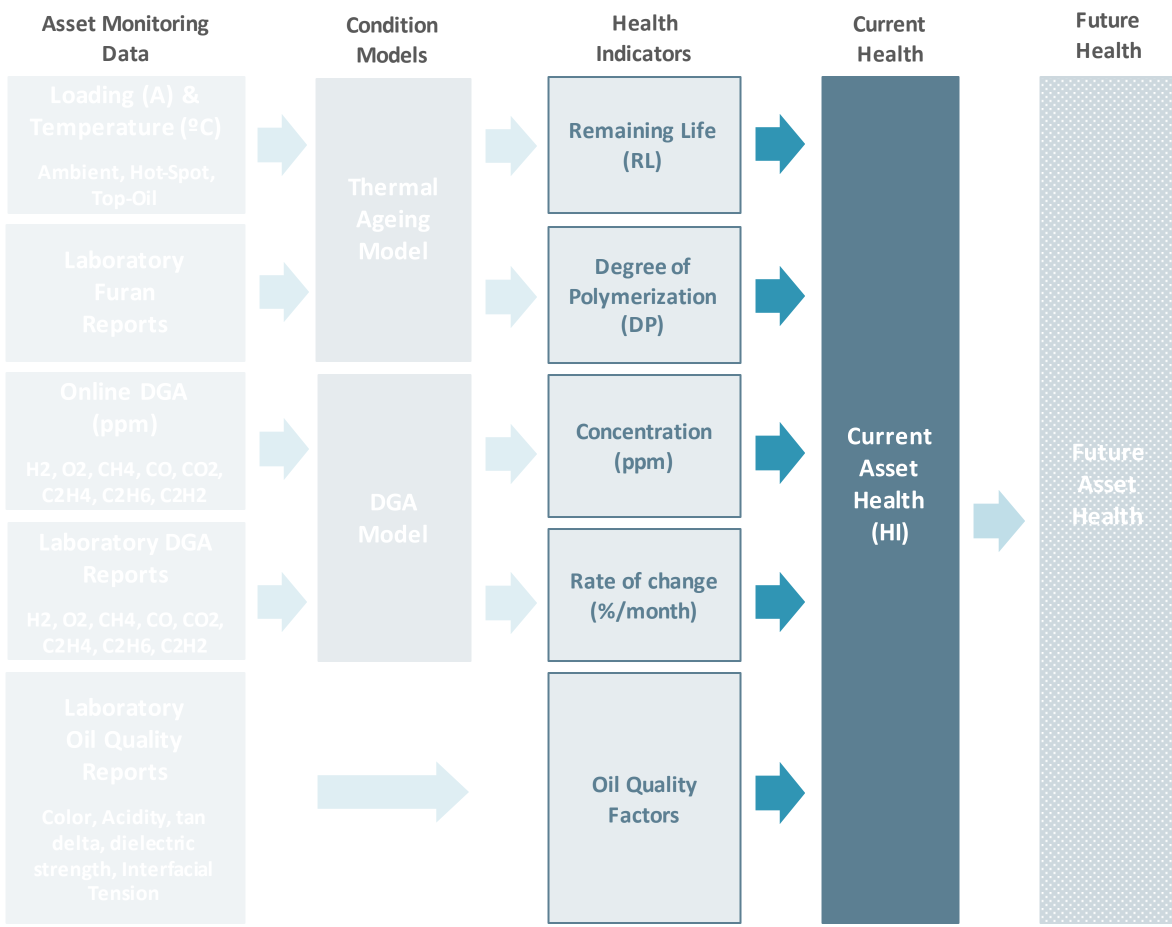
The oil quality parameters are obtained from laboratory testing reports. These reports contain measurements of several oil quality parameters which are then used directly to calculate the overall asset condition.

Currently, the condition models implemented are able to provide health indicators which can be used to evaluate the condition of internal components such as the **winding** or the **oil**.

Other condition assessment models are currently being developed to extract health indicators which could be used to improve the assessment of the overall **Power Transformer** condition by evaluating the condition of other components such as the **bushings, the Online Tap Changer (OLTC) and the cooling systems**.

Asset Health Assessment & Forecast Model

1 ASSET HEALTH ASSESSMENT & FORECAST MODEL | POWER TRANSFORMER USE CASE



Asset Data | Model | Intermediate Results | Under development

- **Current Asset Health Assessment**

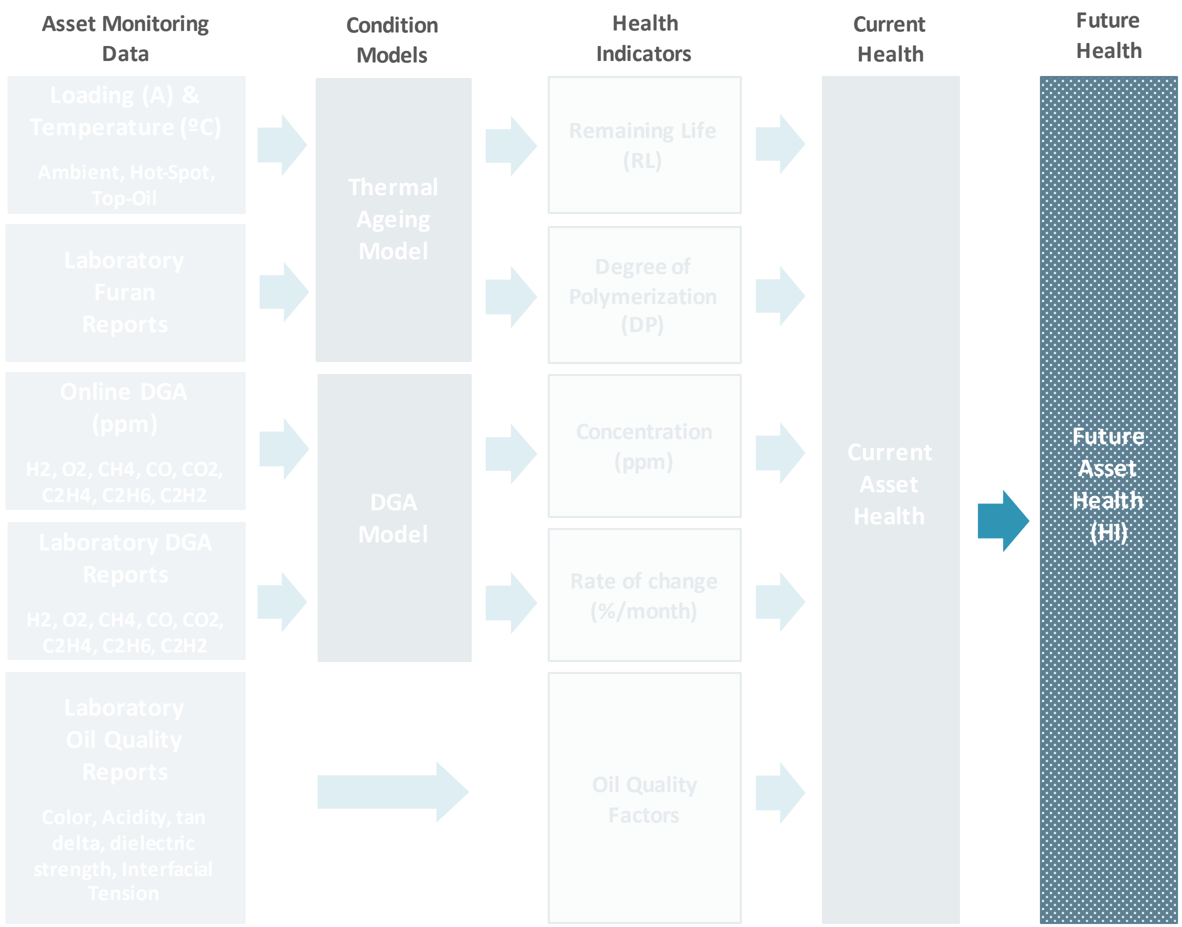
The current method used to assess the overall condition of the asset is based on a weighted average of scores and weights. The **health indicators** obtained from the **condition models** are processed into **condition factors** and **scores** which are further **weighted** in order to **calculate the overall health index (HI) score**.

The condition factors currently implemented are the **Thermal Ageing Factor (TAF)**, **Dissolved Gas Analysis Factor (DGAF)** and **Oil Quality Factor (OQF)**. An example of scoring table is shown below.

HI Score	Condition	Description
85-100	Very Good	No known defects. Aged paper (DP>700). Some aging or minor deterioration. Remaining Life: ≥40.
70-85	Good	No known defects. Aged paper (DP>500). Some aging or minor deterioration. Remaining Life: ≥20.
50-70	Fair	Low energy discharge faults (D1 or PD fault). Low temperature thermal faults (T1). Aged paper (DP>400). Acceptable values for oil degradation. Remaining Life: ≥10.
30-50	Poor	Medium temperature thermal faults (T2 fault). Excessive paper degradation (DP>350). Poor values for oil degradation.
0-30	Very poor	High energy discharge faults (D2 fault). High temperature thermal faults (T3 fault). Critical paper degradation (DP<300). Unacceptable values for oil degradation.

Asset Health Assessment & Forecast Model

1 ASSET HEALTH ASSESSMENT & FORECAST MODEL | POWER TRANSFORMER USE CASE



Asset Data | Model | Intermediate Results | Under development

- **Future Asset Health**

Currently the model only allows the **forecast of the Power Transformer health degradation** by **extrapolating the Degree of Polymerization (DP)** through the **Thermal Ageing Model** (paper degradation physical model) which only considers the influence of the **Loading and Temperatures** patterns. The **Remaining Life (RL)** is calculated as well as the **Probability of Failure (PoF)** based on **Monte Carlo Simulations**.

- ***Under development***

The methodology uses **historical condition and reliability information from assets of similar type and operating conditions to extrapolate an exponential health degradation curve** as it assumes that the rate of degradation (e.g. corrosion, oil oxidation, insulation breakdown, etc.) is accelerated by the products of the deterioration processes.

$$\text{Future HI} = \text{Current HI} \times e^{\beta \times t}$$

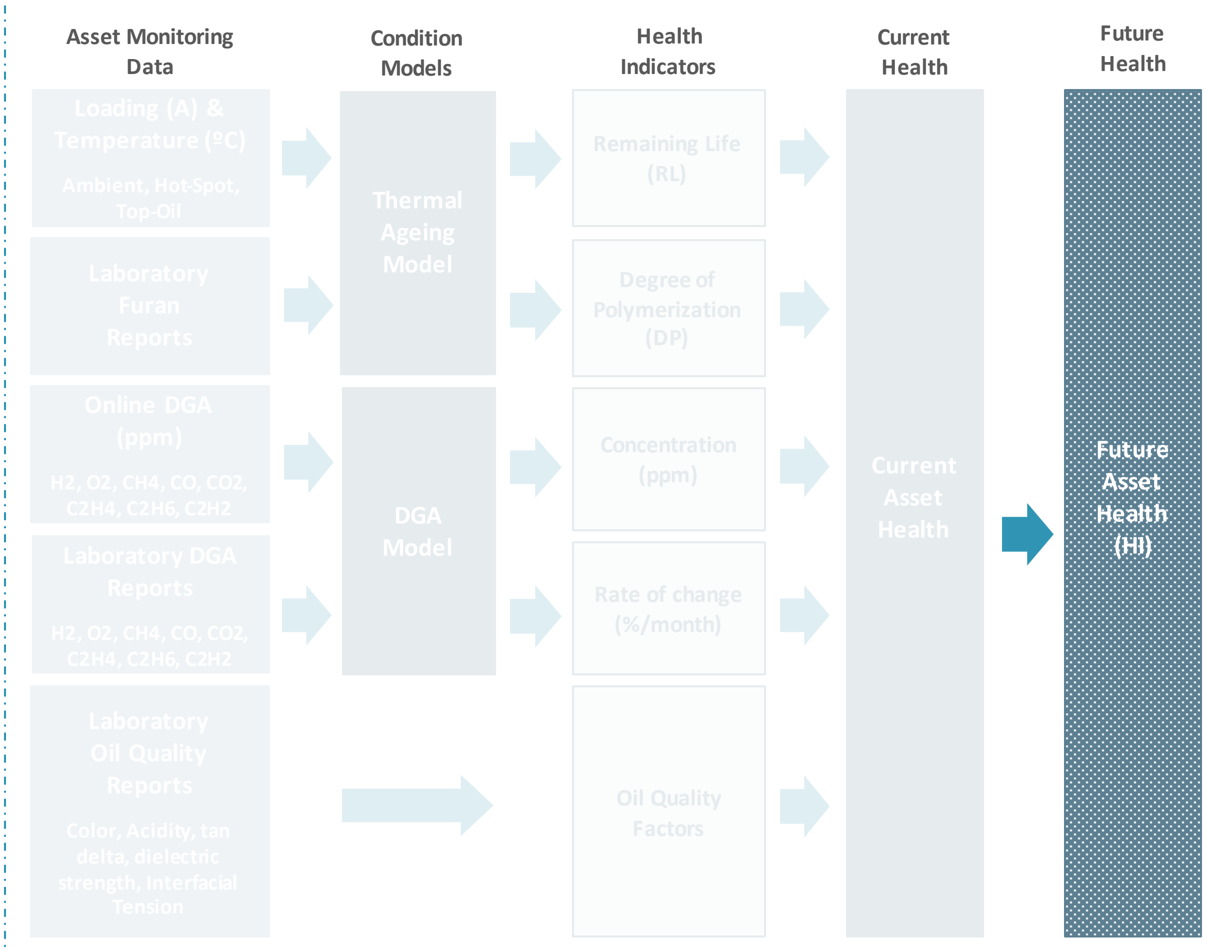
Where:

β is the Forecast Ageing Rate

t is the number of future years

Asset Health Assessment & Forecast Model

1 ASSET HEALTH ASSESSMENT & FORECAST MODEL | POWER TRANSFORMER USE CASE

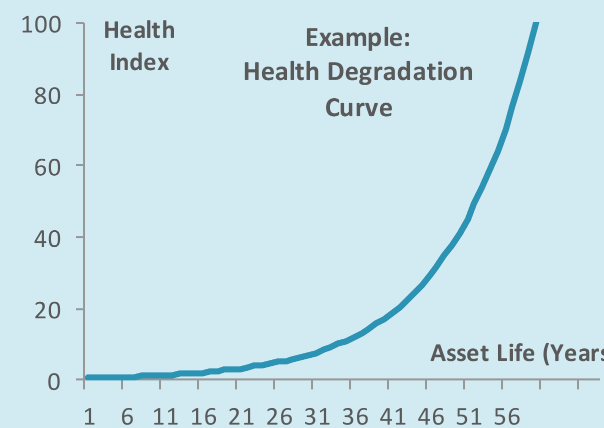


Asset Data | Model | Intermediate Results | Under development

- **Under development**
- **Innovation/Research - Data Science Models**

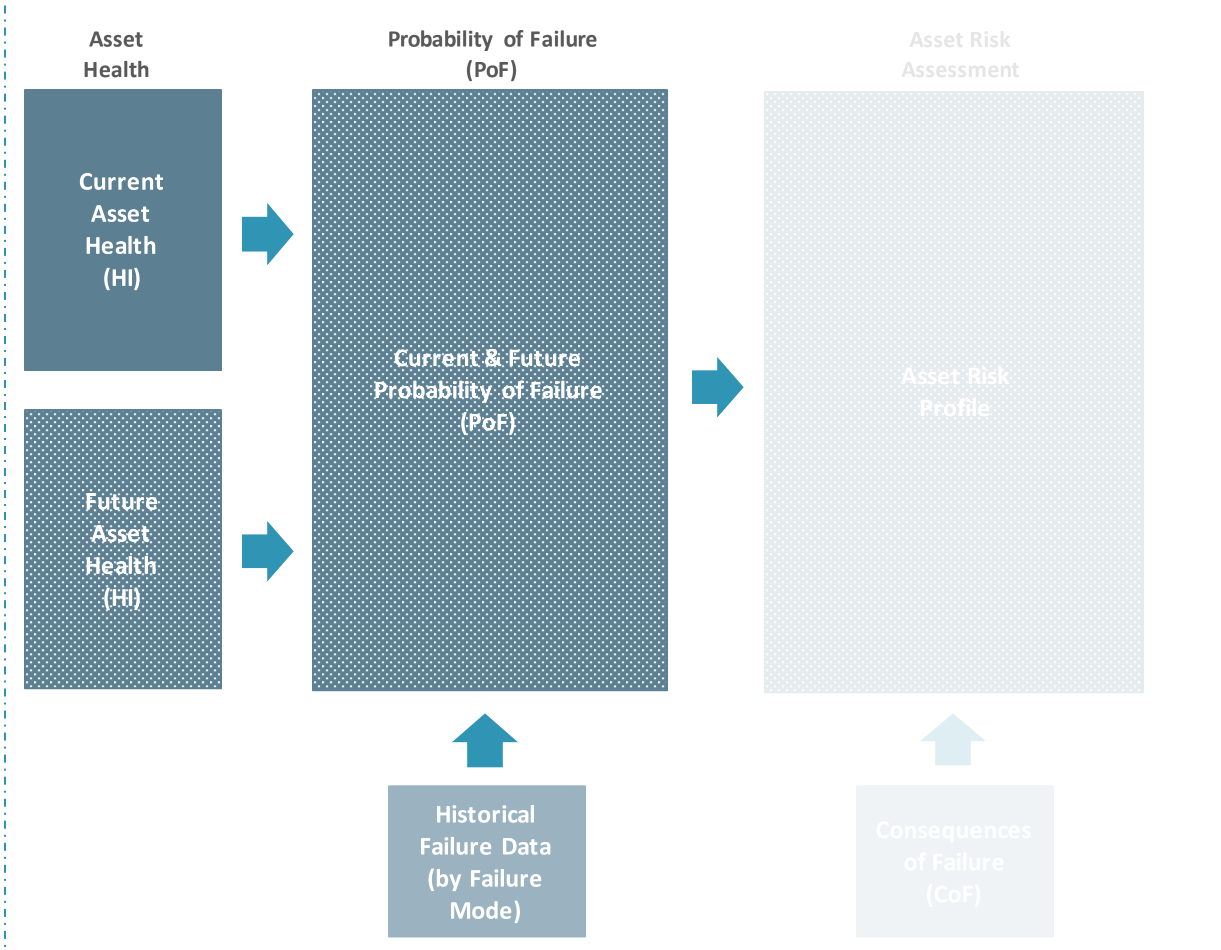
Altran is studying a combination of supervised learning models such as clustering, regression, classification and prediction models to **recognize particular asset degradation patterns** that indicate upcoming behavior such as a failure mode based on the analysis of the relationships among disparate types of asset data.

Those models are under development.



Probability of Failure (PoF) / Risk Model

2 PROBABILITY OF FAILURE / RISK MODEL | POWER TRANSFORMER USE CASE



- **Current & Future Probability of Failure (PoF)**

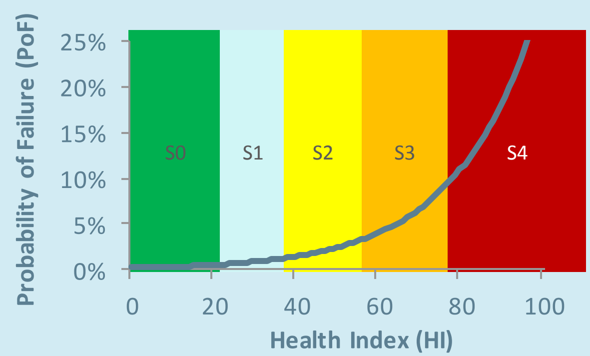
The PoF p/year is calculated using a cubic curve based on the first three terms of the Taylor series for an exponential function which turns the rise of the PoF more controlled than a full exponential curve.

$$PoF = K \times [1 + (C \times HI) + \frac{(C \times HI)^2}{2!} + \frac{(C \times HI)^3}{3!}$$

Where:

- HI is a variable equal to Health Score (Current or Future)
- K and C are constants

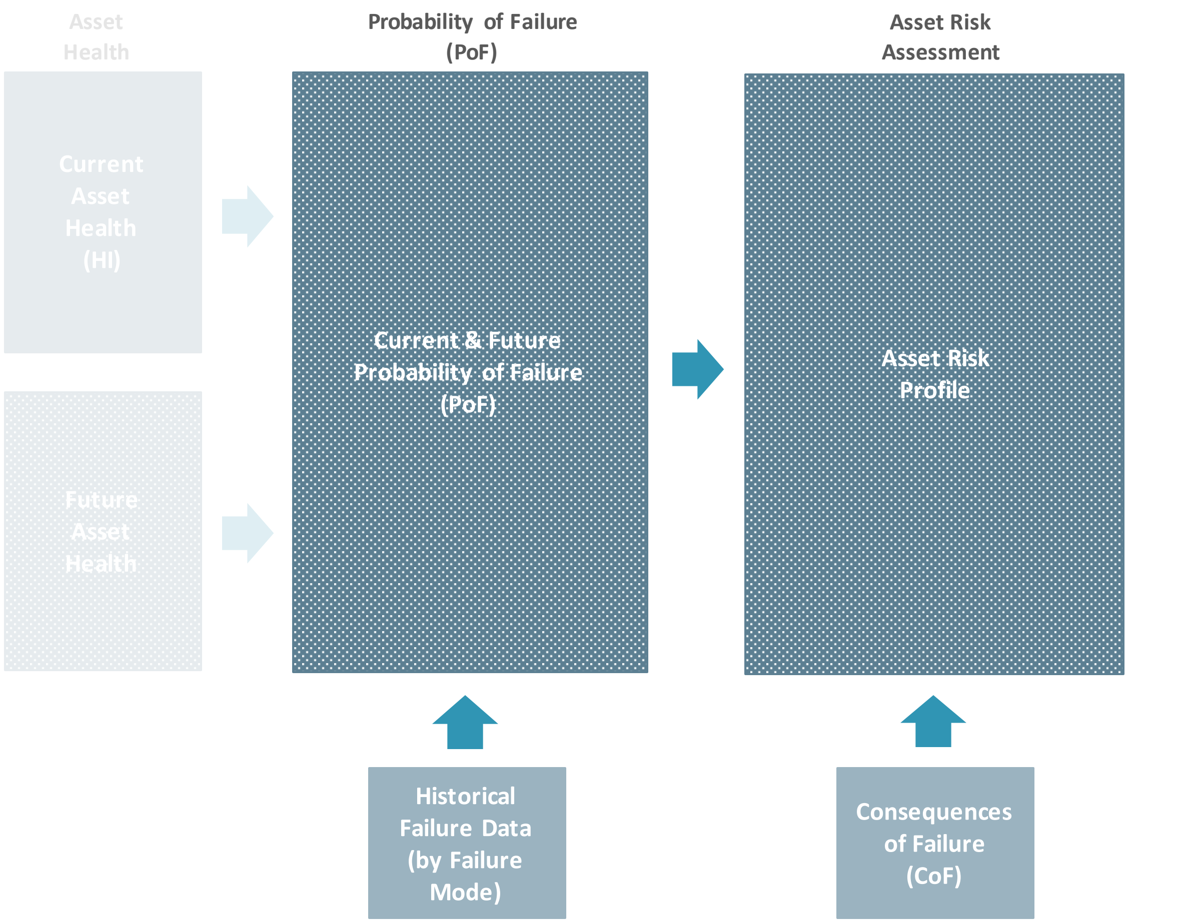
The curve is commonly used in reliability theory. It is further calibrated using failure data across all failure modes from the population of assets.



Asset Data | Model | Intermediate Results | Under development

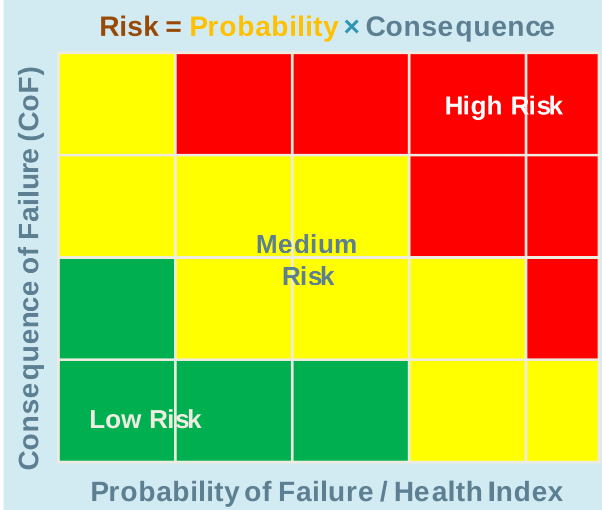
Probability of Failure (PoF) / Risk Model

2 PROBABILITY OF FAILURE / RISK MODEL | POWER TRANSFORMER USE CASE



- **Asset Risk Profile**

The risk of failure associated with each individual asset can be evaluated from the product of the Probability of Failure (PoF) and the Overall Consequence of Failure (CoF) for that asset.

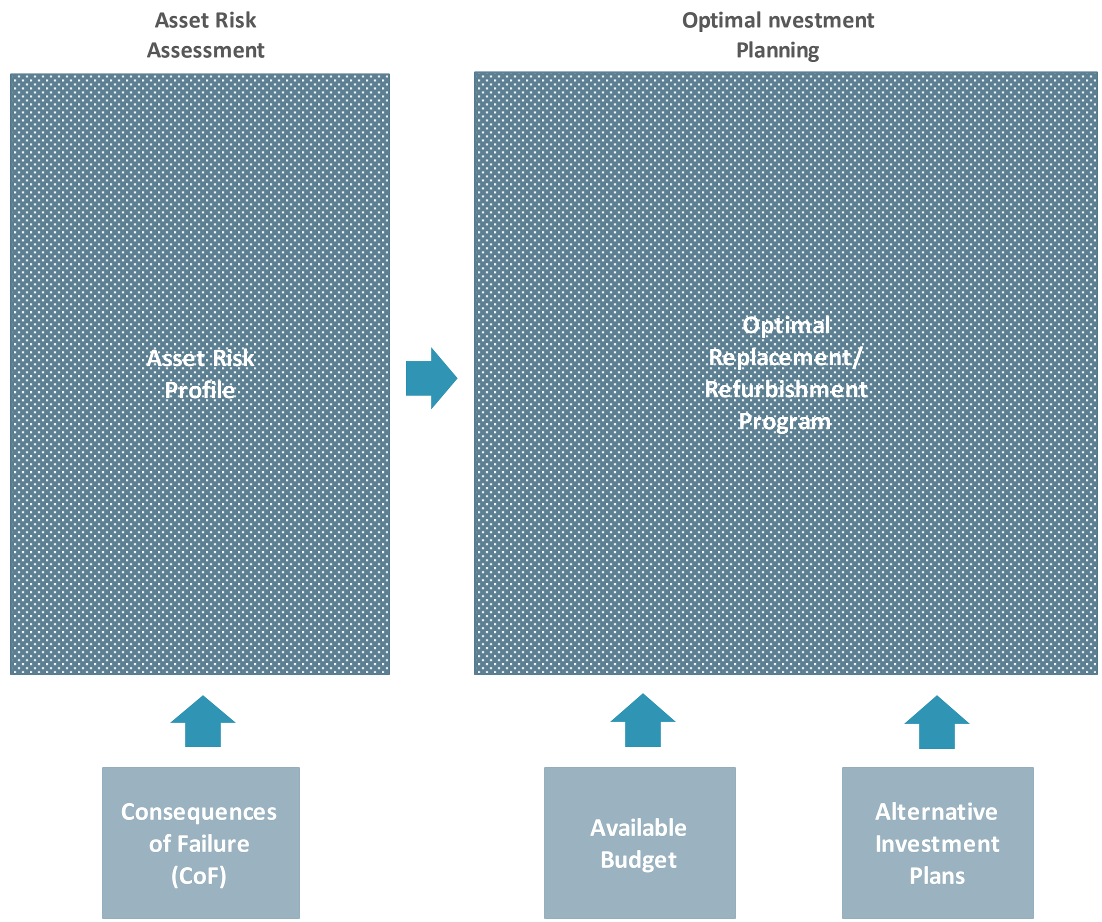


The Consequences Categories considered are **Financial, Safety, Environmental and Network Performance.** Those consequences are quantified and monetized .

Asset Data | Model | Intermediate Results | Under development

Optimal Investment Planning Model

3 OPTIMAL INVESTMENT PLANNING MODEL | POWER TRANSFORMER USE CASE

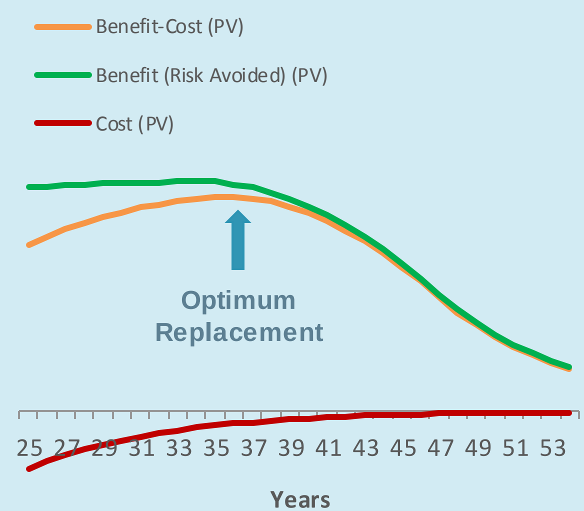


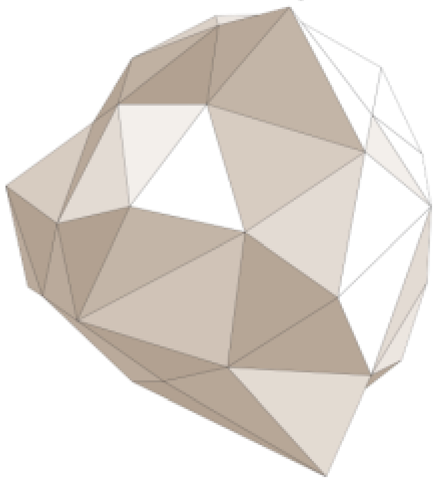
Asset Data | Model | Intermediate Results | Under development

- **Optimal Replacement/ Refurbishment Program**

The model evaluates the Present Value (PV) of the costs/benefits associated with undertaking asset replacement at different points in time during an asset's life in order to determine the optimum replacement year.

The benefit of risk removed in the year of asset replacement is calculated as the difference between the cumulative risk avoided and the risk associated with the new asset.





INNOVATION MAKERS