Reliability Engineering: An Overview

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Outline

- What is Reliability Engineering?
- Areas of Research in Reliability Engineering Education

Reliability Engineering Overview

- Reliability engineering measures and improves resistance to failure over time, estimates expended life, and predicts time to failure
- What reliability engineers do?
  - They study ways to prevent failures from occurring
    - Design items robust enough to minimize failures
    - Monitor and correct degradation and damage to avoid future failures
  - They develop and use models to assess damage, degradation, and aging of items
  - They predict the time of failures those items
  - They apply failure prevention and prediction methods to hardware parts, components, structures, systems, and system-of-systems; human actions; and software products
  - They develop prognosis and health assessment of items

Evolution of Reliability Engineering

- Two Overlapping Themes for Modeling Life and Performance of Items Have Emerged:
  - Data / Evidence Driven View:
    - Statistical
    - Probabilistic
  - Physics Driven View:
    - Empirical: Physics of Failure
    - Physical Laws
- Examples of Areas of Applications
  - Design (Assuring Reliability, Testing, Safety, Human-Software-Machine, Warranty)
  - Operation (Repair, Maintenance, Risks, Obsolescence, Root Cause Evaluations)

Data or Evidence-Based View

- Post WWII Initiatives due to unreliability of electronics and fatigue issues
  - Inspired by the weakest link, statistical process control, insurance and demographic mortality data analysis methods
  - Defined reliability of a basic item for which reliability data exists in terms of the likelihood of no failure (success) based on the life distribution models, $f(x;\boldsymbol{\theta})$ as:

$$R(t;\theta) = \Pr(Time - to - failure \geq desired\ life\ time) = \int_t^{\infty} f(x;\boldsymbol{\theta})\, dx$$

  - Reliability of systems composed of multiple items (parts, human actions, etc.)
    - Based on the topology of the constituent parts of the system (Reliability block diagrams): $R_{sys} = g(R_i); i = 1, \dots N$
    - Based on the logical connections of the components (fault trees, etc.)
- Common Assumptions
  - Use of historical failure data or reliability test data represent the truth about the performance and item failures
  - Items behave the same way as the historical failure data and reliability tests in the future
  - Maintenance and repair contribute to the renewal of the item
  - Degradation can be measured by the hazard rate. In this case $R_i(t) = e^{-H(t)}$,

$$where\ H(t;\theta) = cumulative\ Hazard = \int_0^t h(x;\theta)dx\,;\ \text{and}\ h(t;\theta) = hazard\ rate = \frac{f(t;\theta)}{R(t;\theta)}$$

Physics-Based View

- This view started in the 1960's and revived in the 1990's
- Failures occur due to known underlying failure mechanisms that either:
  - Accumulate damage and when damage exceeds endurance (i.e., resistance to damage), the item fails.
  - Causes performance to decline which when falls below a minimum requirement, the item fails.
- Alternatively failures occur when applied stresses (load) exceeds strength (capacity) to resist the applied stress
- Referred to physics-of-failure, the time-to-failure is empirically modeled:

$$t_f = f(S_o, S_e, g, d_i, \vec{\boldsymbol{\theta}})$$

S_o = Operational Stresses
S_e = Environmental Stresses
g = Geometry related factors
$\vec{\boldsymbol{\theta}}$ = vector of model parameters
d = defects, flaws, etc.

  - Inspired by advances in fracture mechanics
  - Accelerated life and degradation testing
  - Probabilistic models of time-to-failure (PPoF models) developed and simulations
- **Benefits**
  - No or very little dependence on historical failure data
  - Easily connected to all physical models
  - Address the underlying causes of failure (failure mechanisms)
  - Specific to the items and the condition of operation of that item
- **Drawbacks**
  - Hard to model specially interacting failure mechanisms
  - Looks for markers of degradation not the total damage
  - Based of small experimental evidences

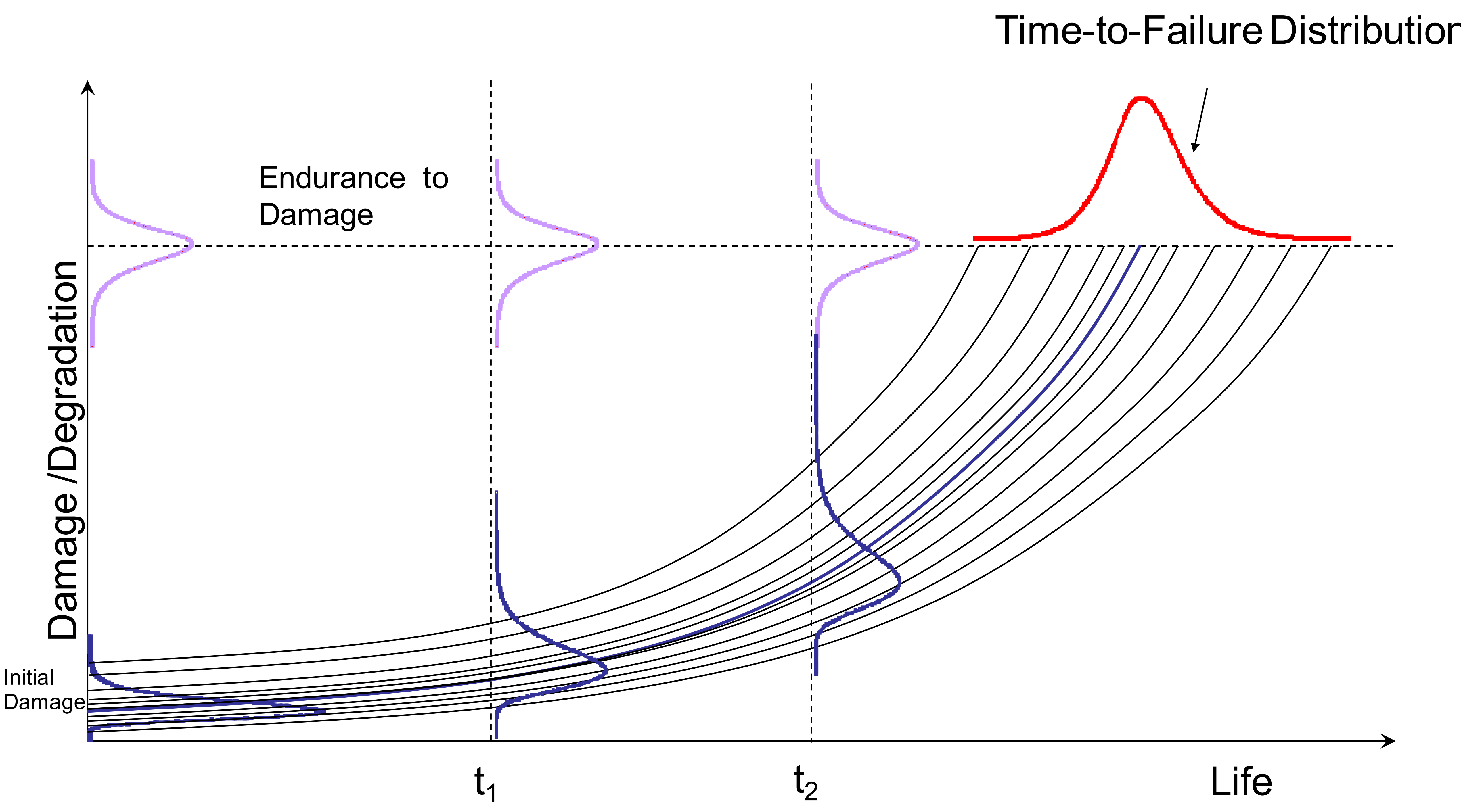
Examples of Current Areas of Interest and Research in Reliability Engineering

- Data / Evidence – Based View
  - Advanced Bayesian analysis of data and model validation
  - Warranty data evaluations
  - Reliability growth
  - Generalized renewal process
  - Software reliability
  - Human reliability assessment
  - Data Science
    - Sensors
    - Data / information fusion
    - Simulation tools (MCMC, Recursive Bayes and Bayesian filtering)
    - Pattern and image recognition, sensor data clustering and classification

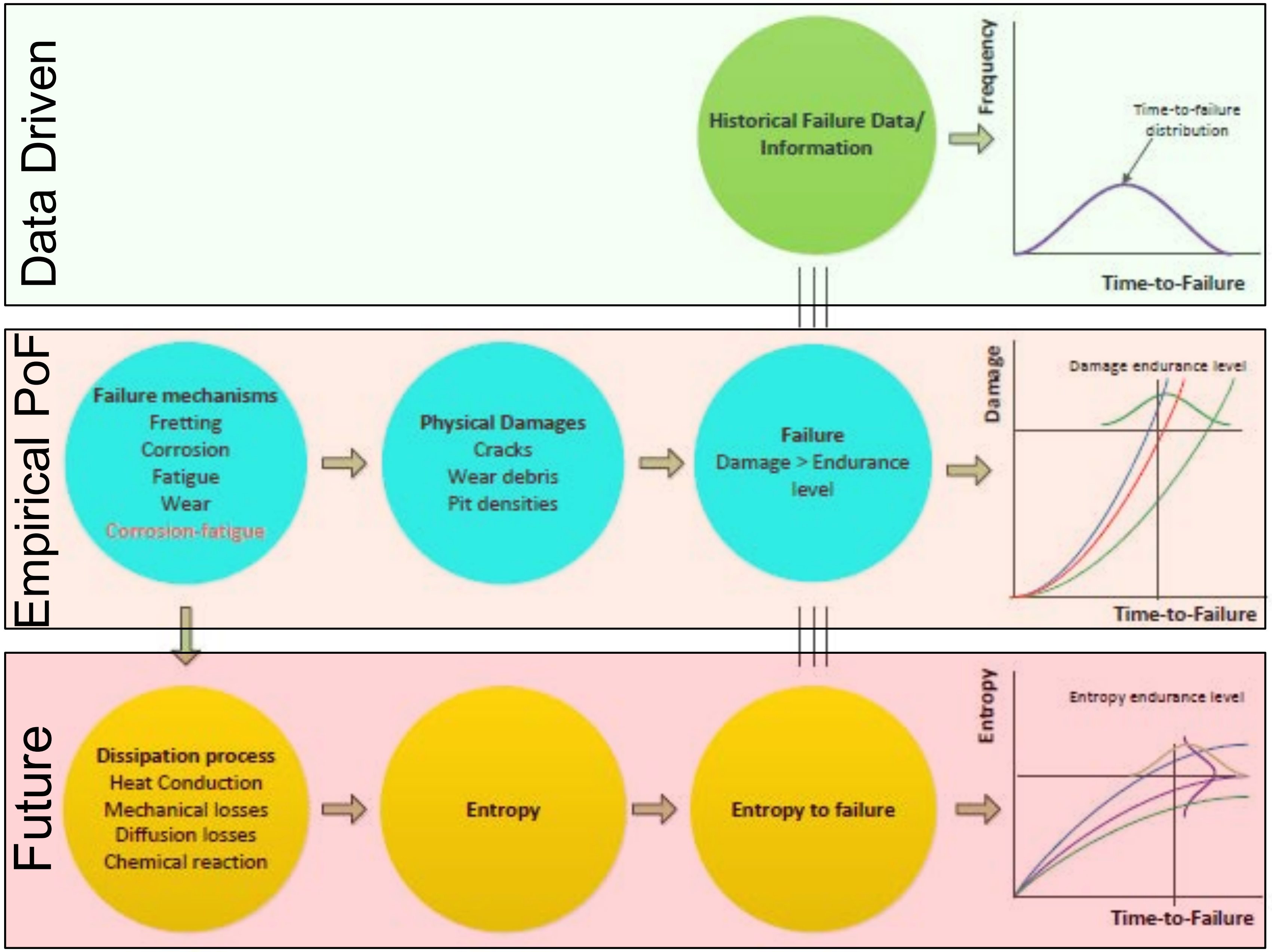
Current Areas of Interest and Research in Reliability Engineering (Cont.)

- Physics – Based View
  - Hybrid Models
    - Complex logics Models and computation algorithms
    - Bayesian Belief Networks
    - Dynamic Belief Networks
    - Agent-Based Computing and Modeling
    - Neural Networks
  - Probabilistic Physics of Failure (PPoF)
    - Accelerated life and degradation tests
    - Time varying accelerated tests
  - Prognosis and Health Management (PHM)
    - PHM methods in support of resilience, replacement, repair and maintenance
    - Reliability of autonomous systems and cyber-physical system safety / security
  - Search for fundamental physical sciences of reliability
    - Thermodynamics
    - Information theory
    - Statistical mechanics

Reliability Summary



Summary of Reliability Engineering



Why Entropy?

- ✓ Entropy can model multiple competing degradation processes leading to damage
- ✓ Entropy is independent of the path to failure ending at similar total entropy at failure
- ✓ Entropy accounts for complex synergistic effects of interacting degradation processes
- ✓ Entropy is scale independent

Conclusions

- Reliability engineering traditionally relied on historical evidences of failures which provide limited and often inaccurate perspective of true reliability
- Physics of failure and simulation methods offer improvement in reliability assessment, but the models are judgmental or at based on limited empirical evidence.
- Entropic damage provides a more fundamental approach to degradation, damage and aging assessment in reliability engineering
- PHM has become a leading approach in preventing failures and improving reliability during operations

Thank you for your attention!