EADS Innovation Works

Prognosis of a complex system for maintenance optimization

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Outlines

1 Complex System and Prognosis

2 Prognosis for IW

3 Subject and First Results

4 Conclusion

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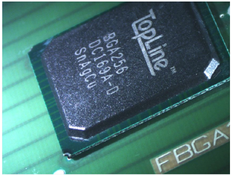
What is a complex system?

Goal : Prognosis of the system

A touch of systems engineering...

- **A physical object** (multi-levels, multi-physics, ...)
- **Some knowledge around the system** (functional, logical, physical)
- **A position in the life cycle** (design, operational, end-of-life, ...)
- **Different Actors** (designers, engineers, maintenance operators, ...)



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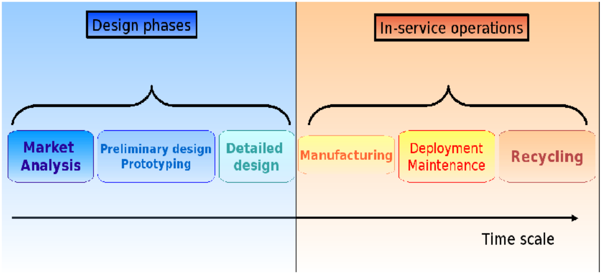
Different Phases of the Life Cycle



- Global System vision
- Few Data
- Uncertainties

- Precise Vision
- Data
- Deterministic

A definition per actor

End User	Goals	Metrics
Program Manager	Assess the economic viability of prognosis technology for specific applications before it can be approved and funded	Cost-benefit type metrics that translate performance in terms of tangible and intangible cost savings
Plant manager	Resource allocation and mission planning based on available prognostic information	Accuracy and precision based metrics that compute RUL estimates for specific Unit Under Test (UUT). Such predictions are based on degradation or damage accumulation models
Operator	Take appropriate action and carry out re planning in the event of contingency during mission	Accuracy and precision based metrics that compute RUL estimates for specific UUTs. These predictions are based on fault growth models for critical failures
Maintainer	Plan maintenance in advance to reduce UUT downtime and maximize availability	Accuracy and precision based metrics that compute RUL estimates based on damage accumulation models

Figure: Needs identified for **Operations** purposes

NASA classification proposal of prognosis metrics based on end-user requirements(2/2)

End User	Goals	Metrics
Designer	Implement the prognostic system within the constraints of user specification. Improve performance	Reliability based metrics to evaluate a design and identify performance bottlenecks. Computational performance metrics to meet resource constraints.
Researcher	Develop and implement robust performance assessment algorithms with desired confidence levels	Accuracy and precision based metrics that employ uncertainty management and output probabilistic predictions in presence of uncertain conditions

Figure: Needs identified for **Engineering** purposes

End User	Goals	Metrics
Policy makers	To assess potential hazards (safety, economic and social) and establish policies to minimize their effects	Cost benefit risk measures, accuracy and precision based RUL measures to establish guidelines and timelines for phasing out of aging fleet and/or resource allocation for future projects

Figure: Needs identified for **Regulatory** purposes

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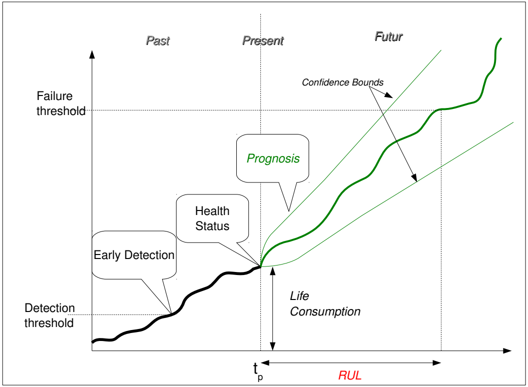
Global Objectives for IW

3 Main Objectives

- What could I expect from prognosis in maintenance terms?
  - Which reachable results?
  - Should I invest?
- How could I get it?
  - what do I need on my system to do prognosis?
  - how much should I pay?
- Where is the prognosis in the Global Health Assessment Process?
  - Links with Diagnosis
  - Industrial Process

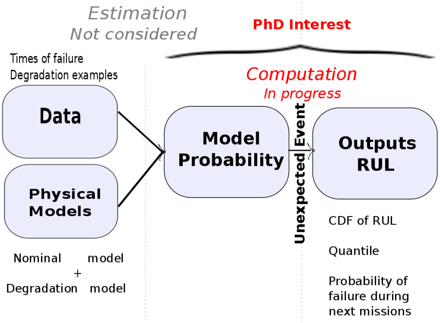
Our Prognosis



Our Definition

Prognosis consists on a supposition about the futur of the system considering past, present and futur information.

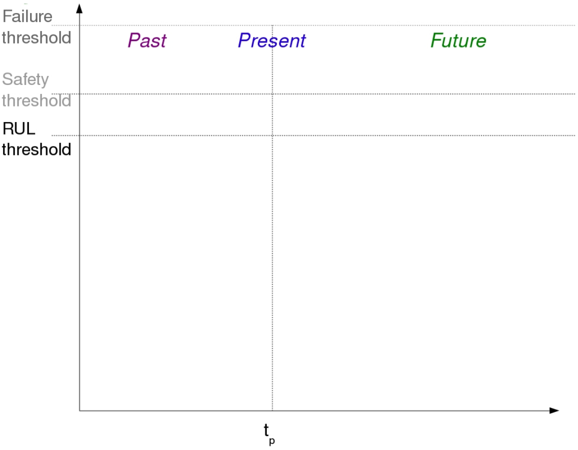
Our choice :Probabilistic Modeling



Specificities

- **Non Safety**
- Actor : Maintenance (operator, maintener)
- Result : RUL density (include A, R) : conditional quantity

Calcul of Remaining Useful Life



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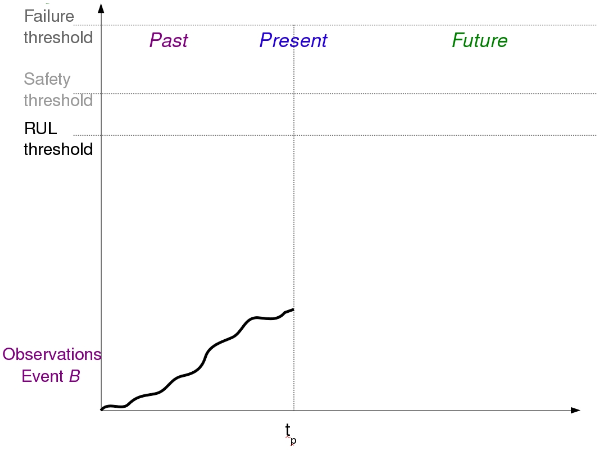

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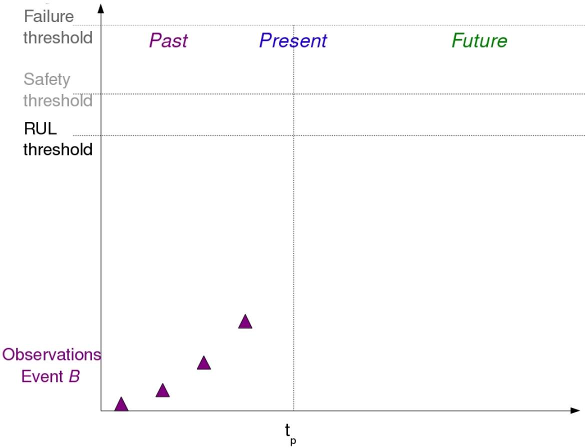

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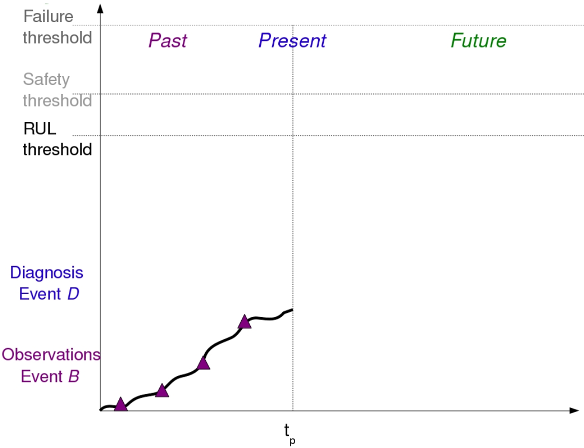

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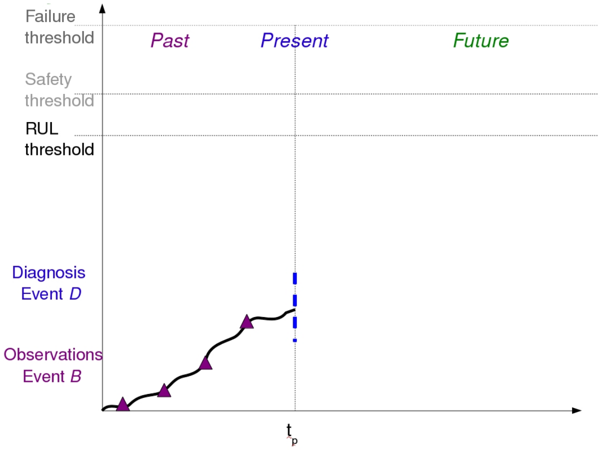

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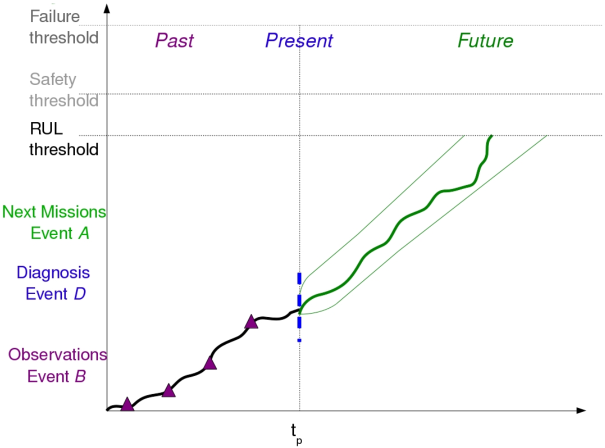

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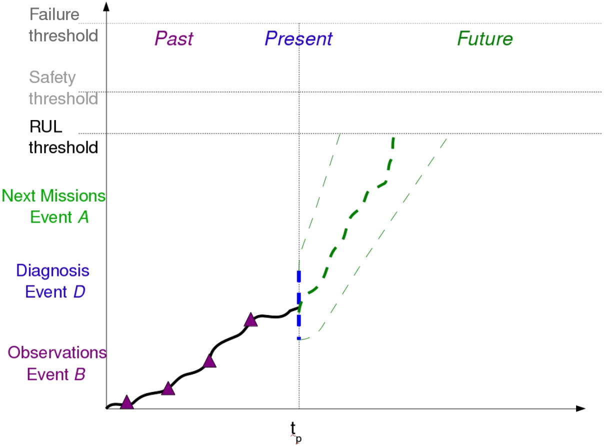

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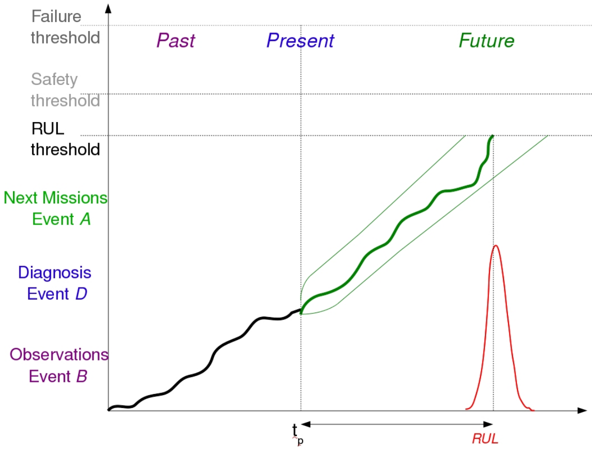

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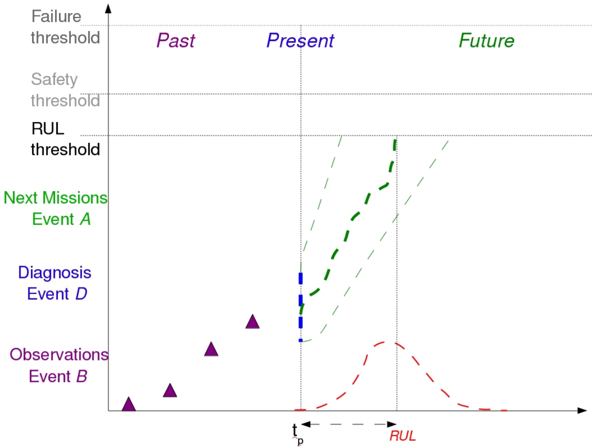

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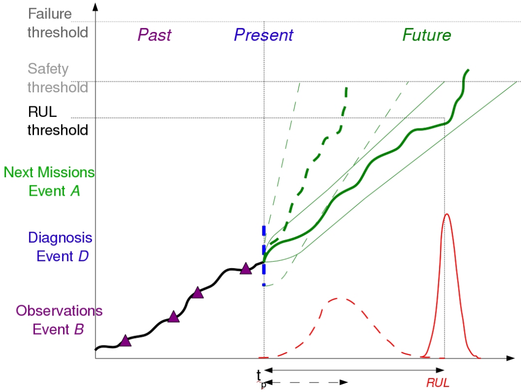

RUL Definition

Remaining Time before an unexpected event using past,present and futur knowledges of the system

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System Modeling : Piecewise Deterministic Markov Process

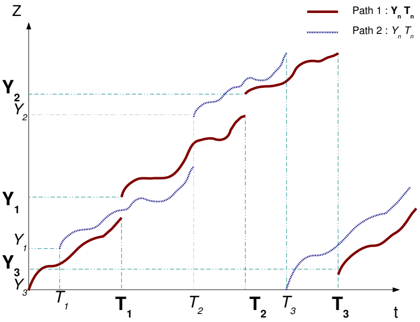
Definition

Physical trajectories of the process cut by random gaps

$$Z_t = \psi(Y_n, t - T_n)$$

<u>Motivation</u>

- Physical Degradation (Experts Knowleges);
- Usual Markov Generalization (λ, μ);
- Hybrid Process : Different environmental conditions;
- Markovian : Feasible Computation



Methodology : Two steps

RUL_t : *Conditional probability* + *Reliability Computation*

Step 1

Conditional probability

- Including past (B) and present (D) information;
- Use of particles filtering Methods. (Del Moral)

Step 2

Reliability Calcul

- Different Methods for PDMP;
- Including Futur (A) like mission conditions.

Dynamic Computation of the *RUL* and use of on line information

Result(1) : RUL through time

COMPLEX SYSTEM

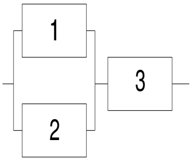


Figure: Reliability Diagram

LifeTime

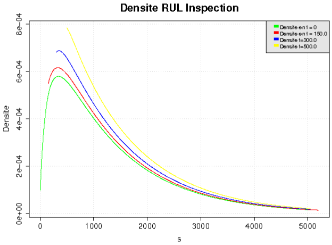


Figure: RULs through time

- Rates
- Reliability Diagramm

Dynamic adaptation of the prognosis throughout the life of the system

Result(2) : RUL for different information

COMPONENT LEVEL

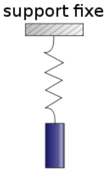


Figure: Harmonic Oscillator

- Nominal Behaviour
- Degradation : Mass Increasing
- Unexpected Event : Amplitude Threshold

Design Phase

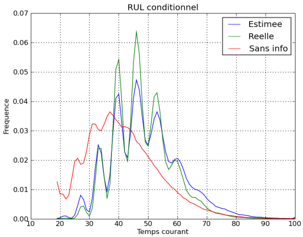


Figure: RUL under several conditions

Impact of available information on the quality of the prognosis

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Conclusion and Perspectives

Achievements :

- Definition of a prognosis in industrial context;
- Identification of a global methodology for prognosis computation;
- Computation of RULs on simple examples;
- Methodology of RULs computation on simple PDMPs (assumptions required)

Perspectives :

- Global Methodology on PDMPs (mathematical problem : less assumptions)
- Optimization of Information for Prognosis Results (French Conference $\lambda - \mu$) for Design Perspectives