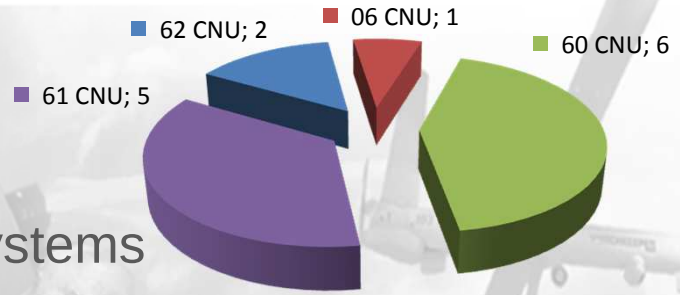
SFD research group « Reliability Engineering and Decision-Making tools »

Head: Bruno CASTANIER

Composition:

- **4 Professors**
- **10 Assistant Professors (4 « *Tenure* »)**
- **1 Industrial and project engineer**
- **12 PhD students**
- **1 postdoc**
- **1 assistant**



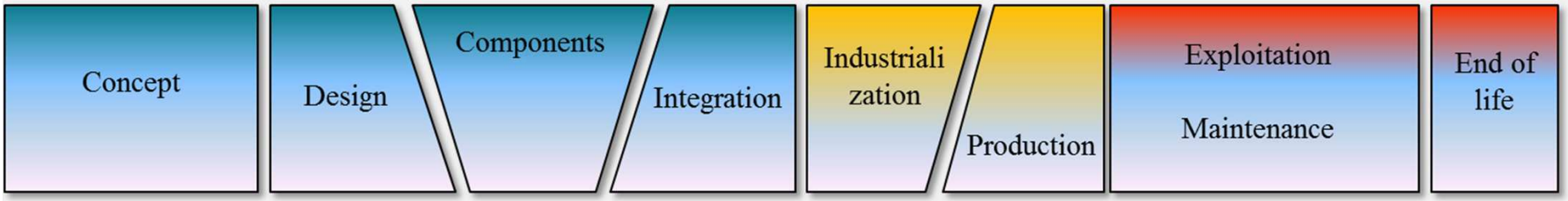
Industrial & Systems Engineering

Mechanical and Civil Engineering

Multi-disciplinary skills: Mechanical and Civil Engineering, Applied statistics, Reliability Engineering, Maintenance optimization, Energy systems, Automatic Control, Management

Research topics

Main topic of the Group: Methodological approaches and assessment/mathematical models for the **performance assurance** of **complex systems** during the **overall life cycle**



Designing « Safe »

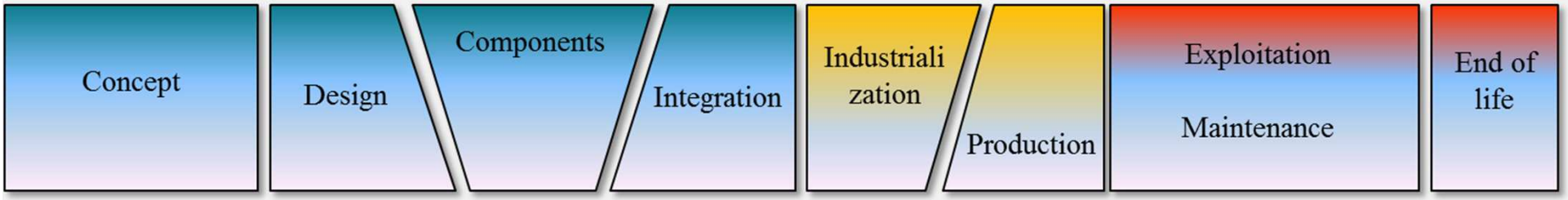
*1. Developing performance assessment models (**data-driven** and **physics-based reliability** models)*
*2. Developing of methodological approaches for performance **assessment** and **allocation** for **new systems** and **buildings***
*3. Defining and implementing **reliability testing models***

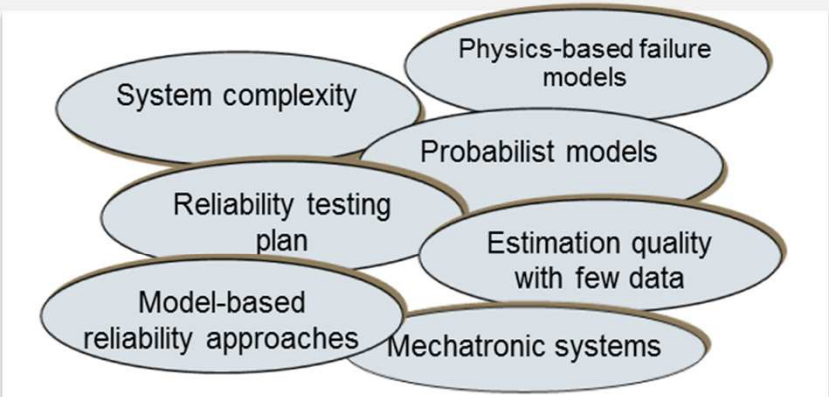
Guarantee "Safe"

*1. Developing **statistical inference** models for various natures of information*
*2. Defining performance **monitoring strategies** in production*
*3. Developing of **diagnosis methods** for complex systems (techno and management)*
*4. Constructing **maintenance policies** for industrial systems and buildings*

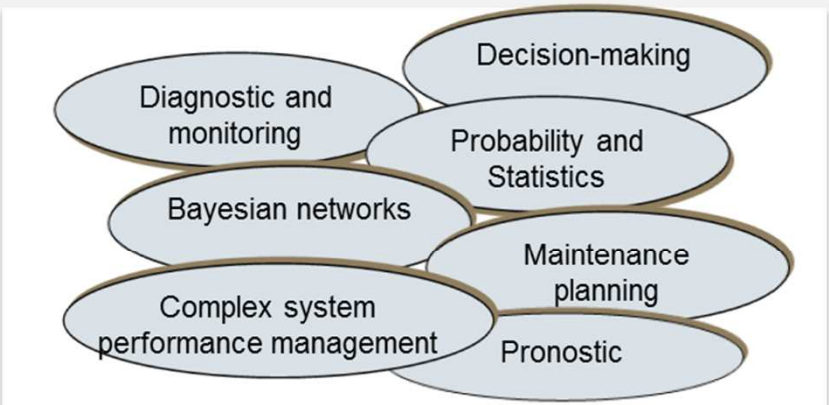
Research topics

Main topic of the Group: Methodological approaches and assessment/mathematical models for the **performance assurance** of **complex systems** during the **overall life cycle**





Axe 1 : Design and qualification of « safe » systems



Axe 1 : Performance assessment of complex systems in operation

Theme 1 - Design and qualification of safe systems

1.1 - Physic-Based Reliability models

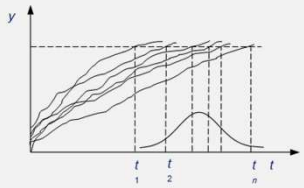
- Improvement of the mechanical-reliability models for well-known failure modes
- Development of reliability assessment models for multiple coupling stresses THMC
- Construction of life testing plans with few data

Theme 1 - Design and qualification of safe systems

1.1 - Physic-Based Reliability models

Illustration: Estimation of the failure distribution of a brake disk

Modeling the disk wear



Wiener process:

$$Z_{ij} = x_0 + m.t_{ij} + \sigma.W_0(t_{ij})$$

Critical wear threshold:

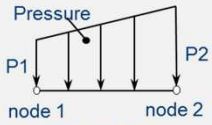
$z_0 = 2$ mm

Construction of the expertise with Finite Elements Method

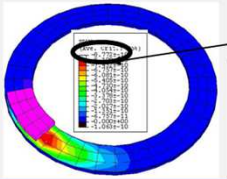
Wear model: Archard

$$dh_i = \left(\frac{k}{3H}\right)_i (F_N)_i \, s_i$$

Load



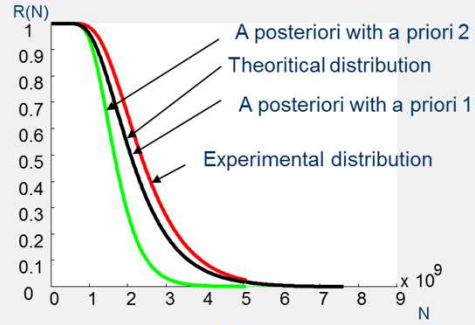
$$(F_N)_i = \int_\Omega (P)_i \, d\Omega_i$$

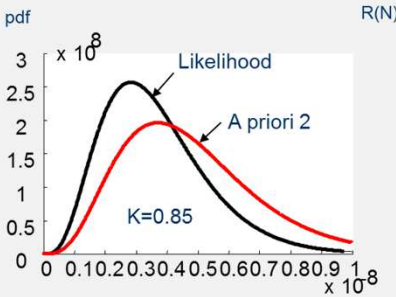


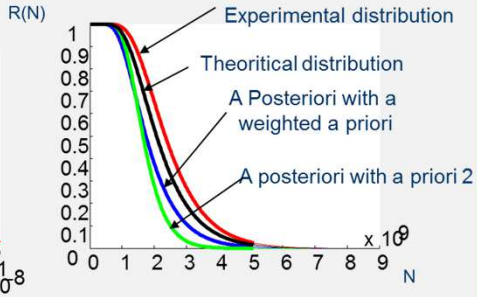
M =dh$_{max}$ = - 8.772 10^{-10}

A priori 1	**A priori 2**
m = 8.772 10^{-10}	m = 15 10^{-10}
s² ∈ [3 10^{-10} , 3.7 10^{-10}]	s² ∈ [10^{-10} , 10^{-9}]

Results







F. GUERIN, A. DEMRI, M. BARREAU, S. CLOUPET, J. HERSANT, R. HAMBLI, “Mathematical and Statistical Methods in Reliability”, Chapitre "Bayesian estimation of degradation model defined by a Wiener process", Eds N. Balakrishnan, M.S. Nikulin, and V.Rykov, Springer’s imprint Birkhäuser Boston, 2010

Theme 1 - Design and qualification of safe systems

1.1 - Physic-Based Reliability models

1.2 – Modelization, assessment and optimization of the system dependability

- Dependability of electronical devices (embedded systems, IoT)
  - Reliability test plans
  - Electro-Magnetic Compatibility and reliability in stressful environment

Theme 1 - Design and qualification of safe systems

1.2 – Modelization, assessment and optimization of the system dependability

Illustration: « Reliability Center » project

Objectives:

- To conduct research for developing reliability assessment models components and systems
- To provide a research/industry/education collaborative platform for reliability qualification issues

Facilities:

- Climatic and vibration chamber
- HAST chamber
- Reliability analysis and modeling softwares

Theme 1 - Design and qualification of safe systems

1.1 - Physic-Based Reliability models

1.2 – Modelization, assessment and optimization of the system dependability

Strengths:

1. Disciplinary Interfaces: Mechanical Engineering, Civil Engineering, Thermal Engineering, Applied Statistics, Reliability Techniques and Tools, Signal Processing
2. Confronting models with data through experimentation

Theme 2 – Performance assessment models for complex systems in operational phase

2.1- Decision-making and data-driven diagnosis

- Bayesian Networks and data analysis techniques for production control (Control Charts)
- Signal processing techniques for improving the fault detection and diagnosis for complex systems
- Mixing statistical and management methods for organization diagnosis

Theme 2 – Performance assessment models for complex systems in operational phase

2.1- Decision-making and data-driven diagnosis

2.2- Performance models in buildings and maintenance optimization

- Hybrid inference models for the diagnostic and the prediction in buildings
- Fusion of qualitative and quantitative models for the supervision of dynamic systems
- Meta-models for structure and infrastructure maintenance optimization

Theme 2 – Performance assessment models for complex systems in operational phase

2.1- Decision-making and data-driven diagnosis

2.2- Performance models in buildings and maintenance optimization

2.3- Performance assessment in complex organizations

- Bayesian models for the estimation of the social perception of standards
- Maximization of the availability for an homogeneous park of systems

Theme 2 – Performance assessment models for complex systems in operational phase

2.1- Decision-making and data-driven diagnosis

2.2- Performance models in buildings and maintenance optimization

2.3- Performance assessment in complex organizations

Strengths:

1. Multidisciplinary skills: Applied statistics, Quality models, Signal processing, diagnostic, optimization, simulation, Civil and mechanical engineering, …
2. Investigation of new applications (Health, Social organization, Buildings, …)

Scientific production and collaborations

Publications	Number (over 2016-2017)	Ratio (per researcher per year)	Type
International journal	33	1,27	RESS, JRR, QTQM, IJRQSE, journal of Solar Energy Engineering, …
International conference	27	1,04	RAMS, ESREL, ALT, ICIT, …

Contracts	Number (over 2016-2017)	Amount (part for the group)	Type
Public fundings	2		Region Pays de la Loire, ANR
Industrial partnerships	7	70k€/year	PhD, research, services, studies, training

- Research collaborations:
  - **French:** LAMPA (Angers), LAREMA (Angers), GeM (Nantes), LS2N (Nantes), IETR (Angers), UTC (Compiègne), UTT, …
  - **International:** Rutgers University (USA), Delft TU (Netherlands), University of West Scotland, Université des Trois Rivières (Québec), Université Cheikh Anta Diop de Dakar (Sénégal), …
- Industrial partnerships:
  - Renault, PSA, Faurecia, Airbus group, CIAT, Rolex, General Electric,…

Ph.D. list

Nabil BEN SAID AMRANI

Abbes CHRIFI ALAOUI

Meriem DJOUDI

Hassan EL GARRAB

Aziza HANNOUCH

Hassan JABER

Paula LAKOMICKI (Phd Student in co-direction with UTT in Troyes)

Nadare MATOIRI CHAIBATI

Ibrahim MJALLAL

Valérie MOLINERO-DEMILLY

Kofisse Rodrigue SOHOIN

Khaoula TIDRIRI

Christelle TRAON

Project Examples

Elaboration of a methodology of the reliability demonstration of an autonomous vehicle

Construction d'une méthodologie pour la démonstration de la fiabilité d'un système autonome

RENAULT
Passion for life

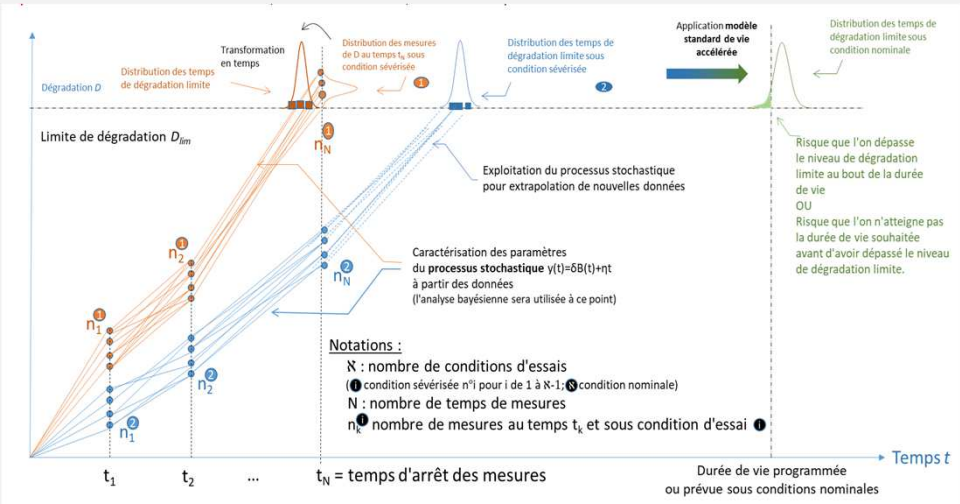
Demonstration and qualification of the reliability of an artificial heart prothesis

MICRO: Innovative composite materials for repairing infrastructure - Reliability approach of the dimensionning for the qualification and durability prediction

- Objective:
  - Qualify the performance of the infrastructure reinforced by composites in terms of reliability
  - Predict the long-term behavior (100 years) based on accelerated life testing plans
  - Bayesian analysis of the degradation test data
- Funded by: ANR
- Partners : IFSTTAR, LMC² (U. Lyon), LARIS, IMP (Insa Lyon), LTDS (ECL), ARMINES (Alès), L2MGC (U. Cergy-Pontoise - Compiègne)

Multi-performance statistical analysis for concrete durability in various aggressive environments

- Objective:
  - Qualification protocol for new concrete formulation.
  - Optimization of accelerated degradation testing plans.
  - Multi-objective analysis (data fusion).
- Funded by: CIFRE
- PhD student: Nadare MATOIRI CHAIBATI

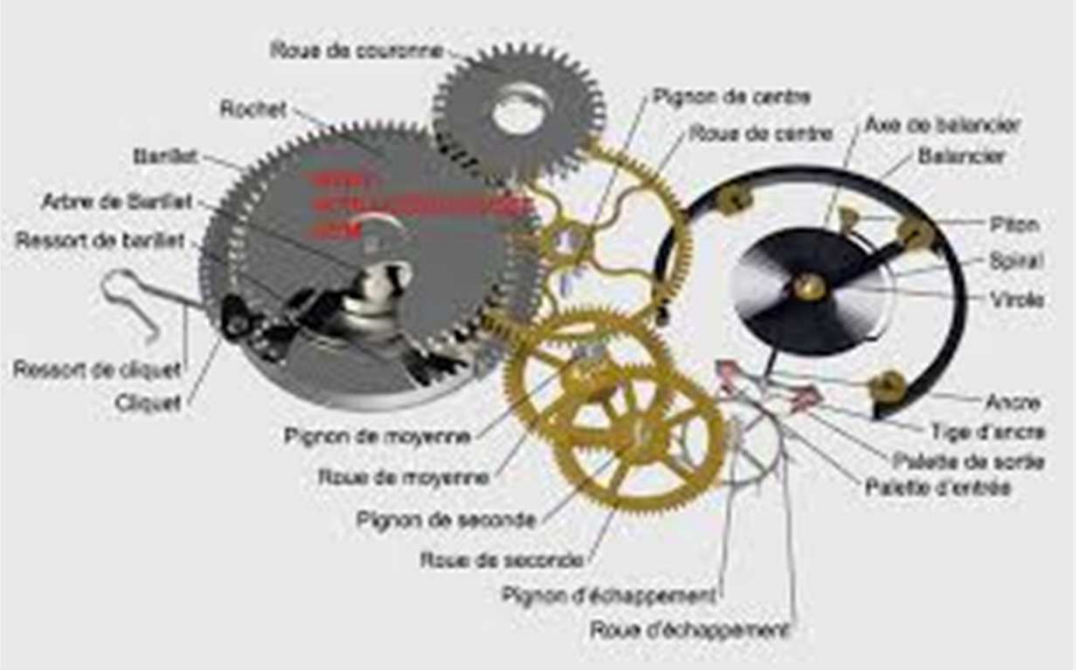


Definition of a methodology for the reliability estimation and for the qualification of mechanical devices in design phase

faurecia

Automotive Seating

Optimization of the reliability and qualification processes when few data are available



ROLEX

Future projects

Reliability of air punctionning electropneumatic valves

Industrial PhD – October 2018

Formuler une méthodologie de détermination des lois d'accélération / endommagement applicable sur les équipements LTS actuels et extrapolable aux futurs équipements. Deux grands axes de travail sont envisagés pour apporter une réponse à la problématique posée :

- **Volet expérimental** : Mettre en place une méthodologie et l'appliquer sur des essais d'endommagement sur des équipements actuels afin de générer des lois d'accélération exploitables dans les calculs thermiques préliminaires.
  - Analyses incidentologiques des produits existants (retour d'expérience et essais),
  - Détermination des contraintes influentes et évaluation de leurs niveaux,
  - Détermination des phénomènes physiques de dégradation (mode de pannes).

- **Volet numérique** : Synchroniser les modèles thermiques (modèles transitoires DYMOLA) et de fiabilité (modèles multi-stress "Pression-Température" ALTA).
  - Définition de modèles standard de vie accélérée pour les différentes vannes de prélèvement,
  - Envisager des modèles de calculs fiabilités/thermiques intégrant les contraintes mécaniques.

Future projects

Probabilistic modeling of micro-structural heterogeneities and analysis of their effects on the lifetime prediction as a function of wear

Co-funded PhD – October 2018

université angers

ARTS ET MÉTIERS ParisTech

Future projects

Buildings performance data collection and analysis – Extension for the O&M decisions under uncertaintity

PhD in industry – October 2018

Cadre : BIM – O&M management

université angers

AIA INGÉNIERIE AIA Life Designers
AIA Ingénierie

Future projects

Definition of the testability strategies for the future electronic cards with high miniaturization/densification and fast signals

PhD in industry – October 2018

Prospectives

- Thalès (PhD) - Elaboration of a model for the diagnostic and the management rules for the mission garantee of a reconfigrable system
- ANR MOEEPI (National project - ANR) – Modeling and optimization of the energetical efficiency in industrial production
- OOCAR (Industry-collaborative project) – Development of a maintenance-oriented mobile app – connected vehicle
- Tronico (Industry_collaborative project) – Definition and optimization of the life time testing plans based on system performance data

Some of current projects: ANR

- **OMEGA** (Outils méthodologiques pour la garantie de la performance énergétique) – Programme Ville et Bâtiments Durables
  - Objectifs :
    - Appréhender, anticiper et maitriser les risques associés à la mise en place d'une garantie de performance.
    - Apporter des solutions permettant d'accompagner le processus de garantie des performances depuis la phase de conception jusqu'à l'exploitation du bâtiment.
  - Mots-clés: analyse de sensibilité (méthode de Sobol) et d'incertitudes (Méthode de Monte Carlo et polynômes de chaos), indentification des paramètres les plus influents définition de plans de mesure et de vérification adaptés, suivi des performances effectives.

Some of current projects: ANR

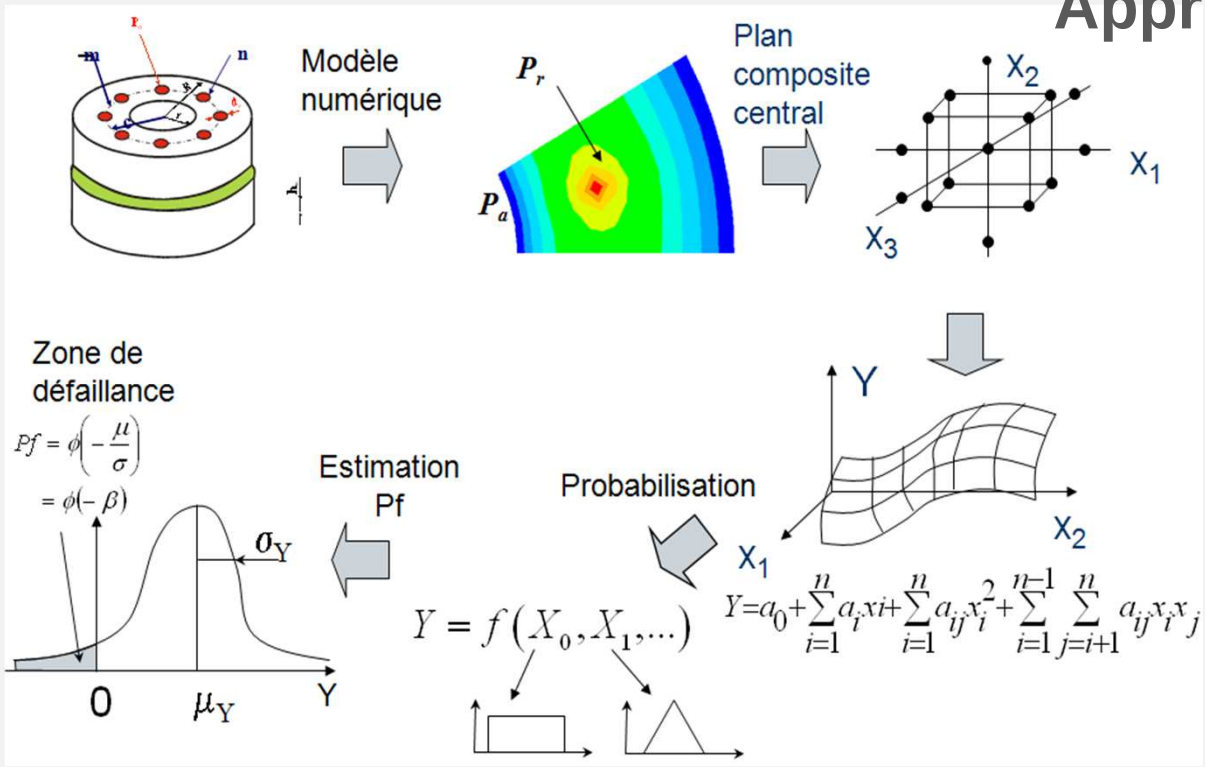
- **MICRO** (**M**atériaux **I**nnovants **C**omposites pour la **R**éparation d'**O**uvrages : Approche fiabiliste du dimensionnement pour leur requalification et la prédiction de leur durabilité)
- Objectifs de la partie SFD:
  - Construire et exploiter les résultats d'**essais accélérés et sévérisés** conduits à **plusieurs échelles** (identification des différents mécanismes de **dégradation de l'assemblage collé** au niveau de la matrice polymère, de l'interface fibre-matrice, de l'interface composite - béton et justification du **choix des indicateurs de durabilité et de fiabilité**.
  - Définir les notions fondamentales de **fiabilité** et de **durabilité** des systèmes du génie civil utilisant des matériaux composites. Le projet s'articulera autour de **la probabilisation des modèles de dégradation/vieillissement et l'établissement de lois statistiques de durée de vie** des ouvrages réparés par matériaux composites collés, puis de l'**incorporation de ces lois dans des formulations fiabilistes des équations de dimensionnement**.

Project examples

Some of our past projects

AXE1: Modélisation et optimisation de la SdF

Illustration: Evaluation de la fiabilité d'un palier



Approche mécano-fiabiliste

solveur Eléments Finis

surface de réponse numérique

probabilisation de la fonction d'état basée sur l'équation de Reynolds

estimation de fiabilité (FORM/SORM, Monte-Carlo,…)

caractérisation de la variabilité par l'application des méthodes de métrologie probabilistes

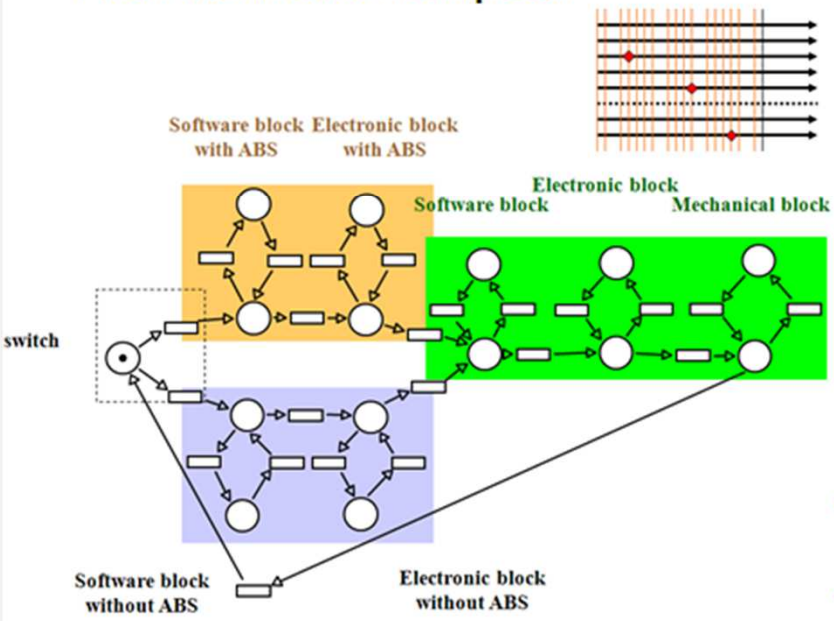
A. CHARKI, R. LARONDE, D. BIGAUD, F. GUERIN, "Fluid Bearing Reliability Evaluation using a Numerical Design of Experiments", dans "Reliability, Risk and Safety – Theory and Applications", Vol. 2, pp. 1405-1409, Taylor and Francis Group, 2010.

AXE1: Modélisation et optimisation de la SdF

Illustration: Modélisation et Evaluation de la fiabilité d'un système ABS

Modélisation → **Simulation dynamique**

- Intégration de la physique de fonctionnement
- Prise en compte de la variabilité d'usage
- Profil de mission complexe



- Simulation Monte Carlo (fonctionnelle + fonctionnelle et dysfonctionnelle)
- Fiabilité des composants mécaniques par la méthode PHI2

↓

Evaluation de la SdF

Estimation des caractéristiques de SdF (Bootstrap, SEM et BRM)

↓

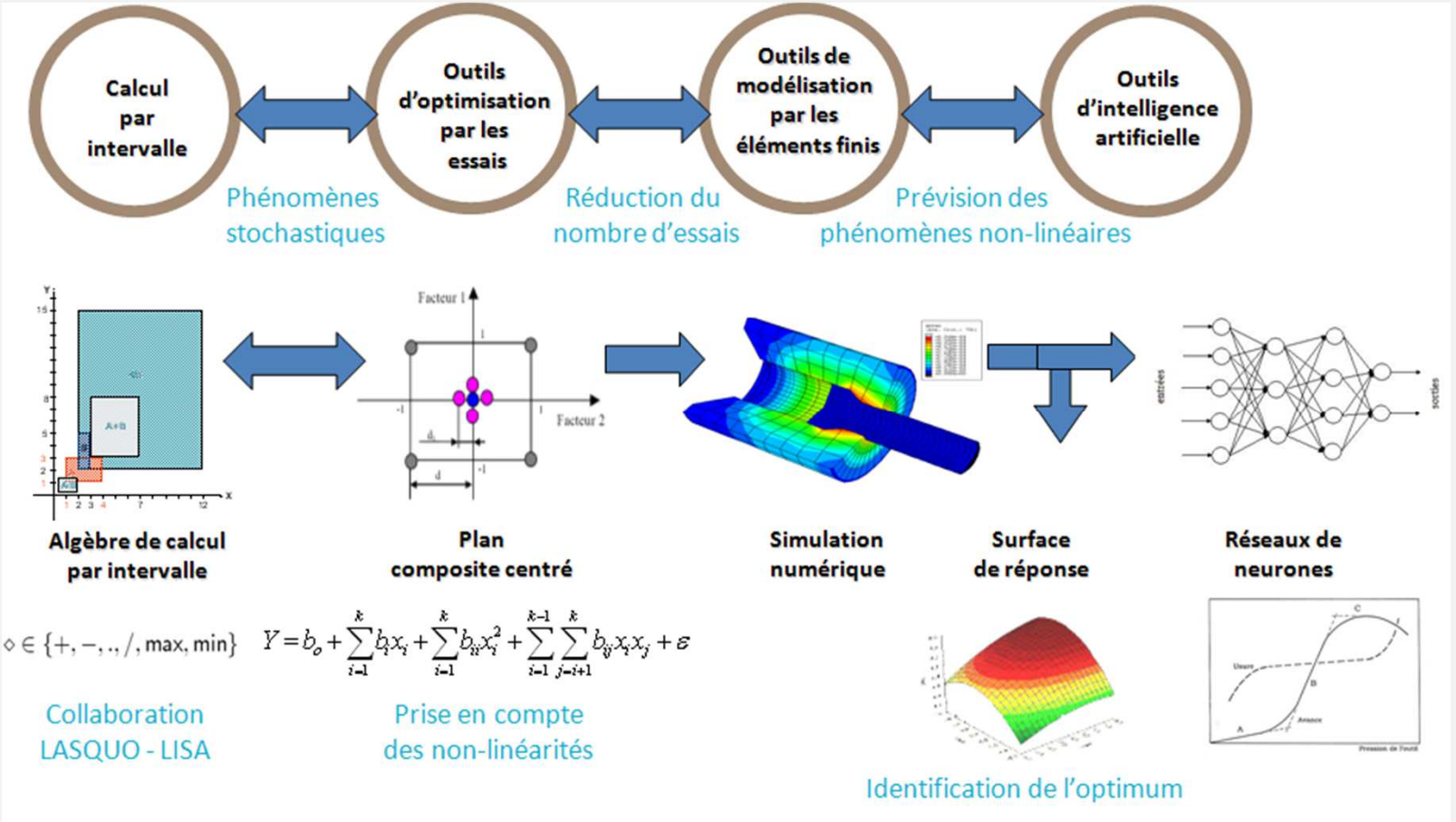
Analyse de la SdF

- Estimation des facteurs de sensibilité (statique et dynamique)
- Etude de la robustesse

A. CHARKI, A. DEMRI, F. GUERIN, D. BIGAUD, "Mechatronic System Reliability Evaluation using Petri Networks and PHI2 Method", dans "Reliability, Risk and Safety – Theory and Applications", Vol. 3, pp. 1597-1601, Taylor and Francis Group, 2010.

AXE 2: Évaluation des performances par les essais en phase de qualification

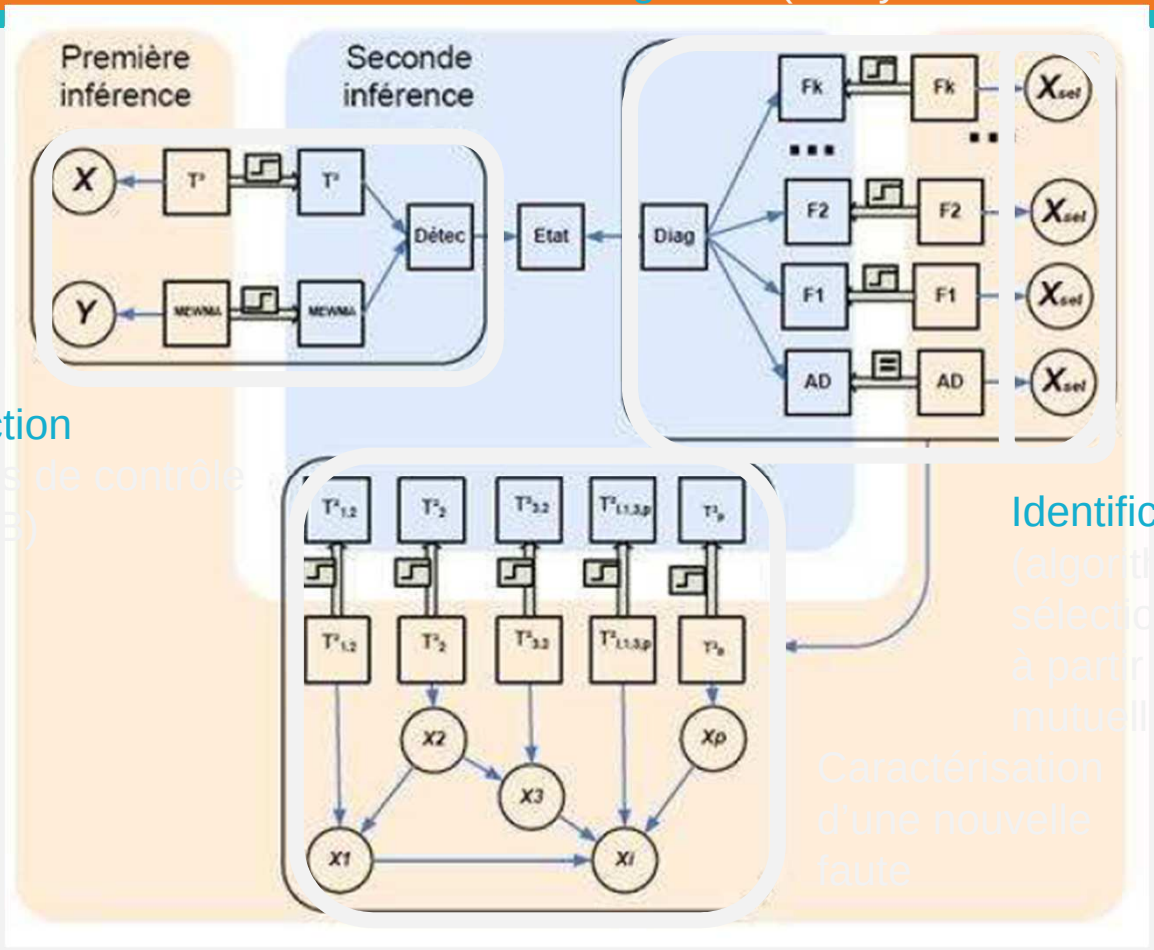
Illustration



D. LEPADATU, A. KOBI, X. BAGUENARD, L. JAULIN, "Springback of stamping process optimization using response surface methodology and interval computation", Quality Technology & Quantitative Management Vol. 6, No. 4, pp. 409-421, 2009.

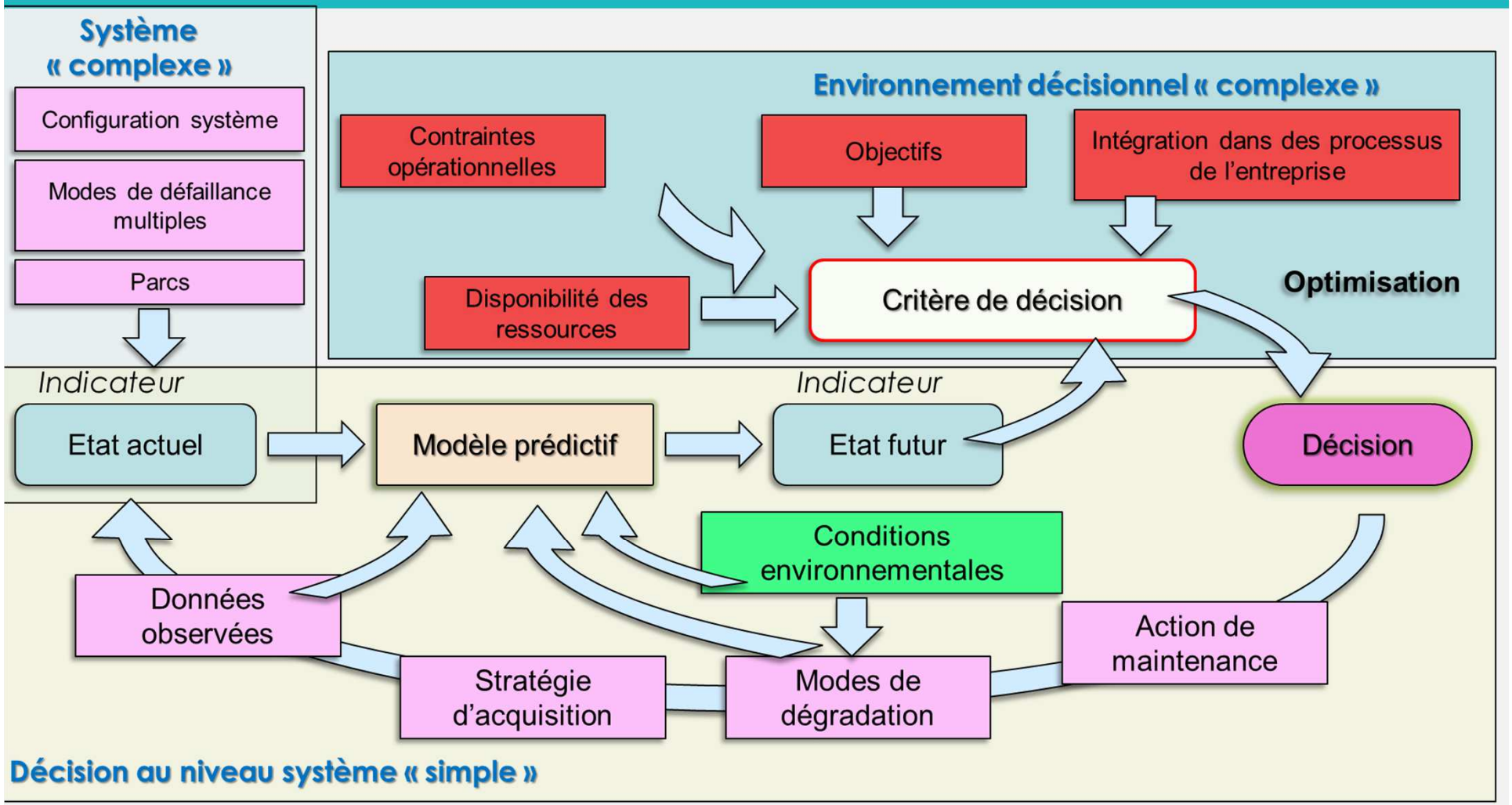
AXE 3: Modèles de garantie de performance de systèmes complexes en phase d'exploitation

Diagnostic (Analyse discriminante par RB)



S. Verron, J. Li et **T. Tiplica**. *Fault detection and isolation of faults in a multivariate process with Bayesian network*. Journal of Process Control Volume 20, Issue 8, Pages 902-911, September **2010**.

AXE 3: Modèles de garantie de performance de systèmes complexes en phase d'exploitation



Projets en cours

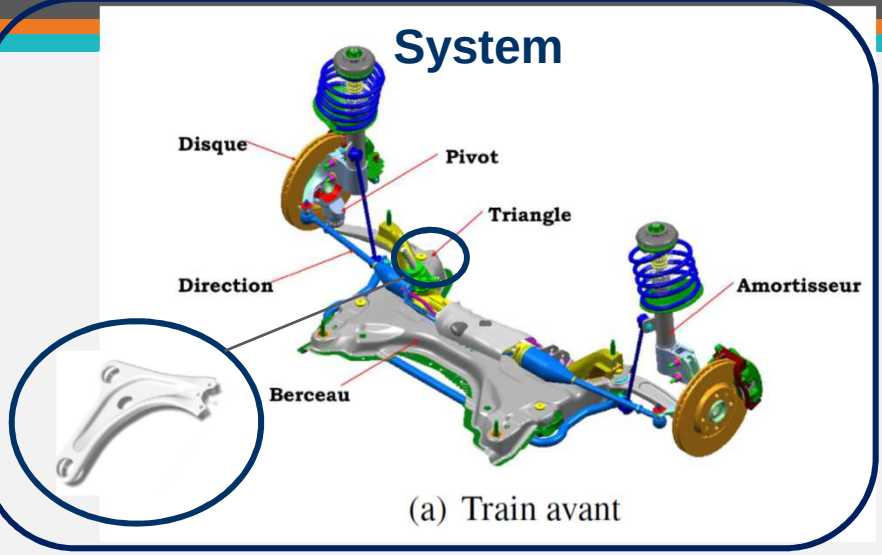
- ANR
  - OMEGA (Outils méthodologiques pour la garantie de la performance énergétique) – Programme Ville et Bâtiments Durables
- Internationaux
  - ARIANE (étude de la dégradation et de la fiabilité des modules photovoltaïques) en coopération avec le CIFRES et l'université Cheikh Anta Diop du Dakar (Sénégal)
  - SENNET (projet Européean – Smart Grid)
  - Horlogerie Suisse (Fiabilité mécanique)
- Nationaux
  - SNECMA (Moteur Ariane)

Projets en cours

- Régionaux
  - AI-Fruit (Approches intégratives du déterminisme structural, génétique et écophysiologique de la qualité de fruits) – Labélisé Végépolys
  - Hydrol44 (Conception, commande et diagnostic de systèmes de production d'énergie renouvelable par hydrolienne) – Labélisé EMC²
  - PVMODREL (PhotoVoltaic MODules RELiability) – en partenariat avec EDF
- CIFRE (Valéo Etudes Electroniques)
  - Développement d'une méthodologie globale d'évaluation de la SdF d'un système complexe par rapport à un niveau de sûreté attendu: application aux systèmes électroniques embarqués
  - Elaboration d'une approche globale de vérification et de validation d'un logiciel embarqué et/ou intégré dans un système, basée sur la génération automatique de cas de test et la preuve de couverture

PSA (Peugeot) Project

System



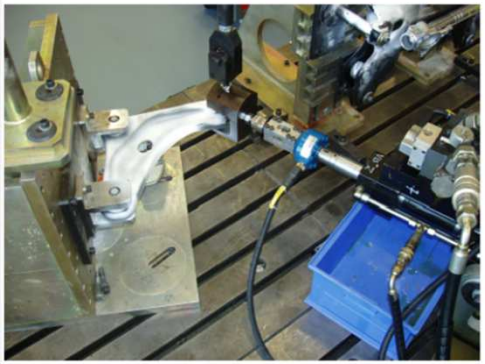
(a) Train avant

Use

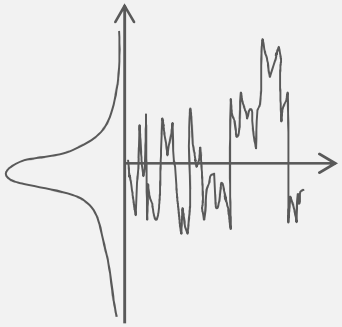
Reliability Objective

Life :
15 years
Admissible Risk :
Pf< 10^{-6}

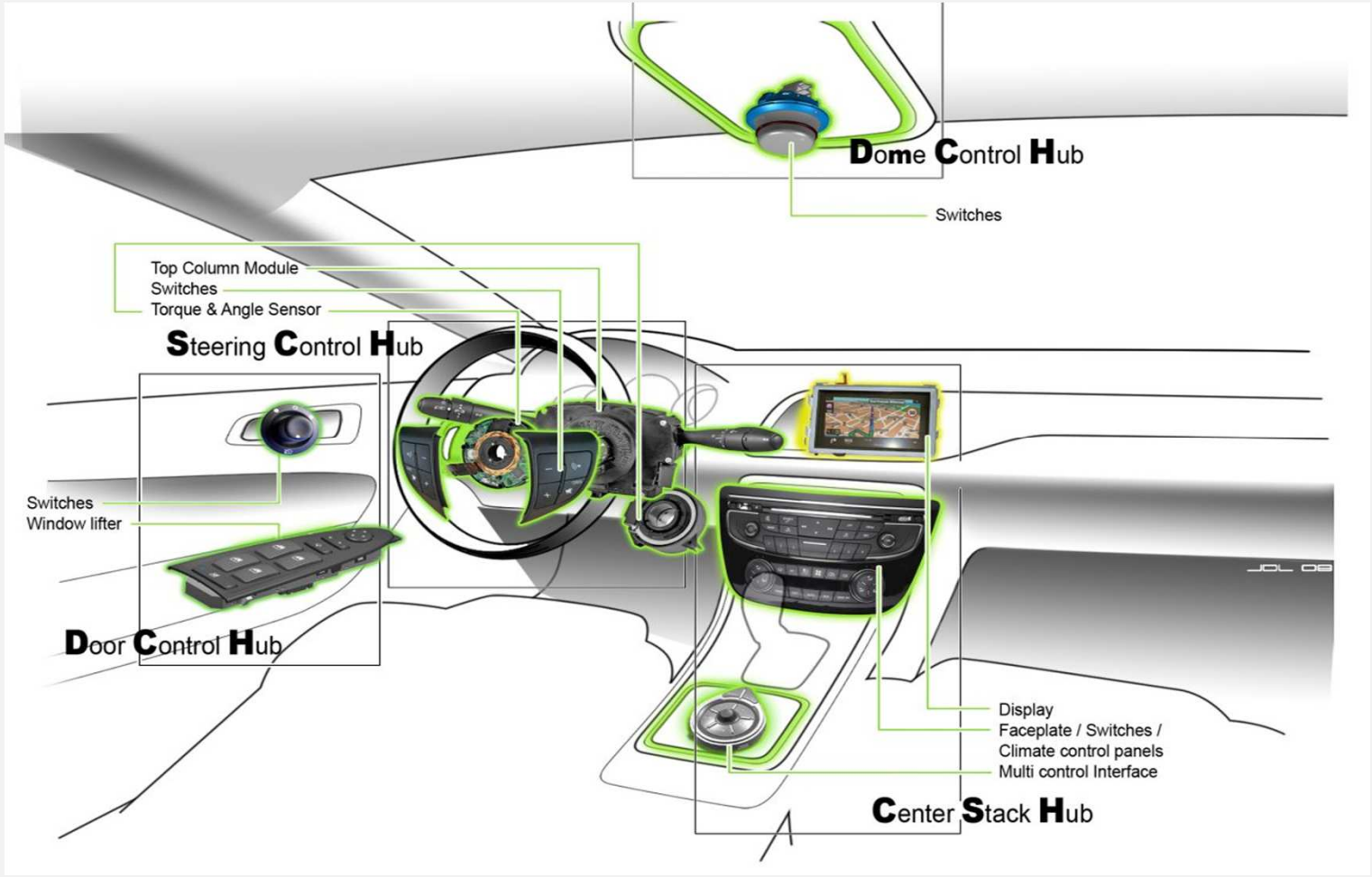
Test



Mission Profile



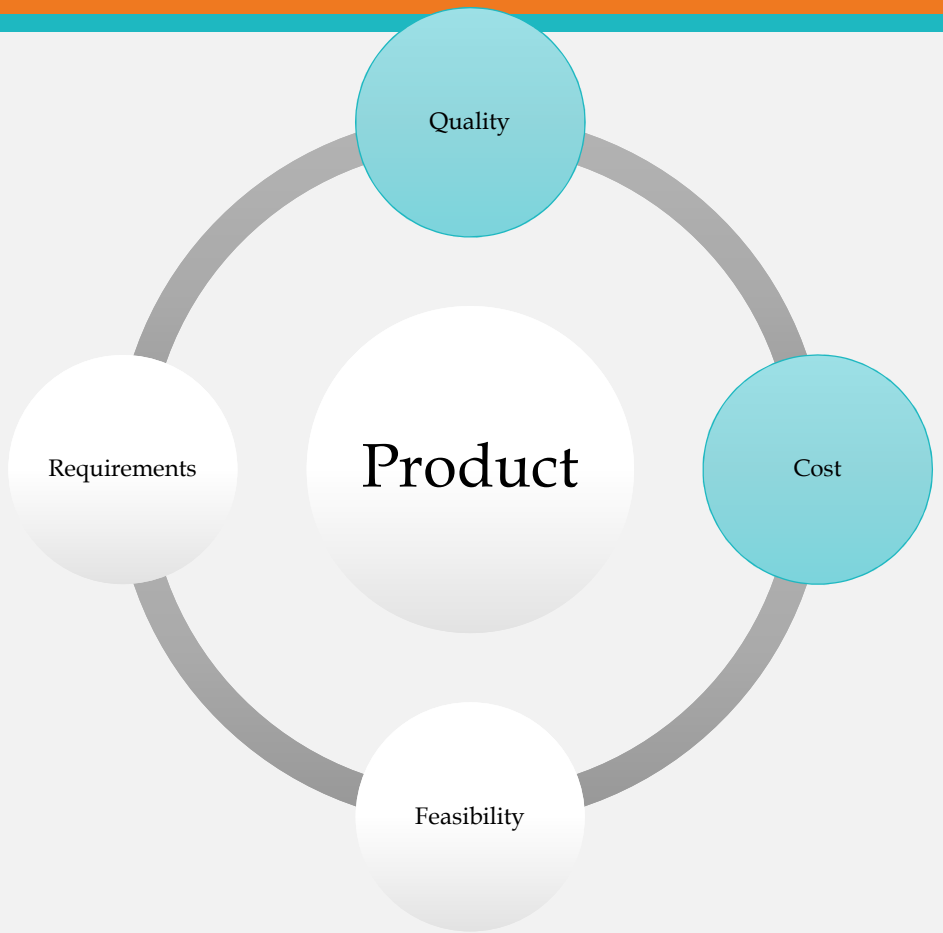
Systèmes embarqués – Projet Valéo



Project Valeo

ISO 26262

- ✓ How to ensure even in the early phases, the concept chosen satisfy the security level set?
- ✓ How to ensure that the adopted architecture is optimized in terms of cost as well?
- ✓ Consider how effectively the various dependencies that result from the occurrence of such events



SNECMA Project

Reliability Growth methodology for ag

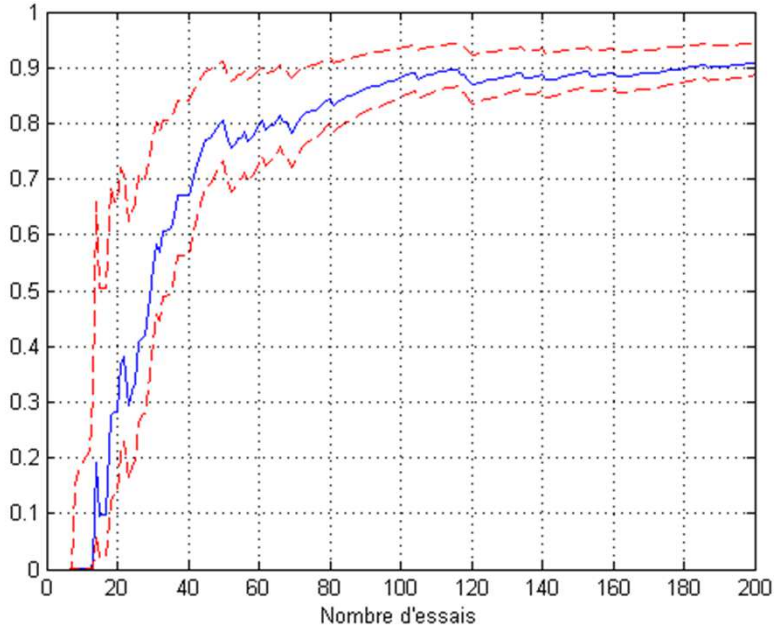
Reliability estimation during test p

Test plan definition and optimization to Qua

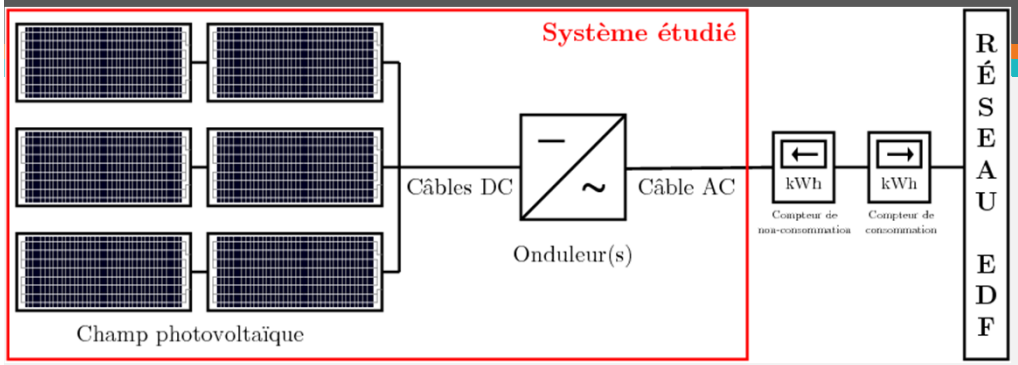
engine

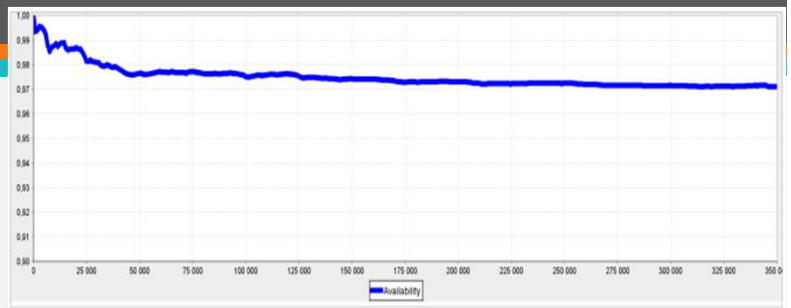
Reliability Growth methodology including stress

- Stress from Operating point (unknown factors)
- Proportional Hazard (Cox) models



Evaluation photovoltaïc system

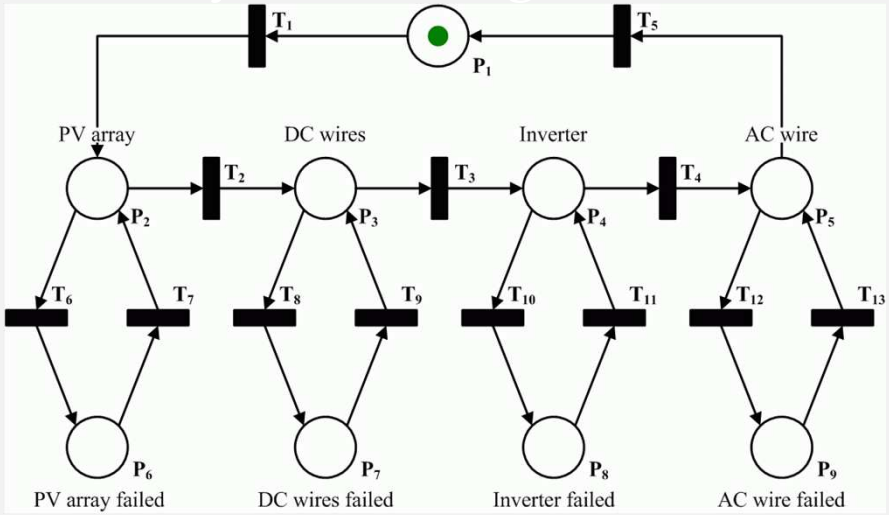




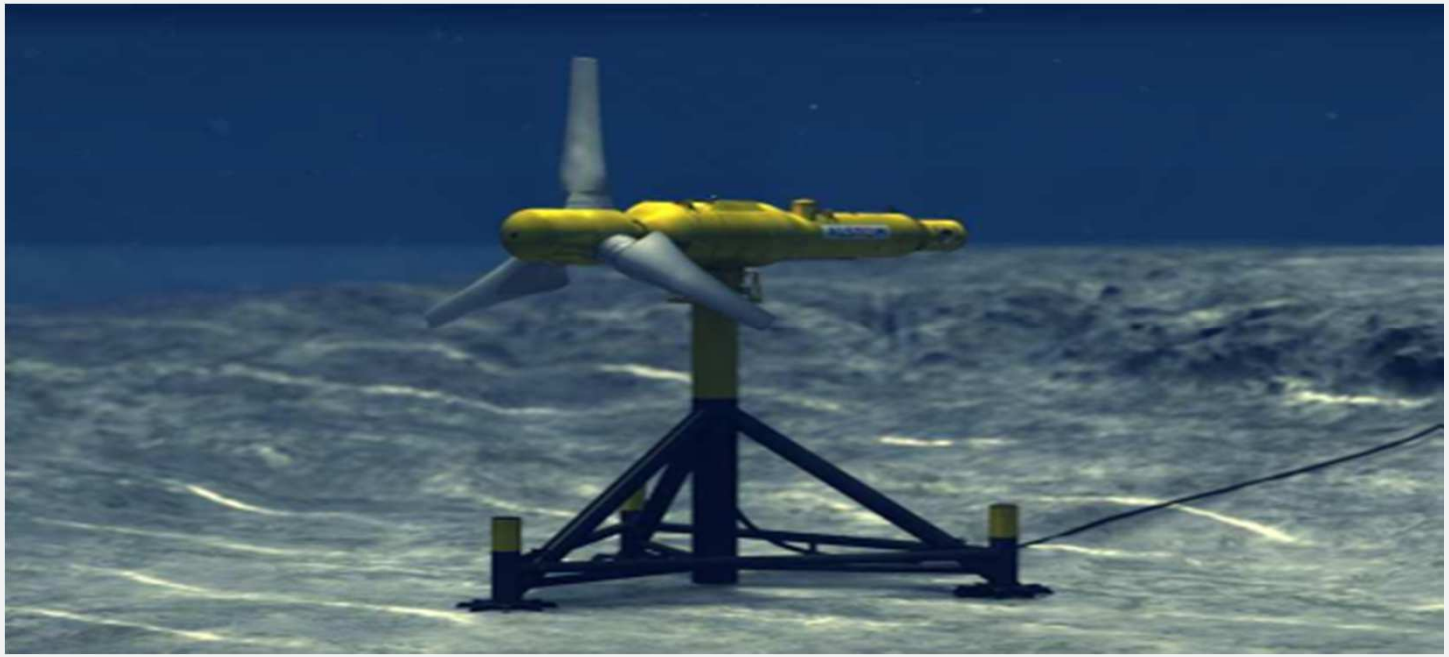
Durability and maintainability of a PV system

Multi-scale approach to system integration

Maintainability and maintenance plan

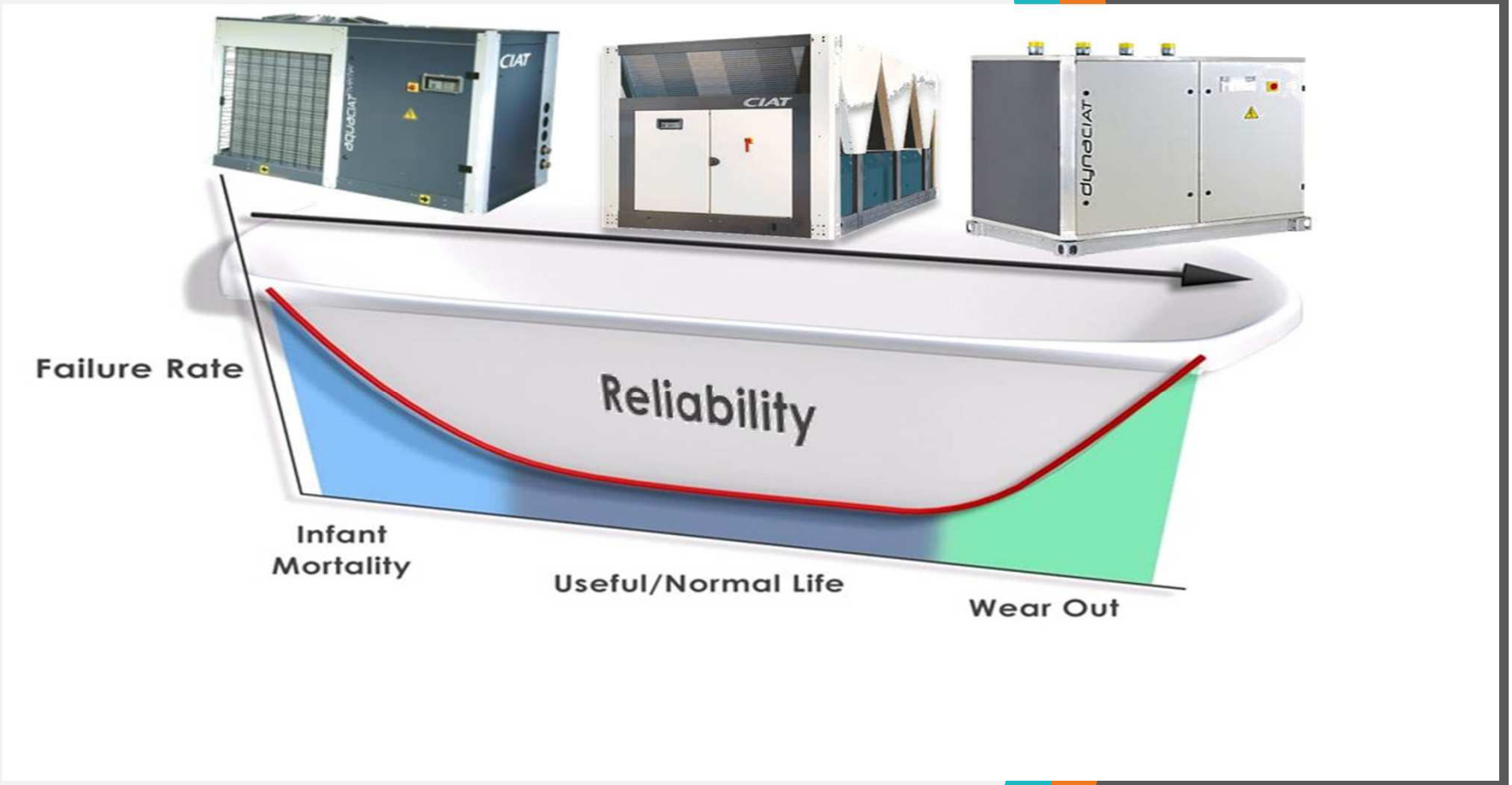


Design, control and diagnosis of renewable energy production systems by tidal



CIAT collaboration

Reliability estimation using accelerate test



Region Project : AI FRUIT