POD/PFA/ROC/Quality of monitoring models

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COST WORKSHOP

AUGUST 23-24, COPENHAGEN, DENMARK

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Institut de Recherche en Génie Civil et Mécanique

Institute for Research in Civil and Mechanical Engineering
220 people – A+ ranked
6 groups

UNIVERSITE DE NANTES

University of Nantes
40 000 students,
200 graduated each year in mechanical and civil engineering
THE ranked

Group (40 people) « Structural integrity, Reliability and probabilitic approaches: application to marine structures »

- ✓ **Time and space dependent degradation modelling and** computing (diffusion, corrosion, fatigue): Gama models, PCE based models, TV fatigue damage, including efficient TV reliability >> **risk assessment, RBI…**

- ✓ **Goal oriented sensors**
- **3D stress assessment through Eshelby FOS (patent)**
- **2-D Patch FOS** for jacket structures loading monitoring and damage updating (*see Workhshop 5-WG1, Thöns*)
- **Resistivity/impedence based sensors for spatial variability assessment in concrete**
- **Image processing for cost reduction and non intrusivity**: 1D -> 3D (algorithms including under-pixel measurement **(Virtual Image Correlation)** (*see Workshop 1- WG4, Pakrashi*)

Operational monitoring (study cases):

- Applied research: 4 quays (2 in discussion), 1 wind turbine (foundation)

- Theoretical research: 1 concrete floating structure (2017), 1 jacket structure (2018)

1. Quantifying the benefit of modelling degradation using stochastic multiphasic multivariate state-based meta-models in a maintenance management context

2. Definition, quantification and use of imperfect quantification assessment in RBI

Real quantification assessment: incomplete, imperfect (technical, human, numerical limitations)

Contribution to WG1:

$$B_1 = \max_{\mathbf{s}} E_{\mathbf{Z}_E}\left[E_{\mathbf{Z}_A}\left[\max_{\mathbf{a},\mathbf{d}} E_{\mathbf{X}|\mathbf{Z}_E,\mathbf{Z}_A}\left[\overline{B}(\ldots)\right]\right]\right] \quad (4)$$

$$\overline{B}(\ldots) = \overline{B}\left(\overline{\mathbf{d}}\left(\overline{\mathbf{a}},\mathbf{X},\overline{\mathbf{Z}}_E,\overline{\mathbf{Z}}_A\right),\mathbf{s},\mathbf{X},\overline{\mathbf{Z}}_E,\overline{\mathbf{Z}}_A\right) \quad (5)$$

Uncertain information from SHM: X

Incomplete X^- and imperfect U_x >> $X \approx U_x X^-$ → Reduced information

→ Bad decisions if not filtered

Part 1

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Quantifying the benefit of modelling degradation using stochastic multiphasic multivariate state-based meta-models in a maintenance management context

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Trinity College
The University of Dublin

Title: The potential added value of heterogeneous databases for maintenance of infrastructures in case of a limited number of monitored structures with imperfect sensors

Introduction

Pathologies are multiphasic

Relate to the same failure

Several physical indicators

Different tendencies

Benefit in terms of Lifecycle management and SHM

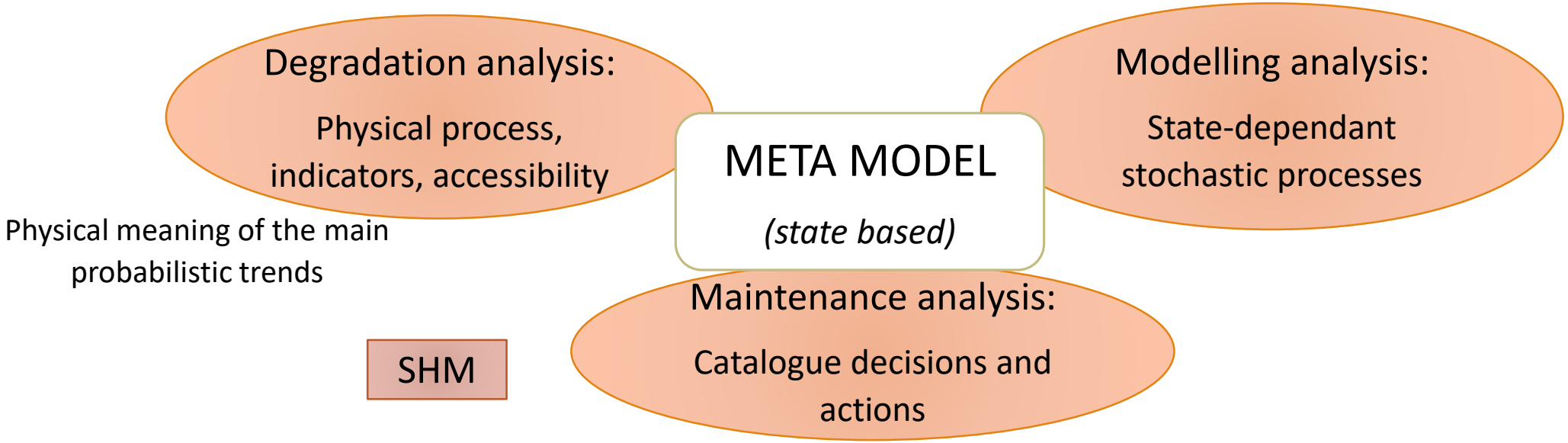
Specific techniques and maintenance actions for each phase and indicator

A combination allows a richer modelling

- ✓ Un-observable degradations
- ✓ Imperfect maintenance actions
- ✓ Individualisation

- ✓ Optimise monitoring (frequency, wireless, cable, etc.)

State based meta-models

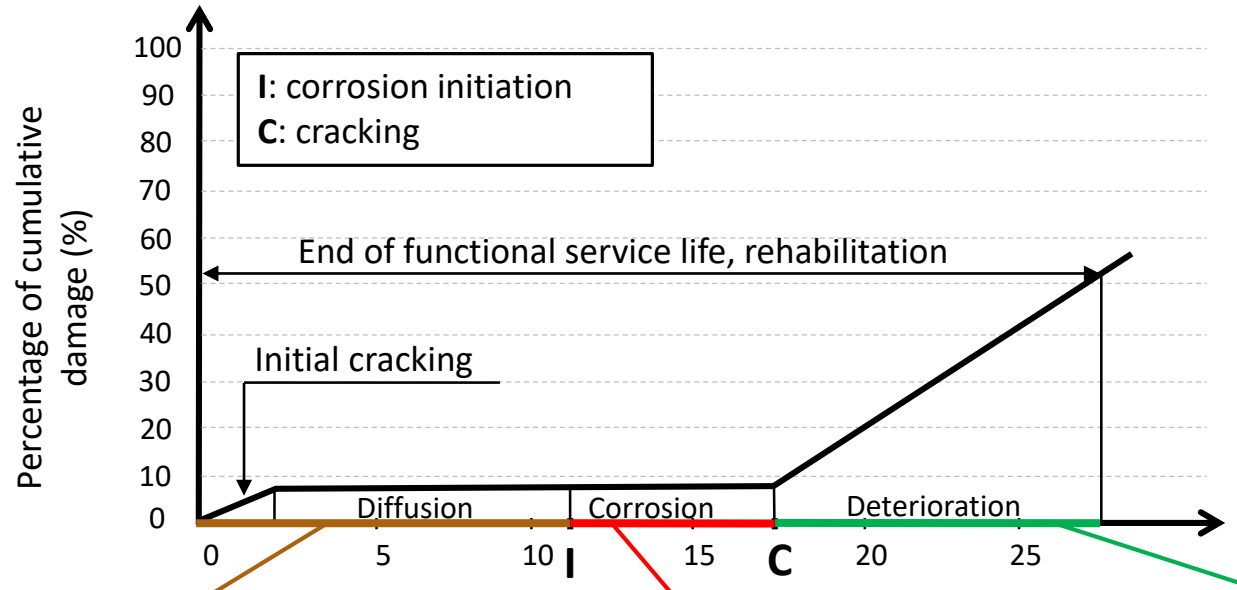


Definition of a degradation meta model

- Small number of parameters
- Probabilistic pertinence and physical expertise
- Indicators of degradation and durability directly accessible through SHM

Multi-phasic modelling

ex: chloride-induced corrosion



For each phase:

A bivariate process written

$$(\rho_t, \theta_t)_{\forall t \geq 0}$$

ρ_t: condition indicator
θ_t: potential of evolution

Choice of indicators:

- Accessibility via. SHM
- Representation of the degradation process

Diffusion of chloride

- $(\rho_{1,t})_{\forall t \geq 0}$ $[Cl^-]$: Chloride concentration
- $(\theta_{1,t})_{\forall t \geq 0}$ PH

Corrosion of reinforcement

- $(\rho_{2,t})_{\forall t \geq 0}$ σ: Internal stress
- $(\theta_{2,t})_{\forall t \geq 0}$ i_{corr}: corrosion current density

Crack propagation

- $(\rho_{3,t})_{\forall t \geq 0}$ a: Crack width
- $(\theta_{3,t})_{\forall t \geq 0}$ i_{corr}: corrosion current density

ρ_t: Condition indicator | θ_t: potential of evolution

Phase 1 : Chloride diffusion

$[Cl^-]$ | PH

$[Cl^-]$ (%)

$unirnd[0.4 - 0.5]$

(Angst et al. 2009)

$(\rho_{1,t})_{\forall t \geq 0}$

S-shaped

PH

$(\theta_{1,t})_{\forall t \geq 0}$

L-shaped

Phase 2: Corrosion of the reinforcement

σ | i_{corr}

σ (Mpa)

$unirnd[2.7 - 3.1]$

$(\rho_{2,t})_{\forall t \geq 0}$

L-shaped

i_{corr}

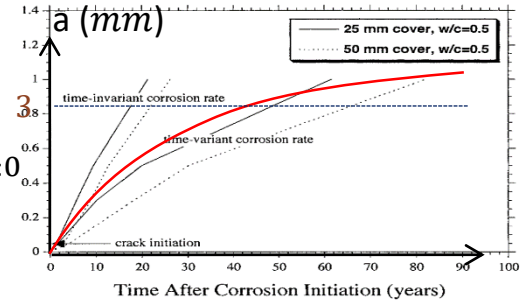
$(\theta_{2,t})_{\forall t \geq 0}$

S-shaped

Phase 3: Crack propagation

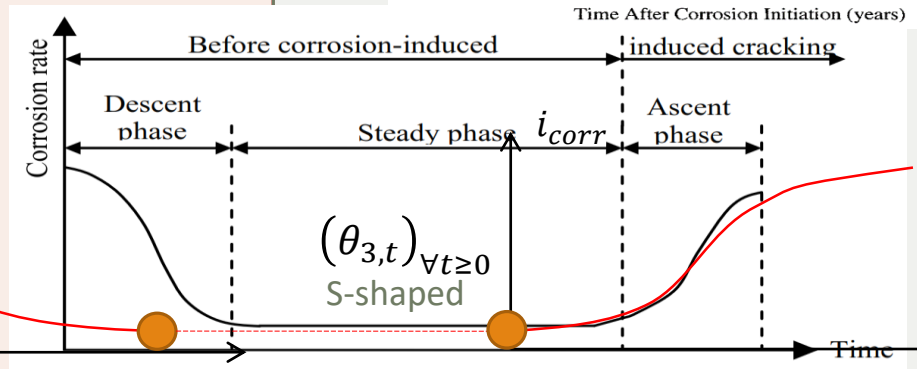
a | i_{corr}

a (mm)



$(\rho_{3,t})_{\forall t \geq 0}$

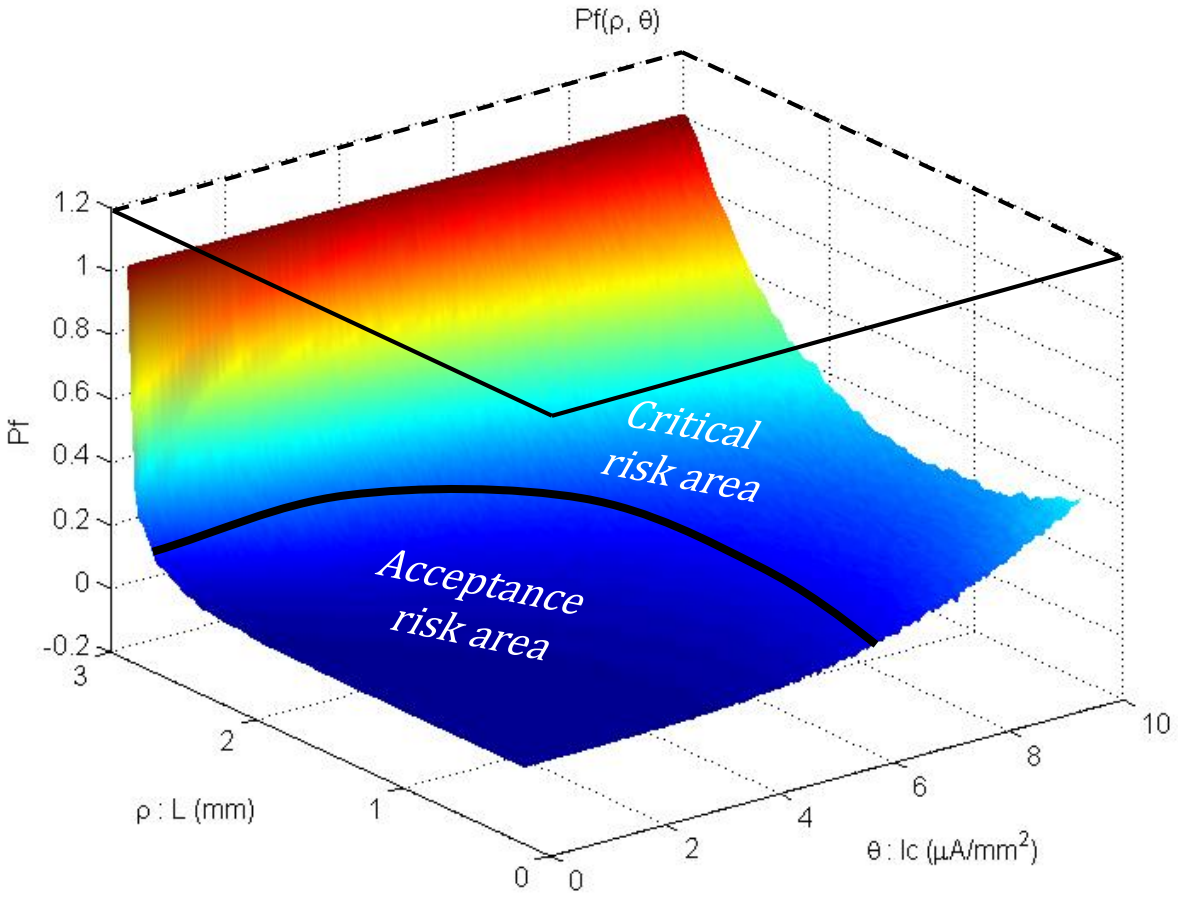
L-shaped

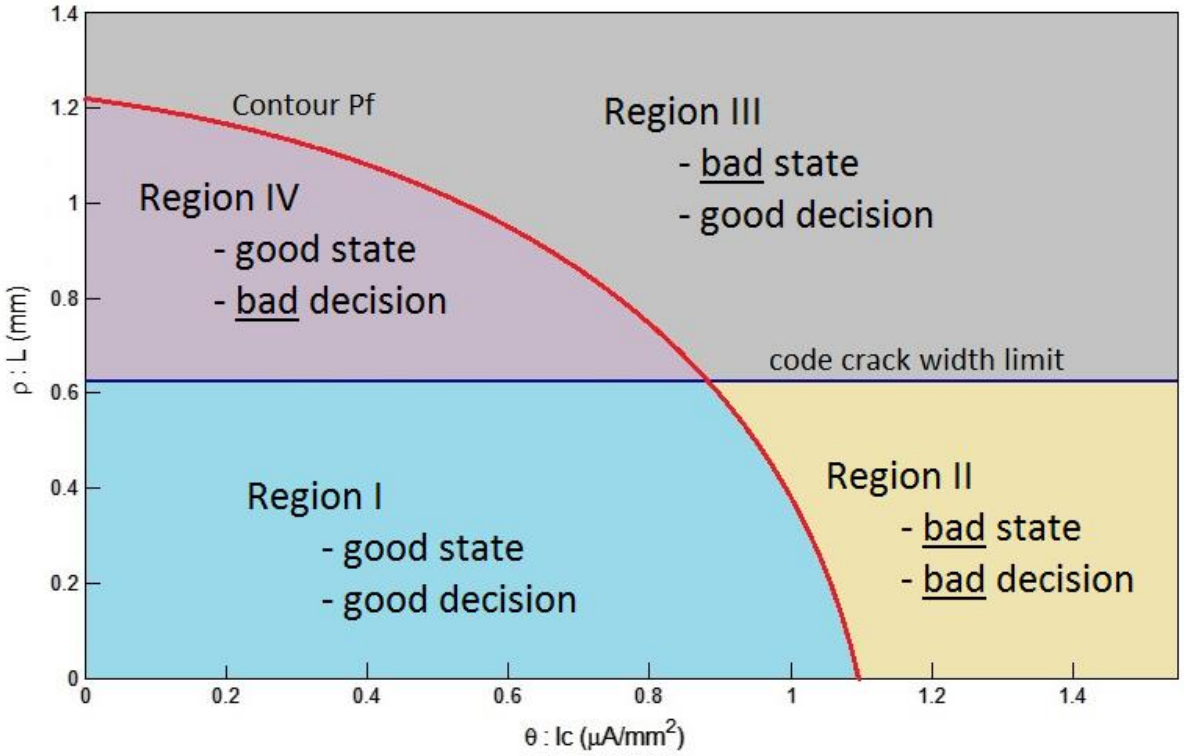


$(\theta_{3,t})_{\forall t \geq 0}$

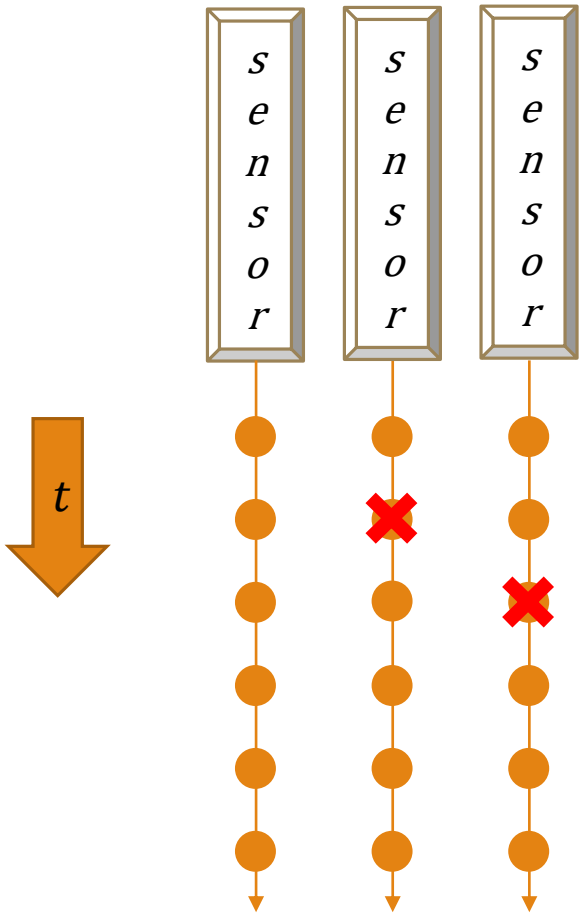
S-shaped

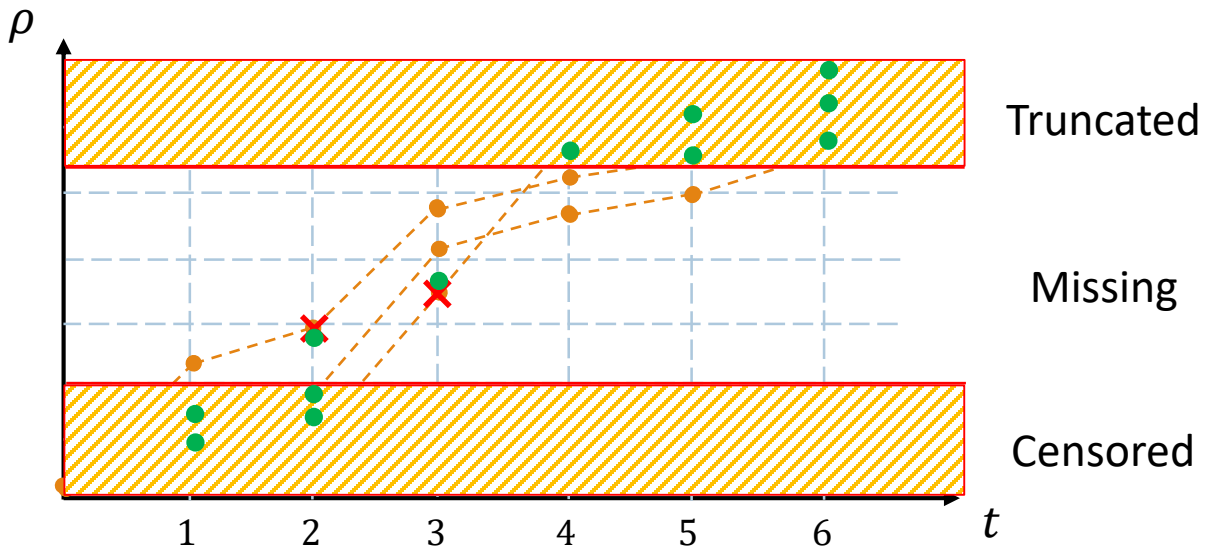
Multi-variate state-based probability of failure





Realistic situations and possible solutions





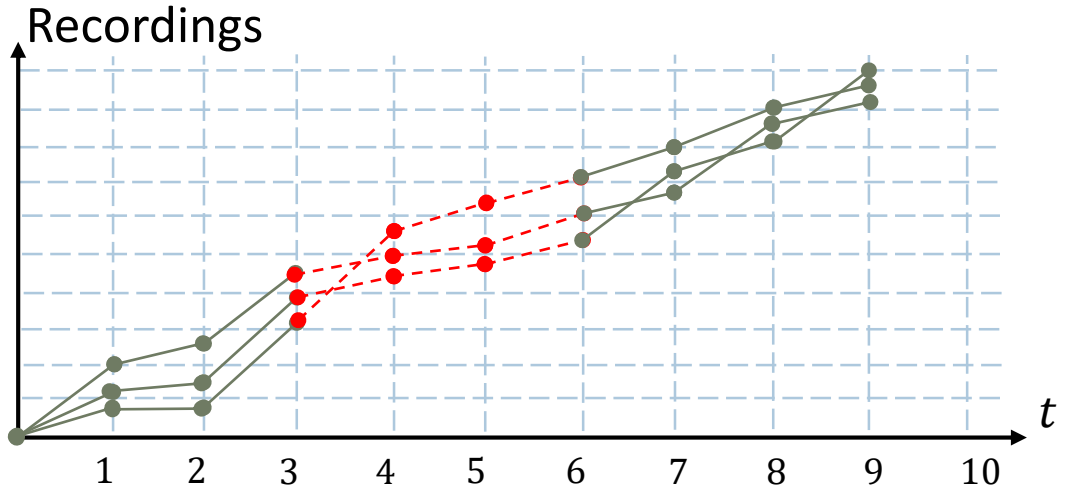
Maximum likelihood estimation (+fixed-point)

Stochastic Estimation Maximization (SEM)

Benefit of heterogeneous databases

Benefit of heterogeneous info in SHM

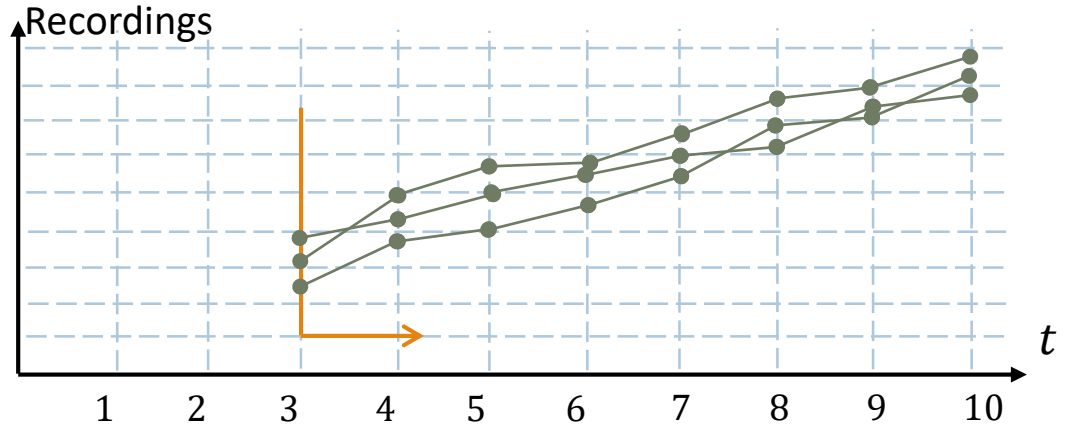
Family of structures #1



Live censors

Offline censors

Family of structures #2



Installation of a new network of sensors on structures #2

Part 2

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Definition, quantification and use of imperfect quantification assessment in RBI: PoD PFA, ROC

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Probabilistic Modelling Of SHM results

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RBI (optimize the planning)

In harsh environment

Bad detections exist

(detection of a non existing defect, non detection of an existing defect)

Bad decisions (over-costs)

- *Non necessary repair (detection of a non existing defect)*
- *Failure (non detection of an existing defect)*

SHM, NDT and destructive tests

Ageing laws

Consequenceanal ysis

Structural network

Limit states

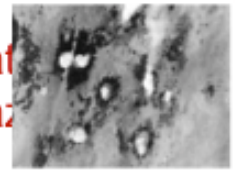
Risk Assessment

Using SHM results in RBI context

- Model the uncertainty

- Take into account expert judgement and model its choice

The real world



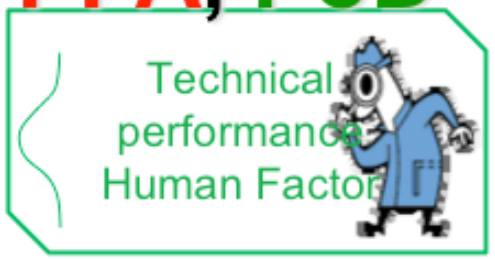
SELECTED APPROACH:

- **Probabilistic modelling of inspection based on detection theory**

- **Bayesian modelling of inspection results**
- **Introduce the expert judgement**

The accessible world

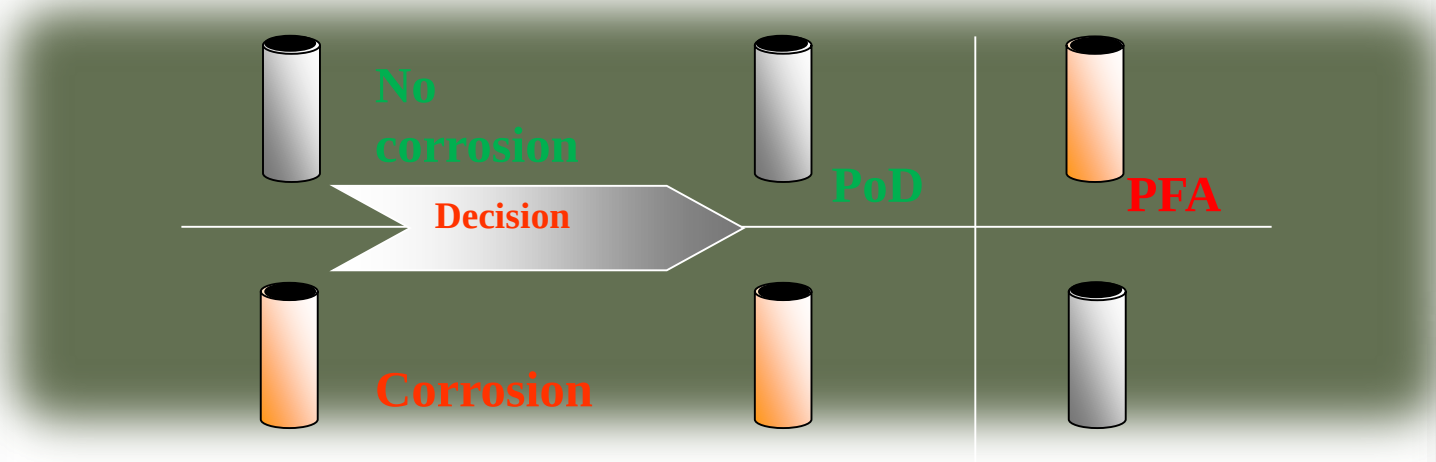
PFA, PoD



The needs for decision

$P_i = f(PoD, PFA, \gamma)$

Probabilistic modelling of inspection results



Real defect X

Decision d(X) ?

***PoD* : Probability Of Detection**

***PFA* : Probability of False Alarm**

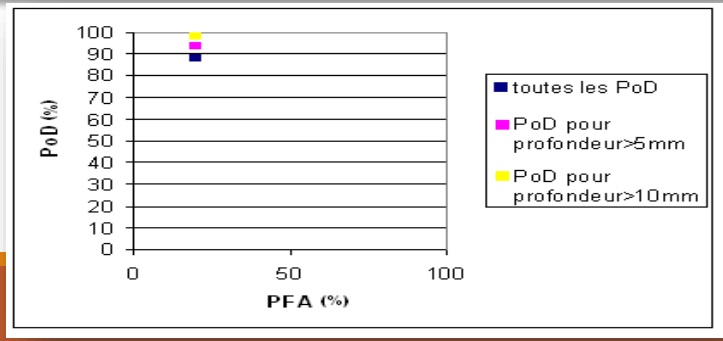
PoD and PFA assessment

Statistical approach

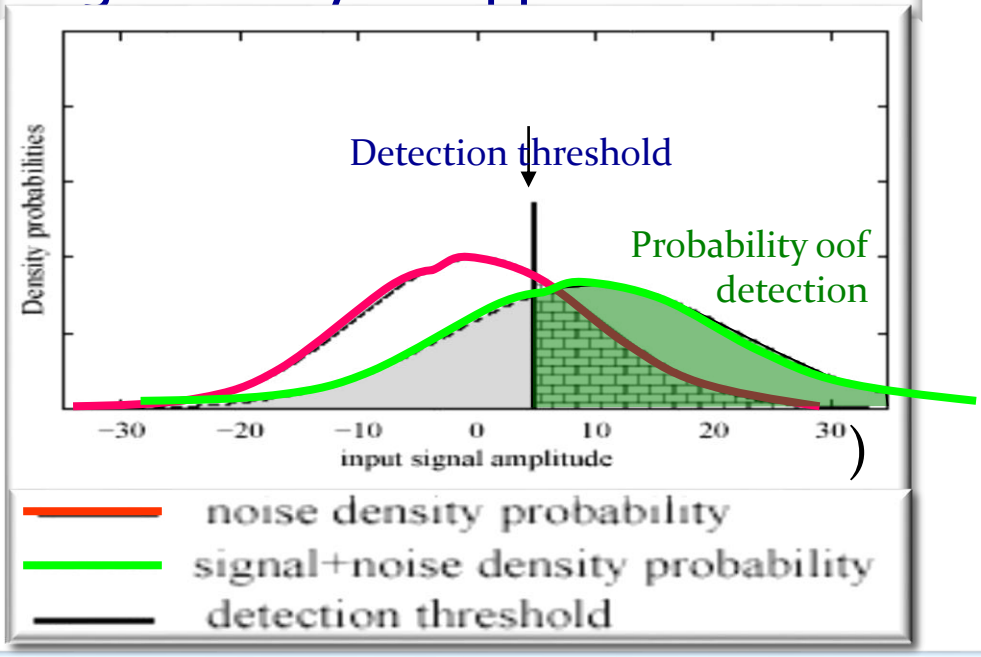
The real size of the defect is known

Intercalibration approach
(see ICON project 1996 in O&G)

NDT threshold level can be assessed



Signal analysis approach



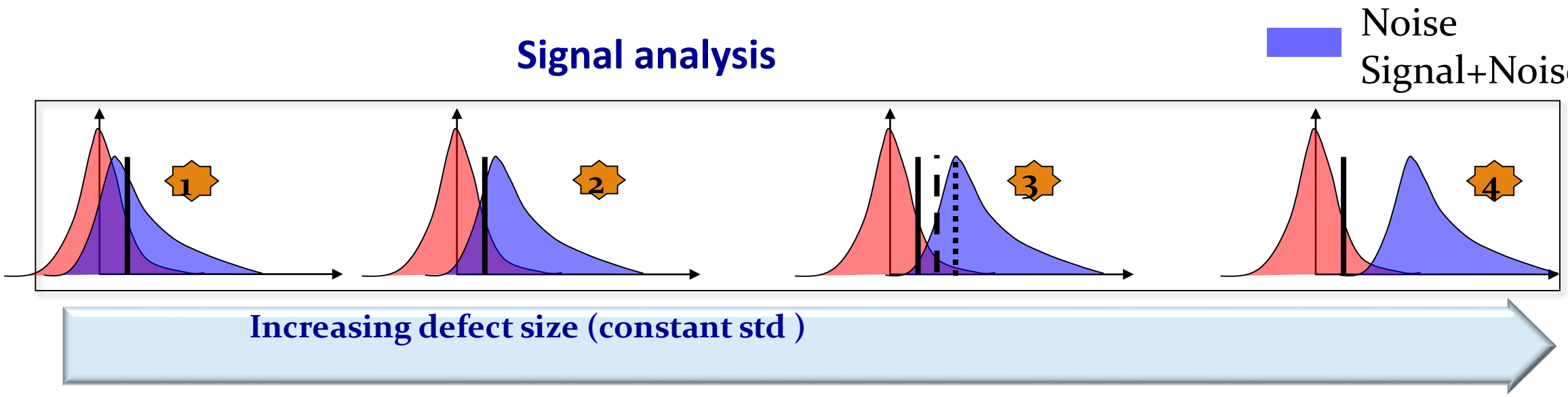
Assumption on the value of the real defect (error modelling + expert judgement)

Assumption on the detection threshold level (if PoD is needed)

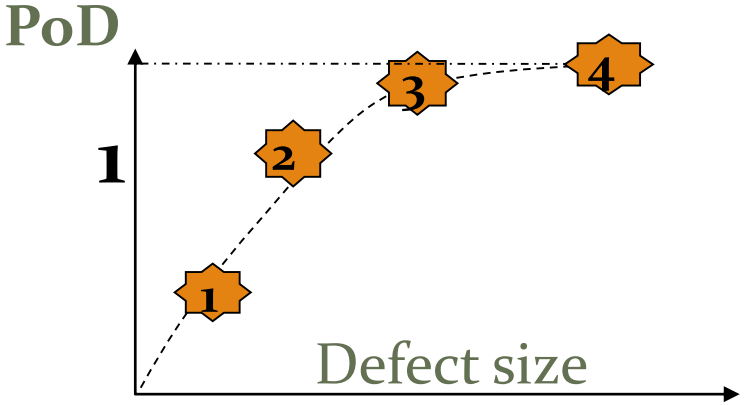
[Pakrashi & al., 2007 and Medachs 2008, paper #81]

Propagation in the decision theory

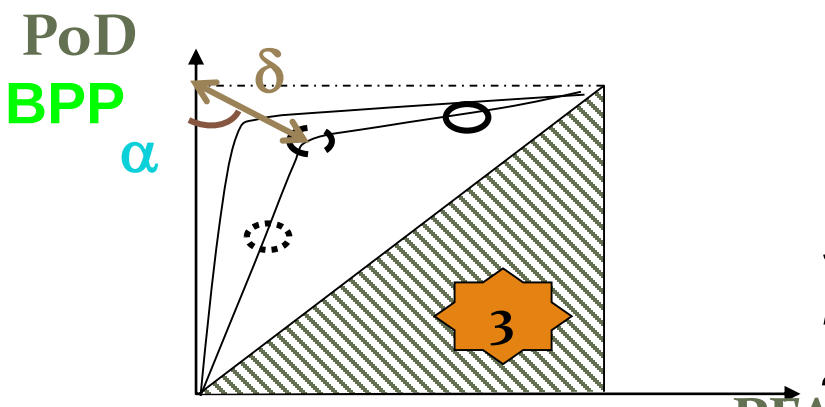
Signal analysis



Detection threshold is known



Receiver Operating Characteristic curve ROC



Schoefs & Boéro, 2010

Implementation in a decision policy (decision tree)

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Decision chain

Inspection planning
Manager
P_1 ; P_2
P_3 ; P_4

On-the-spot checking
NDT easy-to-use + diver +
N.D.T + top side operator
PoD ; PFA

History
(γ ; ex: PCP)

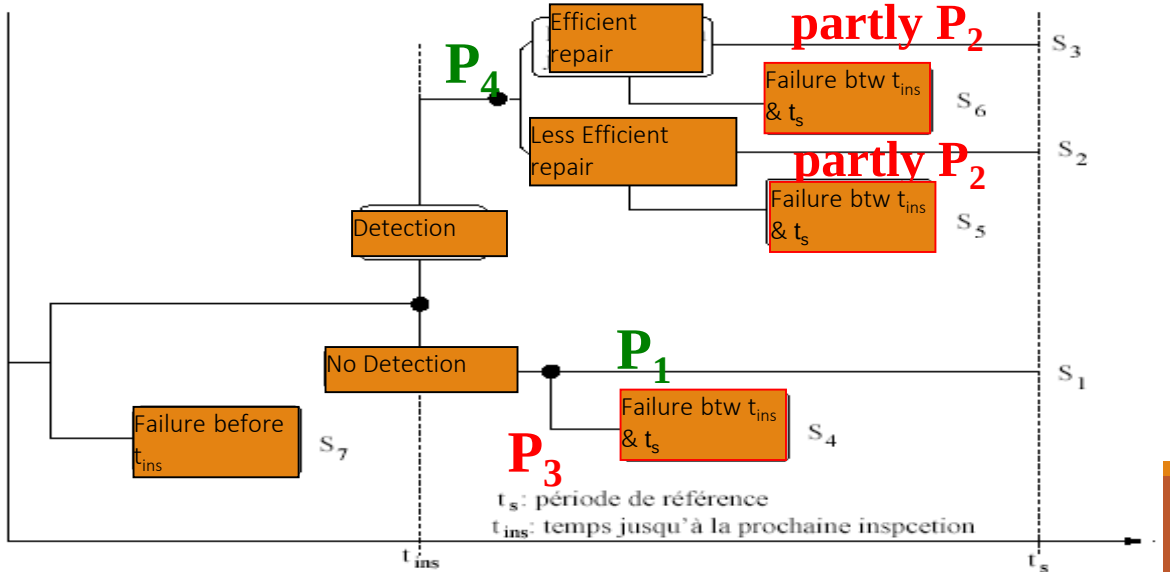
$\mathcal{F}_1$

$\mathcal{F}_2$

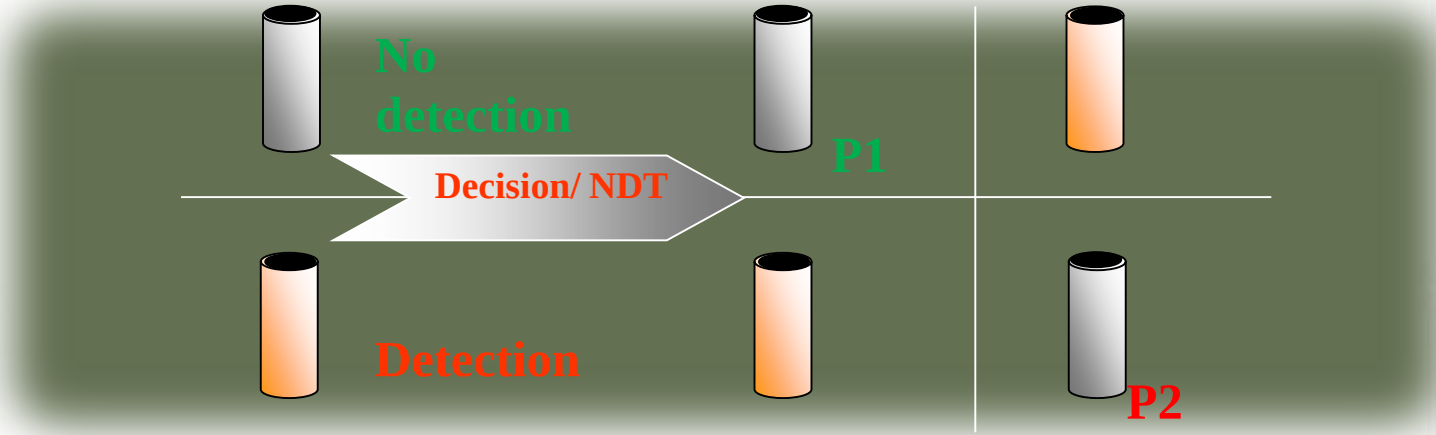
Laboratory testing
NDT optimal performance
$PoD_{(lab)}$; $PFA_{(lab)}$.

Intercalibration

Or Signal analysis



Decision theory



P1: **Probability of No Defect / No detection**

P2: **Probability of No Defect / Detection**

+ γ **: probability of defect presence** P= P(X=1)

Probability of No Defect/no Detection:
P1 = P(X=0 | d(X)=0)

Probability of No Defect/Detection:
P2 = P(X=0 | d(X)=1)

Conclusion and interaction

1. Define optimal detection threshold once the system is defined or for comparison of several systems (cost/benefit analysis)
2. Quantify the consequences of bad decisions (vulnerability) on the utility function

1. Include incomplete multi-techniques information in multi-phasic degradation models

Conclusion and interaction

Interactions

- WG2 (strategies): (i) performances and limits of embedded FOS, (ii) assessing spatial variability of concrete from SHM, (iii) Damage detection for image processing (ULTIR data base), (iv) Under-pixel measurement through Virtual Image Correlation, (v) underwater inspectioncprotocol for image processing

- WG4: study cases (concrete degradation in sea environment,
  reliability updating from measurement of Jacket offshore structures (**1 common design for the COST action?**)
  quantification of uncertainty of measurements available for several types of measurements *

Factsheets: Incomplete information and gama processes / Quantification of error of measurement
Decision from multi-techniques monitoring and multi-phasic degradation models / TV probabilistic fatigue model

* Chapt. 19 in Book: Maintenance and Safety of Aging Infrastructure: Structures and Infrastructures Book Series, Vol. 10

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Maintenance and Life Cycle Assessment of Structures and Industrial Systems

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