Predictive tools for gas turbine maintenance decision support

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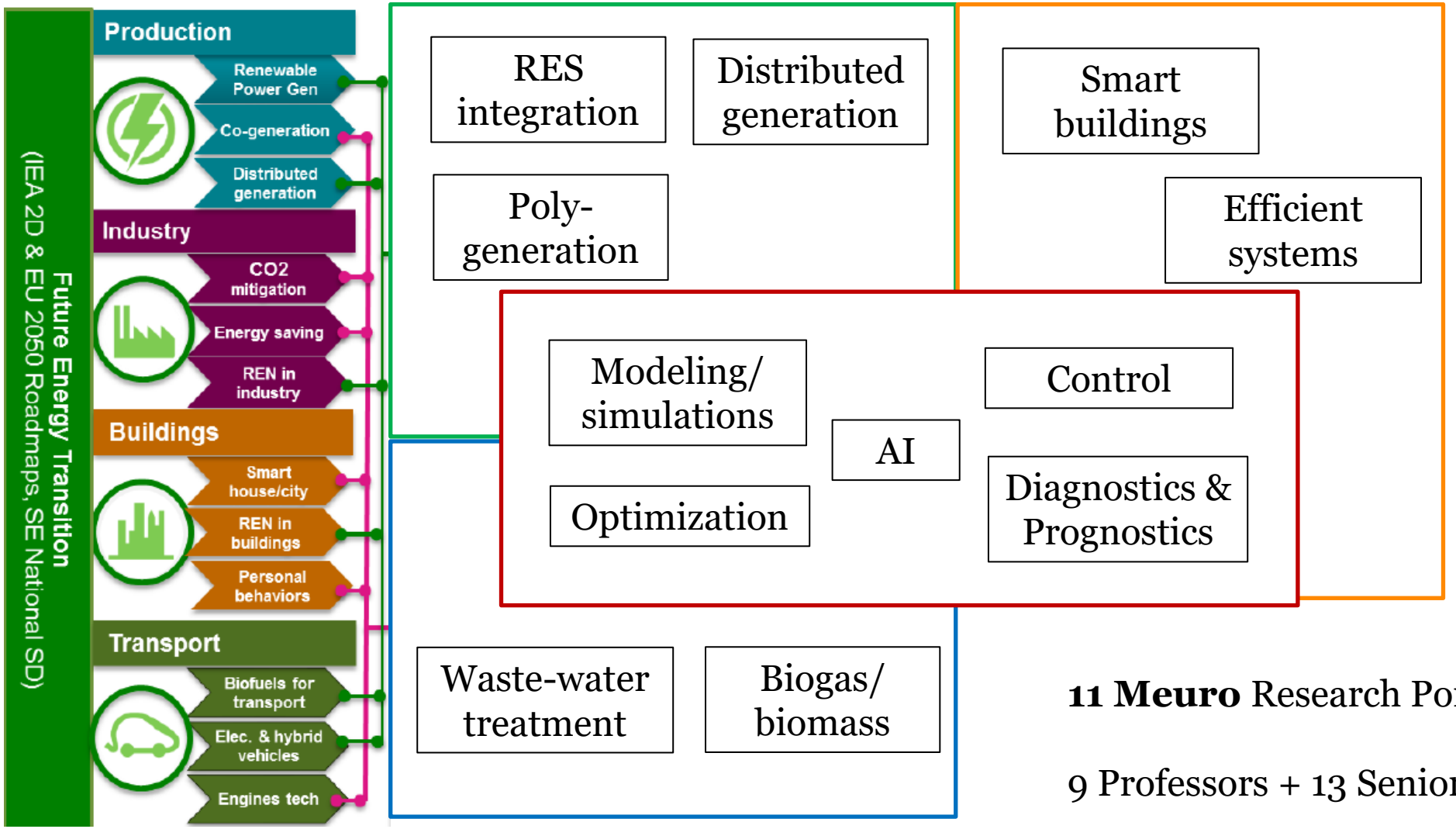


11 Meuro Research Portfolio

9 Professors + 13 Senior researchers + 40 PhD

Background

The problem

Challenges in condition prognostics:

- Lack of run-to-failure data.
- Integration of condition monitoring data and reliability models is challenging:
  - Condition monitoring can give a short term prognostic
  - Reliability models are only general.
- Effect of failures interaction.
- Effect of maintenance actions.

Background

Three steps needed:

- Relationship between failure mechanisms and operating conditions
- Damage propagation models
- Lifetime prediction models.

State of the Art:

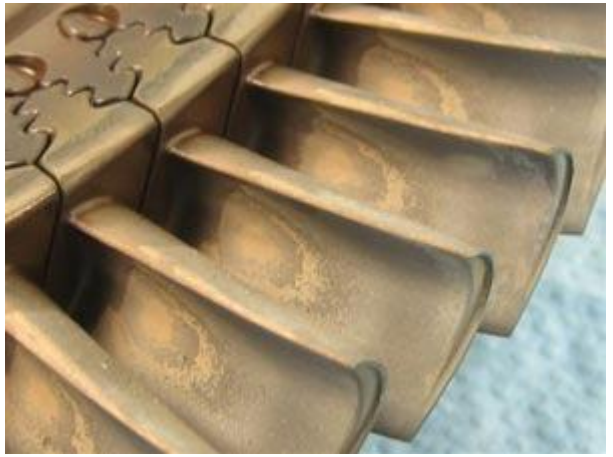
- Remaining life models: physics-based, semi-empirical, statistical, or pure mathematical expressions.
- Significant amount of data needed to fine-tune the models.

Predictability

What is needed for meaningful decisions is *predictability* concerning:

- Schedule maintenance
- Single component lifetime
- Conditions after maintenance

Can we extend maintenance interval?

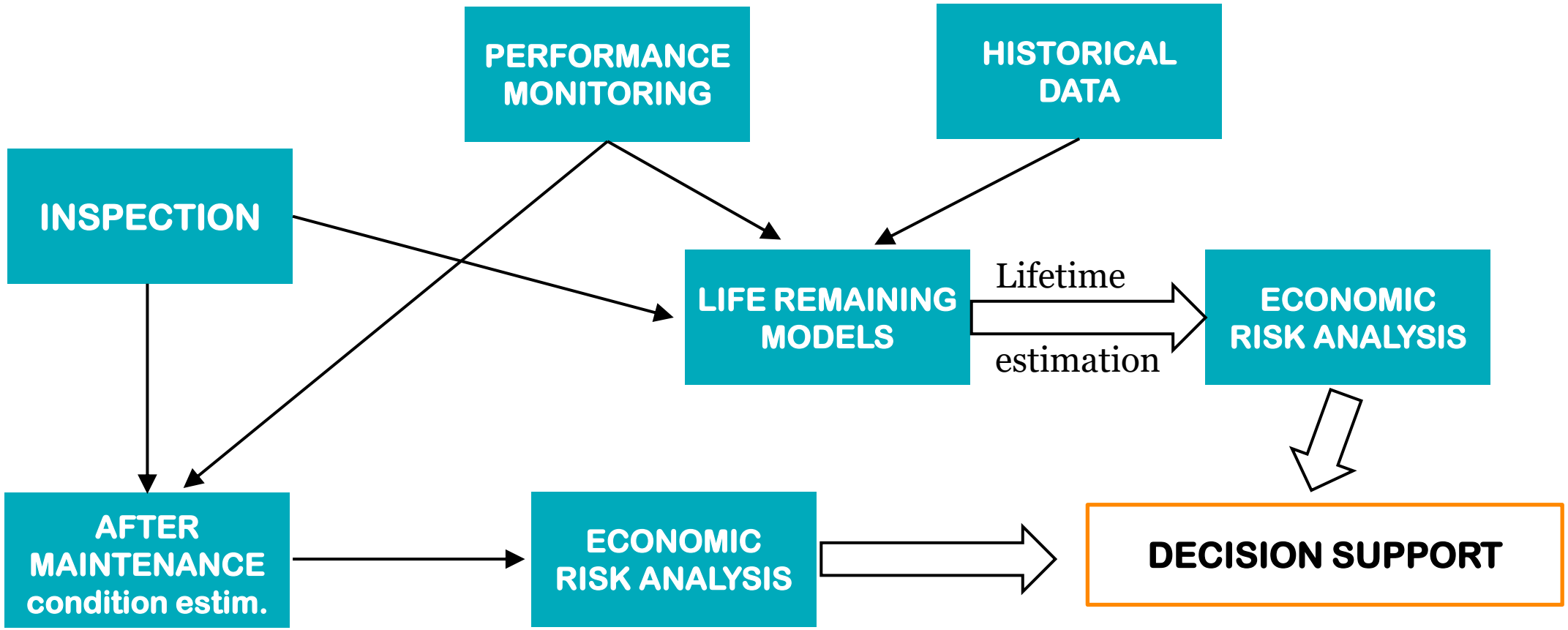


Life remaining models

Low cycle fatigue	Manson-Coffin	$\varepsilon_t = \frac{\Delta\varepsilon}{2} = \frac{\sigma_f}{E}(2N_f)^b + \varepsilon_f(2N_f)^C$
Creep	Larson-Miller	$P = \frac{T}{1000}(\log t_r + C)$
Oxidation	Thermally grown oxide layer	$[\log C - \log(d^2/t)][T + 460] = Q/R$
Other components	Weibull distribution	$f(t) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} e^{-\left(t/\eta\right)^{\beta}}$

- Blades
- Disc

The concept: a framework for decision support under uncertainty



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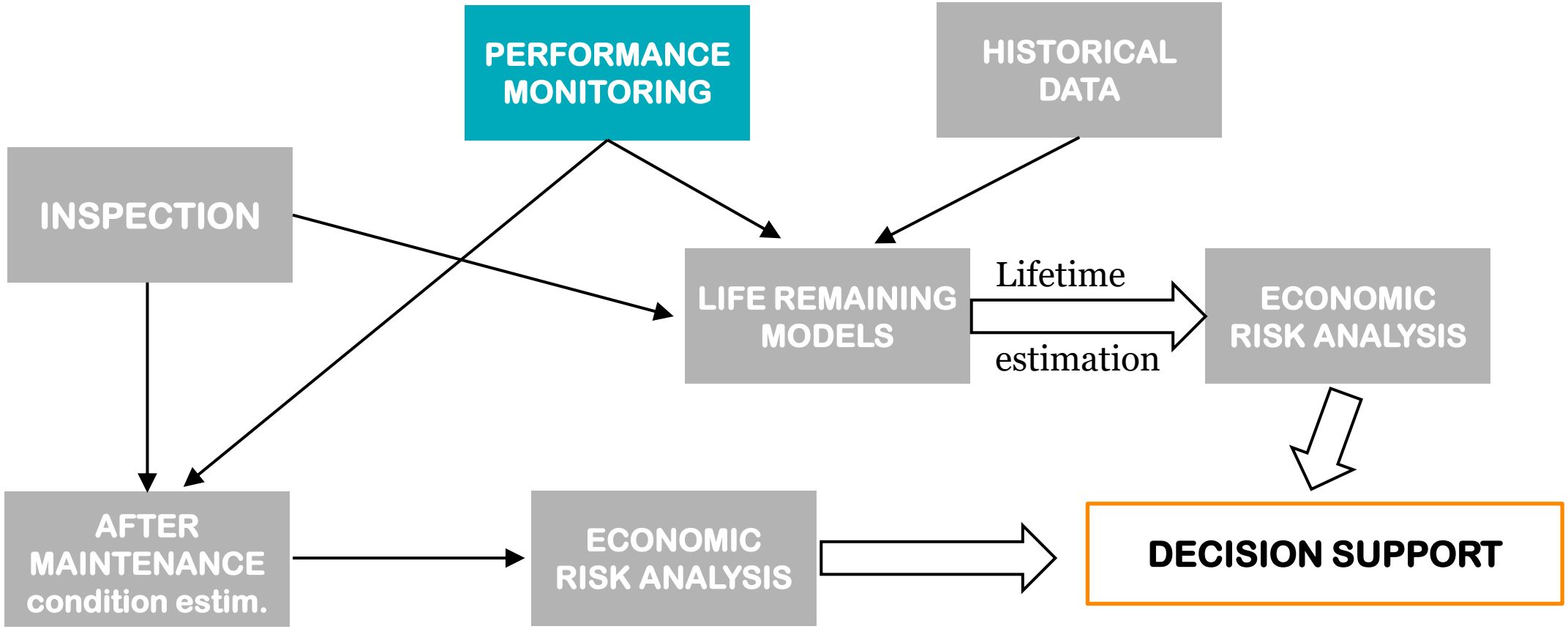
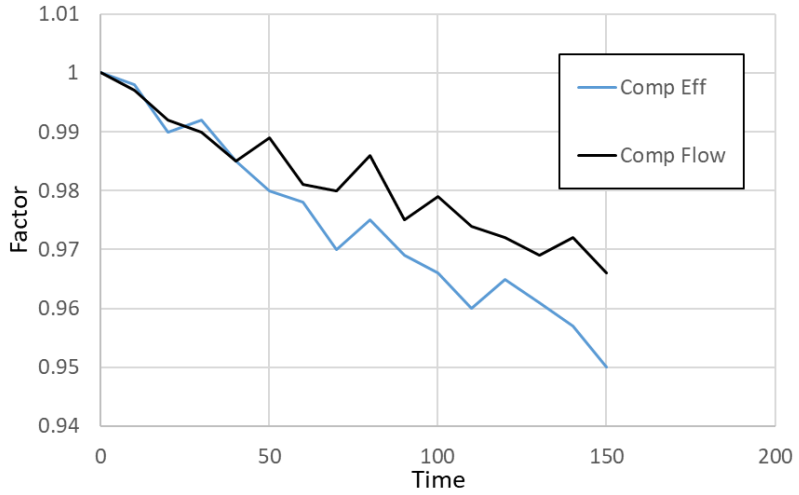


Results from performance monitor

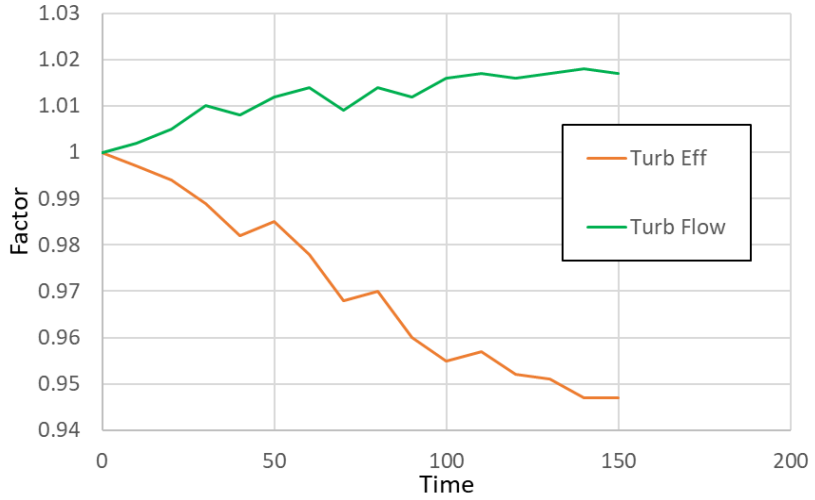
Measurements

Adaptive model



Compressor efficiency drop 5%
flow capacity drop 3%

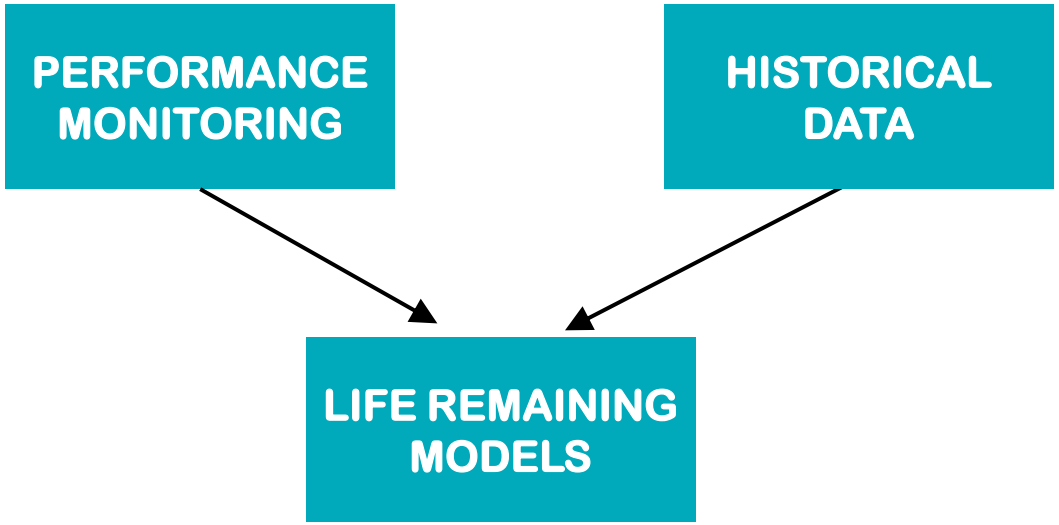
→ Compressor fouling



Turbine efficiency drop 5%
flow capacity increase 2%

→ Turbine erosion

Integration for enhanced predictability



- Interaction between mechanisms, e.g. creep causes blades to rub against the case and damage, tip clearance can increase and induce loss
- Erosion or corrosion reduce blade section and strength
- The key is integration of condition monitoring and reliability models: the latter need to be updated with the first

Life remaining model

Low cycle fatigue	Manson-Coffin	$\varepsilon_t = \frac{\Delta\varepsilon}{2} = \frac{\sigma_f}{E}(2N_f)^b + \varepsilon_f(2N_f)^C$	→ Stress analysis
Creep - Blades - Disc	Larson-Miller	$P = \frac{T}{1000}(\log t_r + C)$	Hybrid creep models can be also integrated
Oxidation	Thermally grown oxide layer	$[\log C - \log(d^2/t)][T + 460] = Q/R$	
Other components	Weibull distribution	$f(t) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} e^{-\left(t/\eta\right)^{\beta}}$	

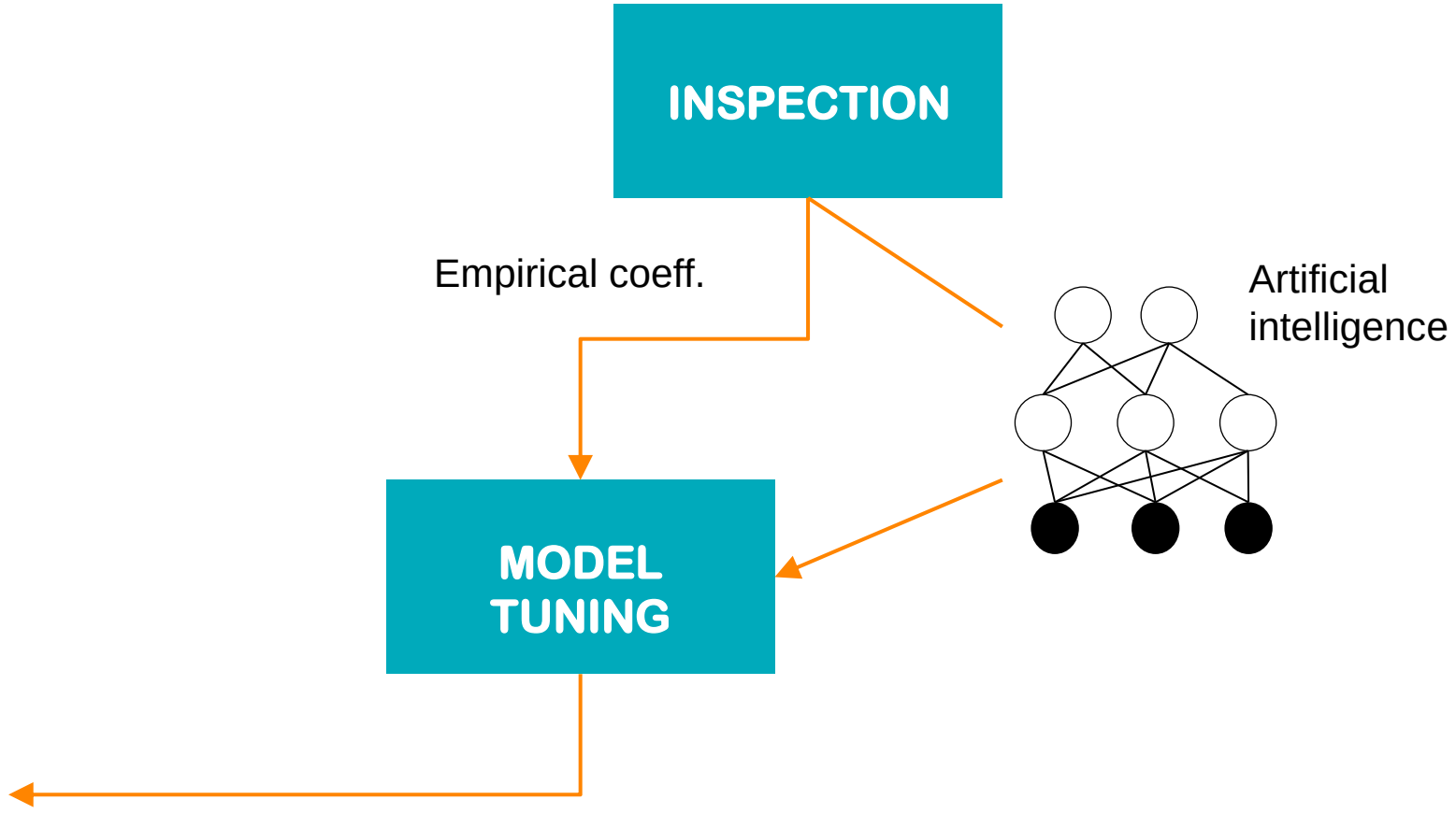
Results from risk analysis

Rotor inlet T = 1573 K
Cooling flow T = 913 K
Number of cycles = $4*10^9$
Cycle duration = 8 h

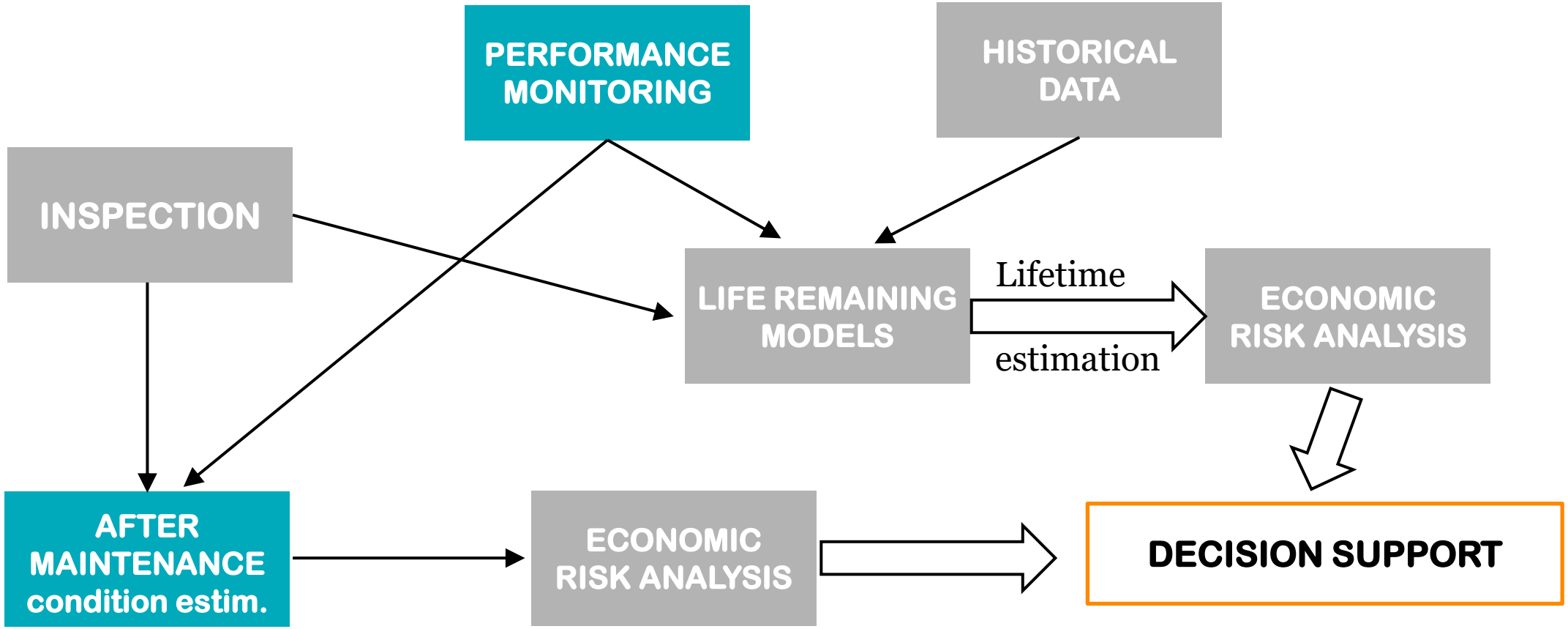
Blade LCF life = $24*10^3$ h
Blade creep life = $30*10^4$ h
Disc creep life = $26*10^9$ h
Weibull life = $21*10^3$ h

Suggested TBO = $21*10^3$ h

Updated TBO = $19*10^3$ h

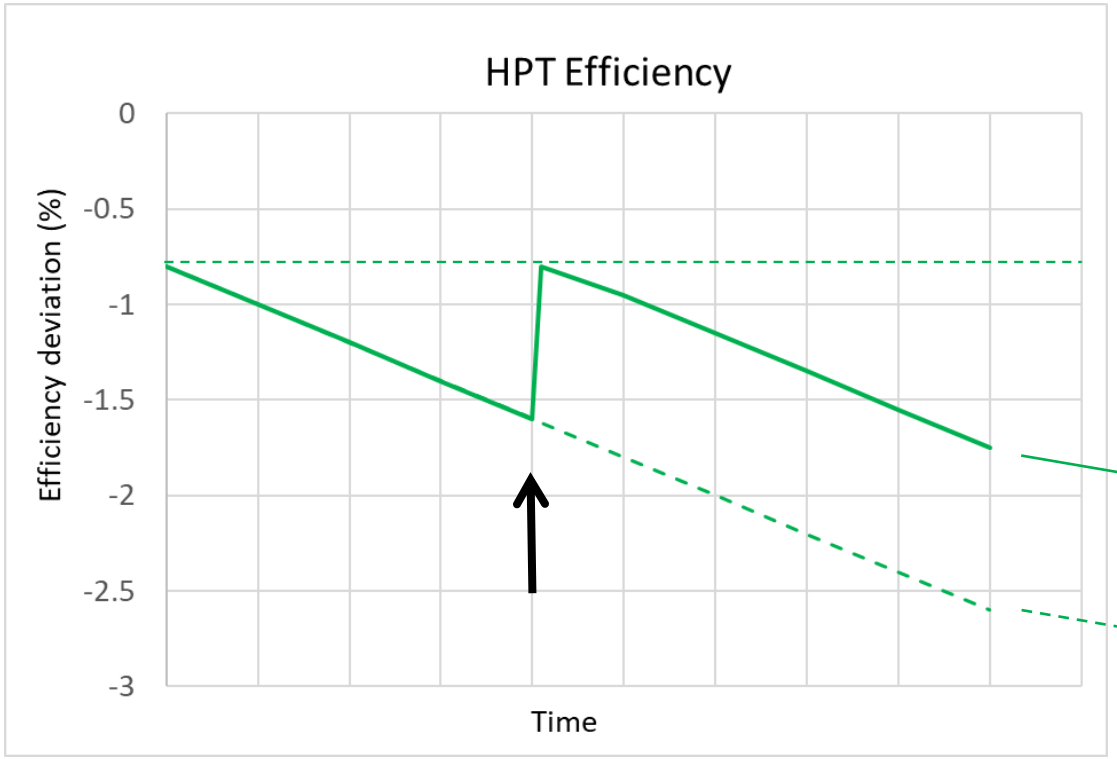


The concept: a framework for decision support under uncertainty



Estimated condition after maintenance

Turbine blades erosion



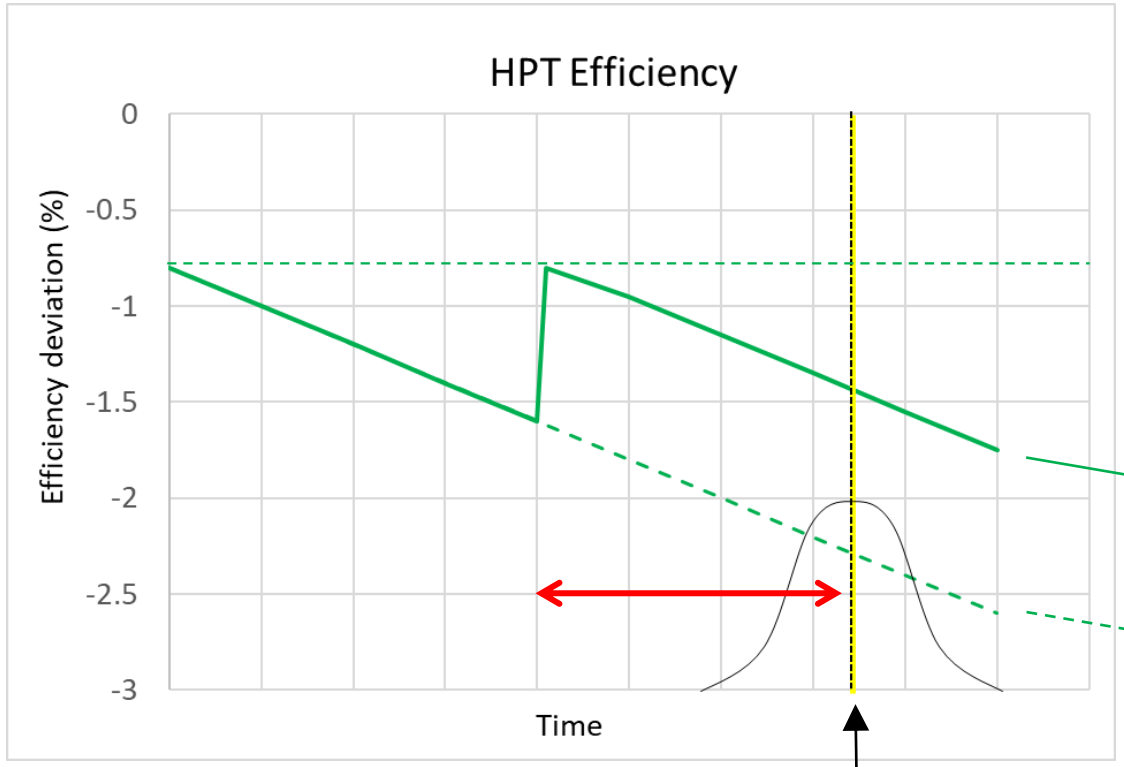
Initial efficiency loss
(manufacturing tolerance etc.)

Efficiency deviation after maintenance

Efficiency deviation if no maintenance

Estimated condition after maintenance

Turbine blades erosion



Initial efficiency loss
(manufacturing tolerance etc.)

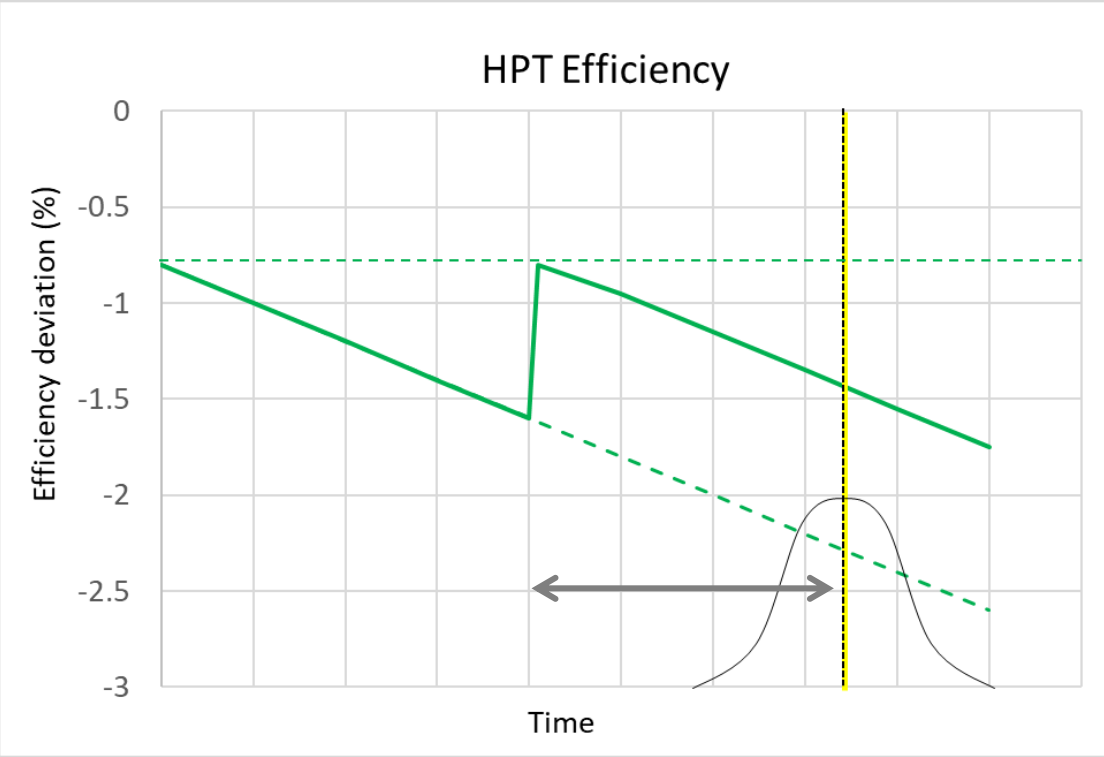
Efficiency deviation after maintenance

Efficiency deviation if no maintenance

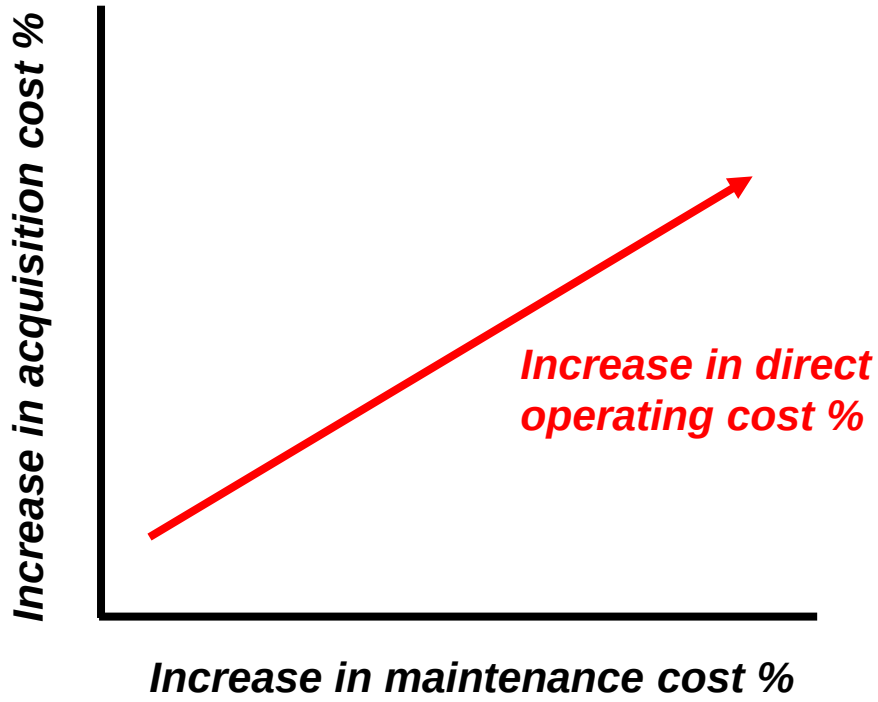
Estimated remaining life

Creep and fatigue life are affected by blade conditions

Estimated condition after maintenance

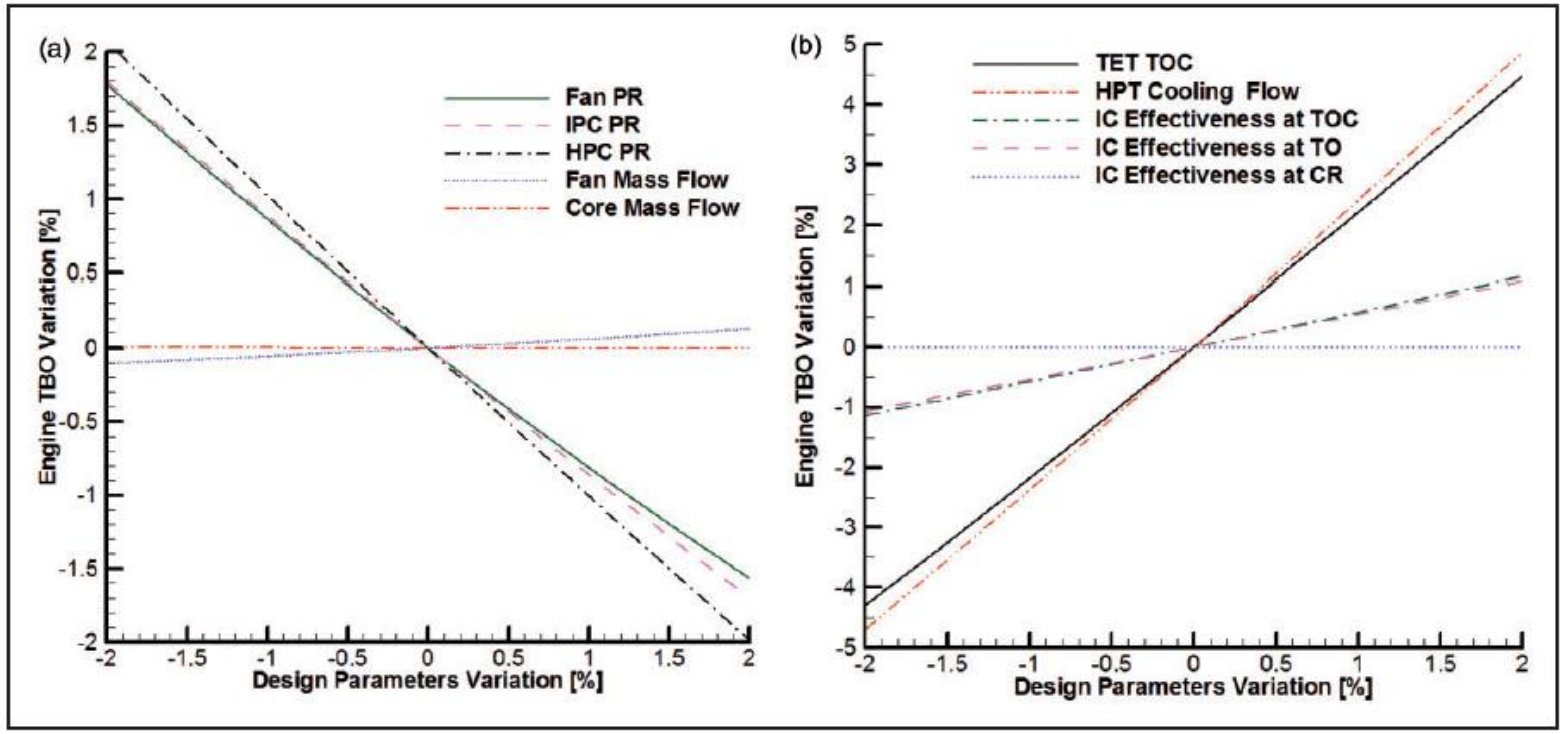


Turbine blades erosion



- Updated lifetime models
- Maintenance model
- Production loss
- Other costs

Sensitivity analysis



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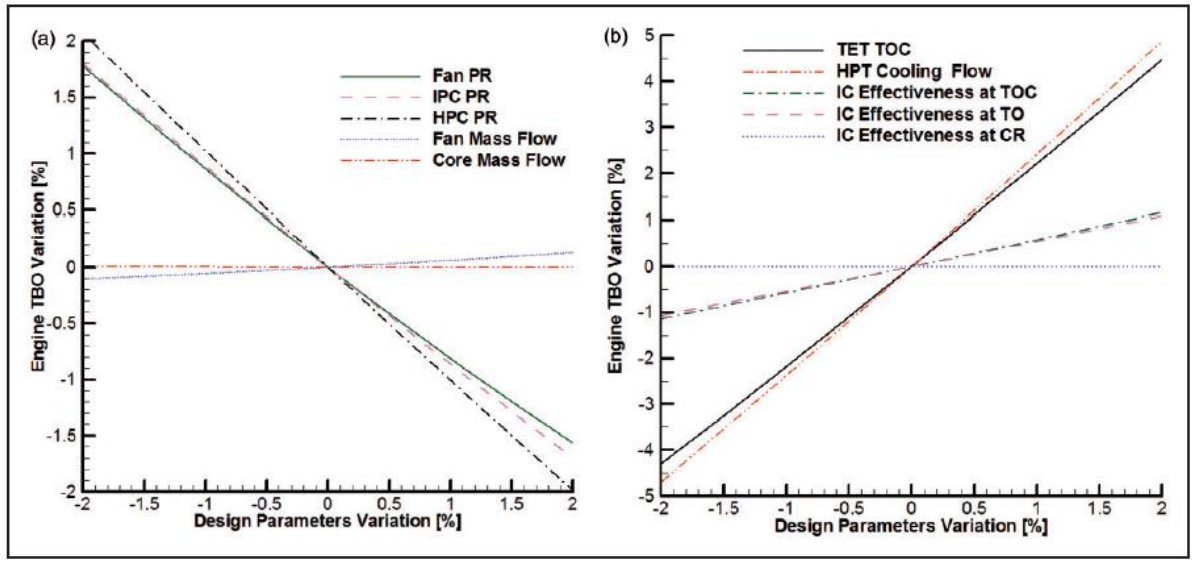
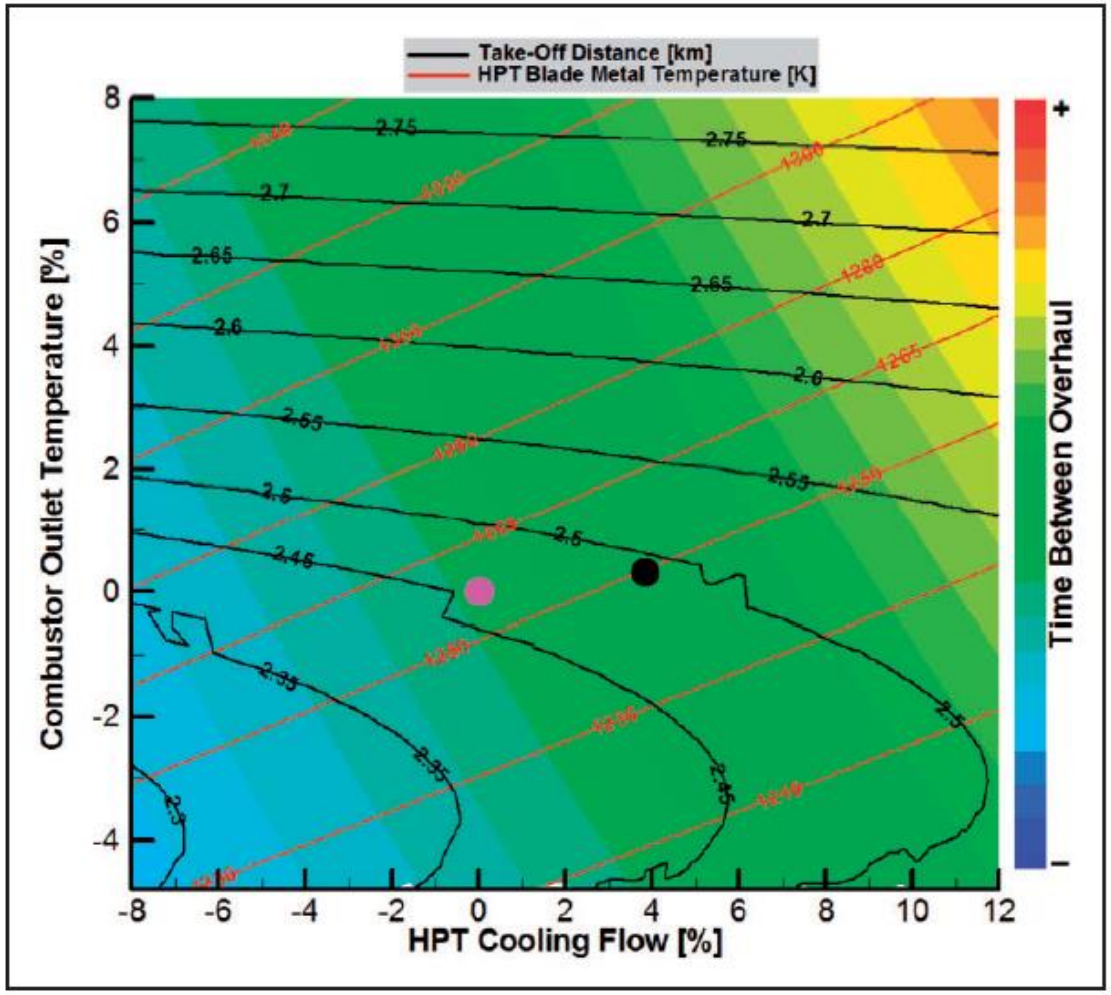
Sensitivity analysis and optimization study





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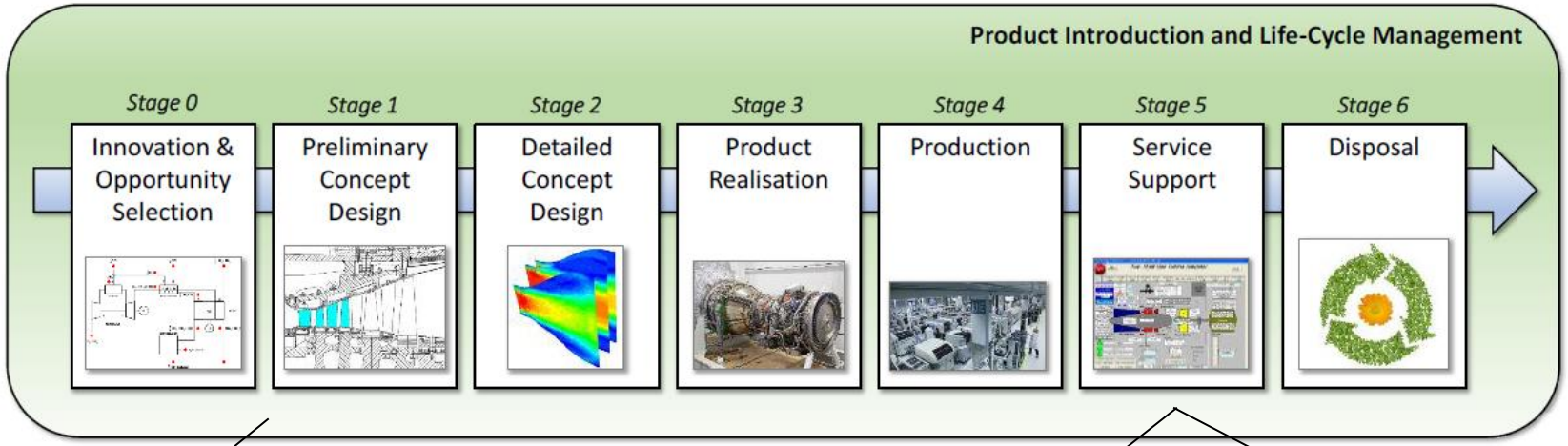
Life cycle and economic risk assessment

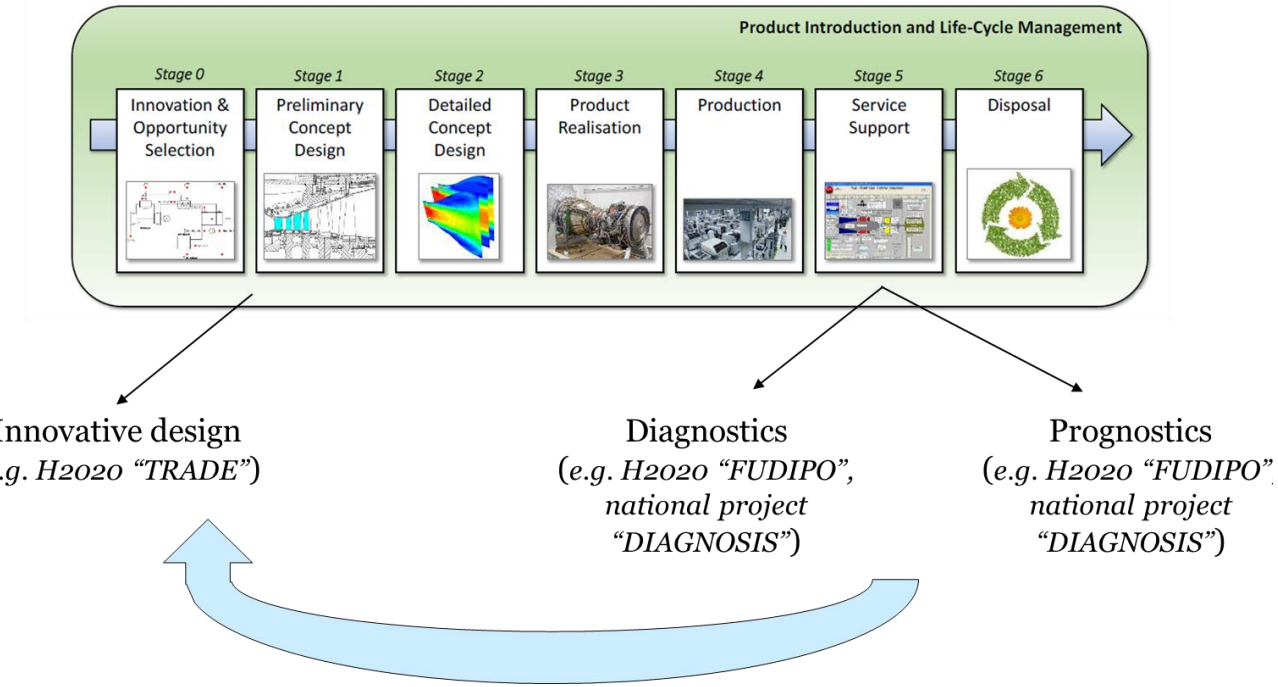


Innovative design
(*e.g. H2020 "TRADE"*)

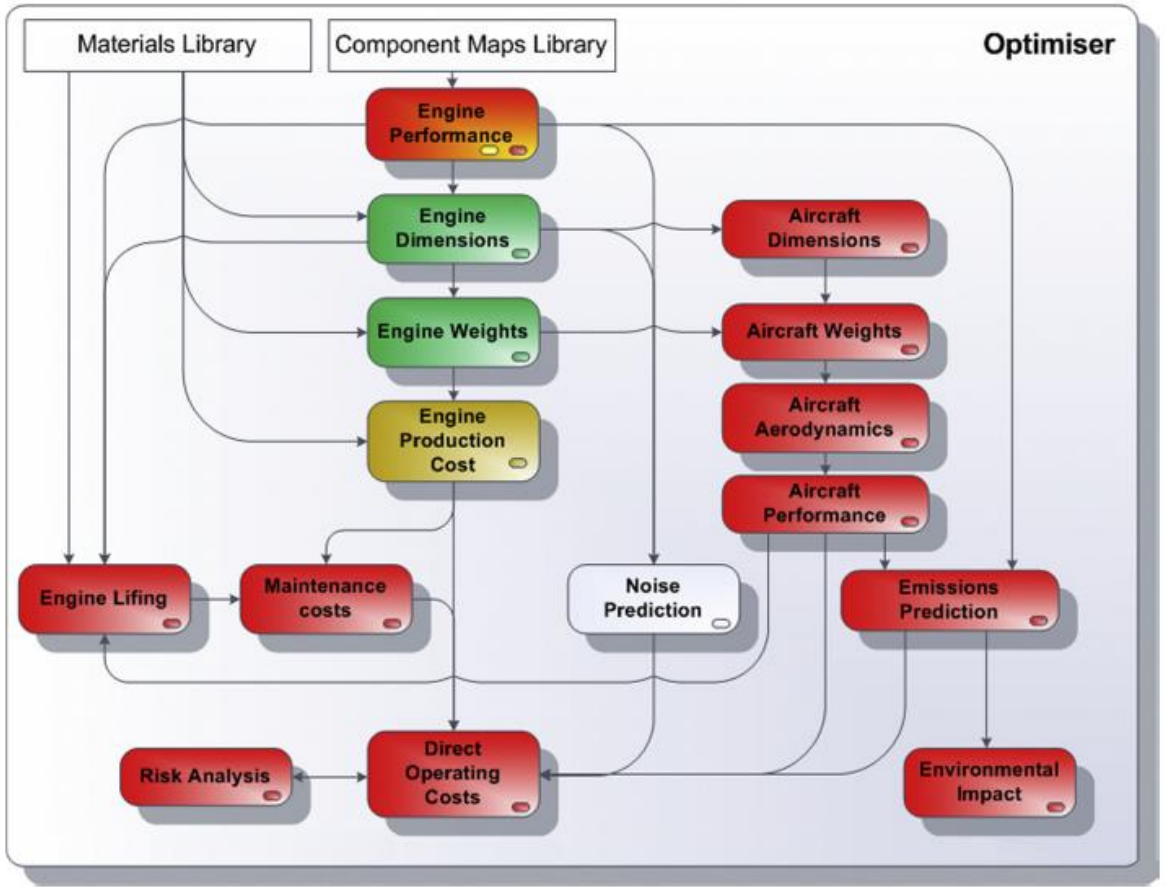
Diagnostics
(*e.g. H2020 "FUDIPO", national project "DIAGNOSIS"*)

Prognostics
(*e.g. H2020 "FUDIPO", national project "DIAGNOSIS"*)

Life cycle and economic risk assessment



EVA – Environmental Assessment of novel propulsion cycles



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