Comparison of health monitoring strategies for a gradually deteriorating system in a stressful environment

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Overview & Outline

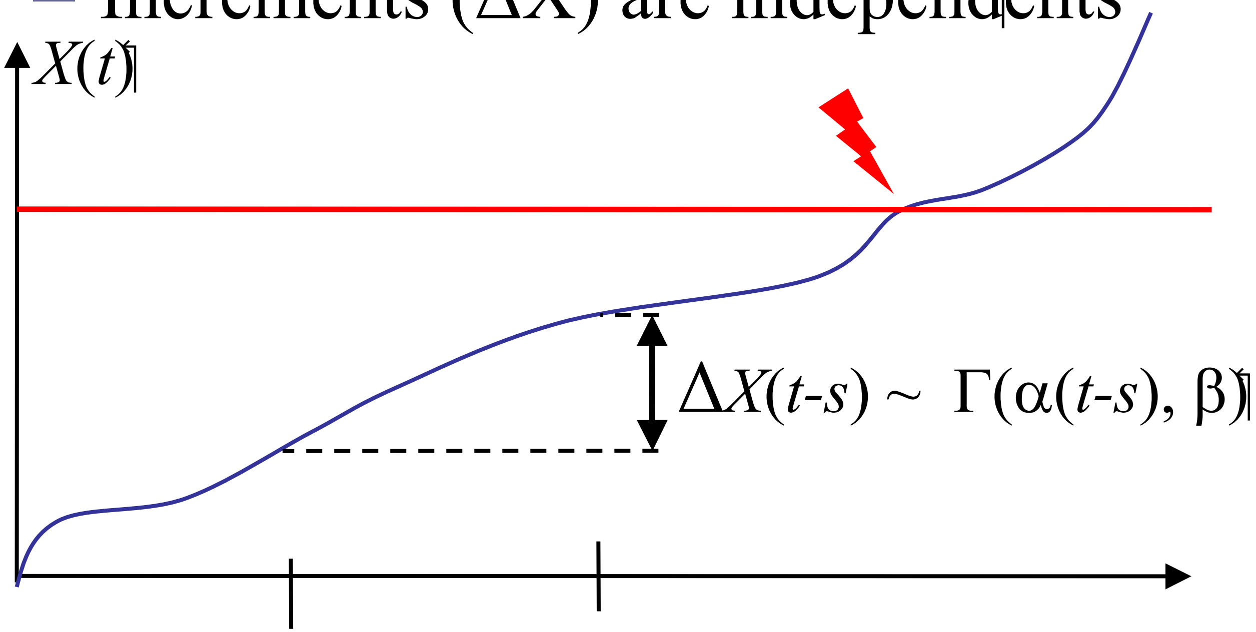
- Introduction: problem statement
- Description of the system
- Maintenance strategies
- Numerical results
- Summary & conclusions

Introduction

- Objective : Develop different maintenance strategies based on the knowledge level on the system:
  - a cumulative deterioration process
  - a stress process:
    - a priori knowlegde
    - information continuously available

System Description

- Deterioration process: Gamma process
  – X(t) = deterioration variable
  – Increments (ΔX) are independents



$$E\left(X(t)\right) = \frac{\alpha}{\beta} t$$

$$V\left(X(t)\right) = \frac{E\left(X(t)\right)}{\beta}$$

System Description

- Stress process
  - Y_t=1 : the system is stressed
  - Y_t=0 : the system is not stressed
  - The time intervals between successive state changes are exponentially distributed

- Impact of the stress on the deterioration process:

$$Y_{(t-s)} = 0: \quad X_{(t-s)} \sim \Gamma(\alpha(t-s), \beta)$$
$$Y_{(t-s)} = 1: \quad X_{(t-s)} \sim \Gamma(\alpha(t-s)e^{\gamma}, \beta)$$
$$\text{Finally:} \quad X_{(t-s)} \sim \Gamma(\alpha(t-s)e^{\gamma\, y}, \beta)$$

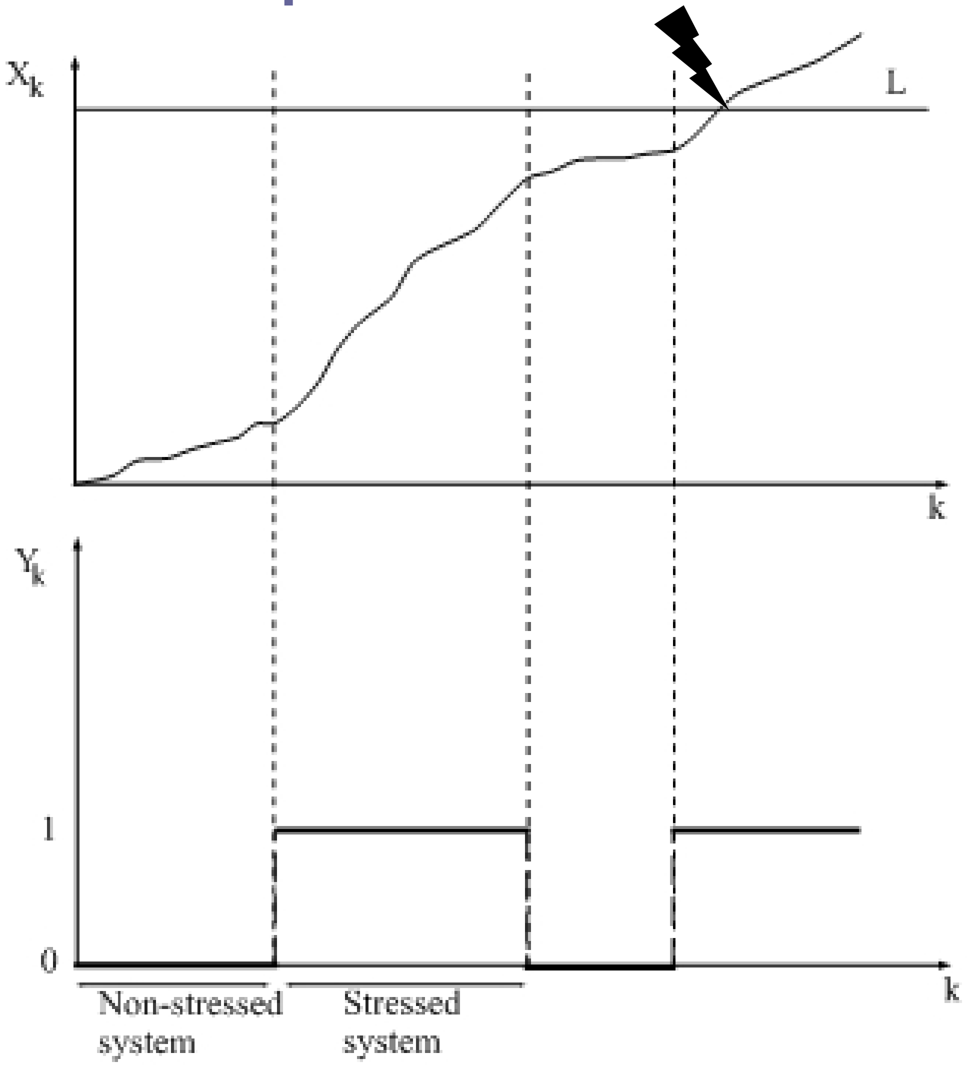
System Description

- In average the mean of the shape parameter:

$$\overline{\alpha} = \alpha(e^{\gamma} + \overline{r}(1 - e^{\gamma}))$$

- Where $\overline{r}$ is the mean time elapsed in the stressed state and *r(t)* is the actual proportion of time elapsed in the stressed state

System Description



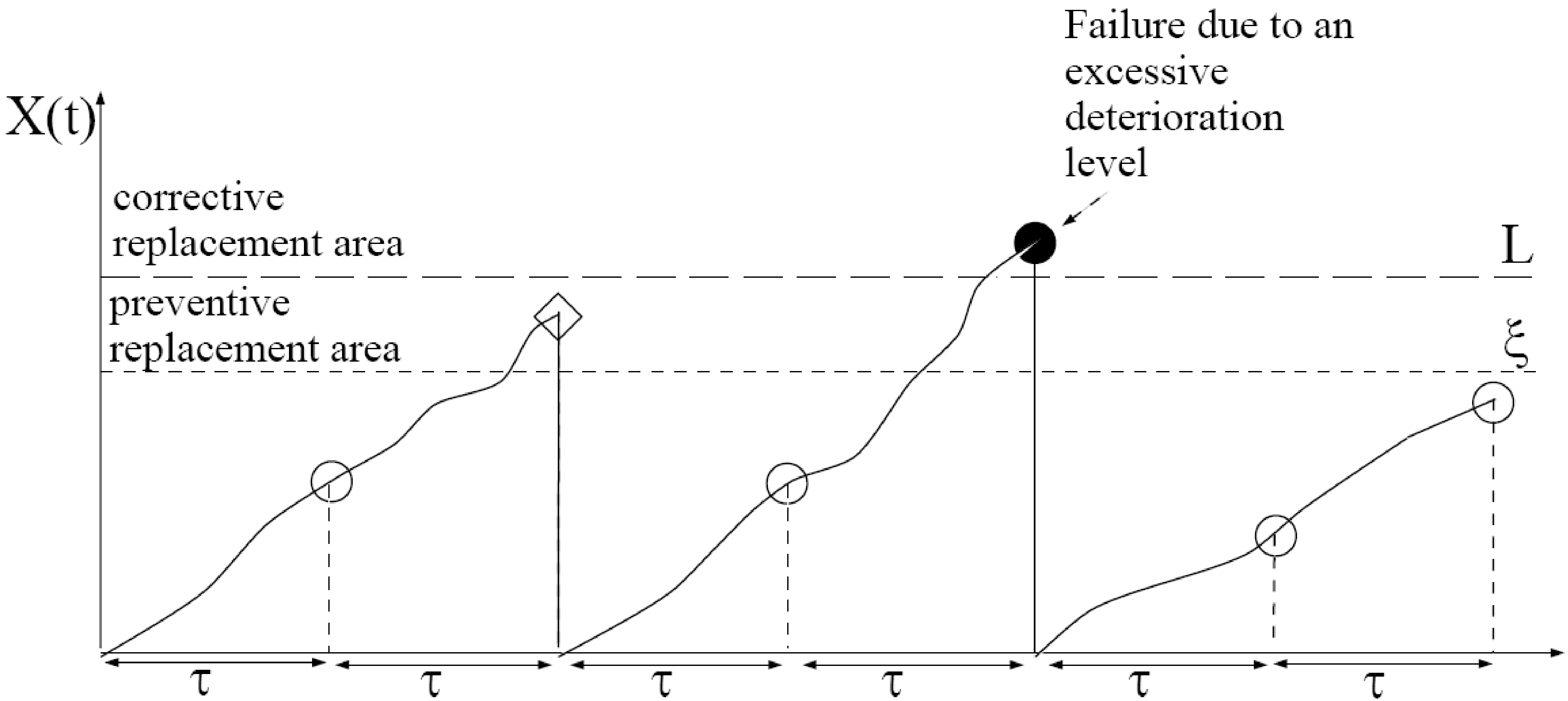
Stationary maintenance policy

Stress process: only an a priori knowledge (only $\bar{r}$ is known)

- Condition-Based Maintenance for X_t
  - Periodic Inspection -τ- to measure the deterioration level (NDT techniques) - expensive inspection c_{ix}

- Preventive replacement if:
  - an inspection is performed
  - $X_t \in (\xi, L)$
  - cost: $c_{ix} + c_p$
- Corrective replacement if:
  - an inspection is performed
  - $X_t > L$
  - cost: $c_{ix} + c_c + c_u D_u$

Stationary maintenance policy



Performance of the Stationary Maintenance Policy

- Maintenance cost criterion

$$C_\infty(\tau,\xi) = \lim_{t\to\infty} \frac{C(t)}{t} = \frac{E(C(S))}{E(S)}$$

  - C(t) :

$$C(t) = c_{ix} N_{ix}(t) + c_p N_p(t) + c_c N_c(t) + c_u D_u(t)$$

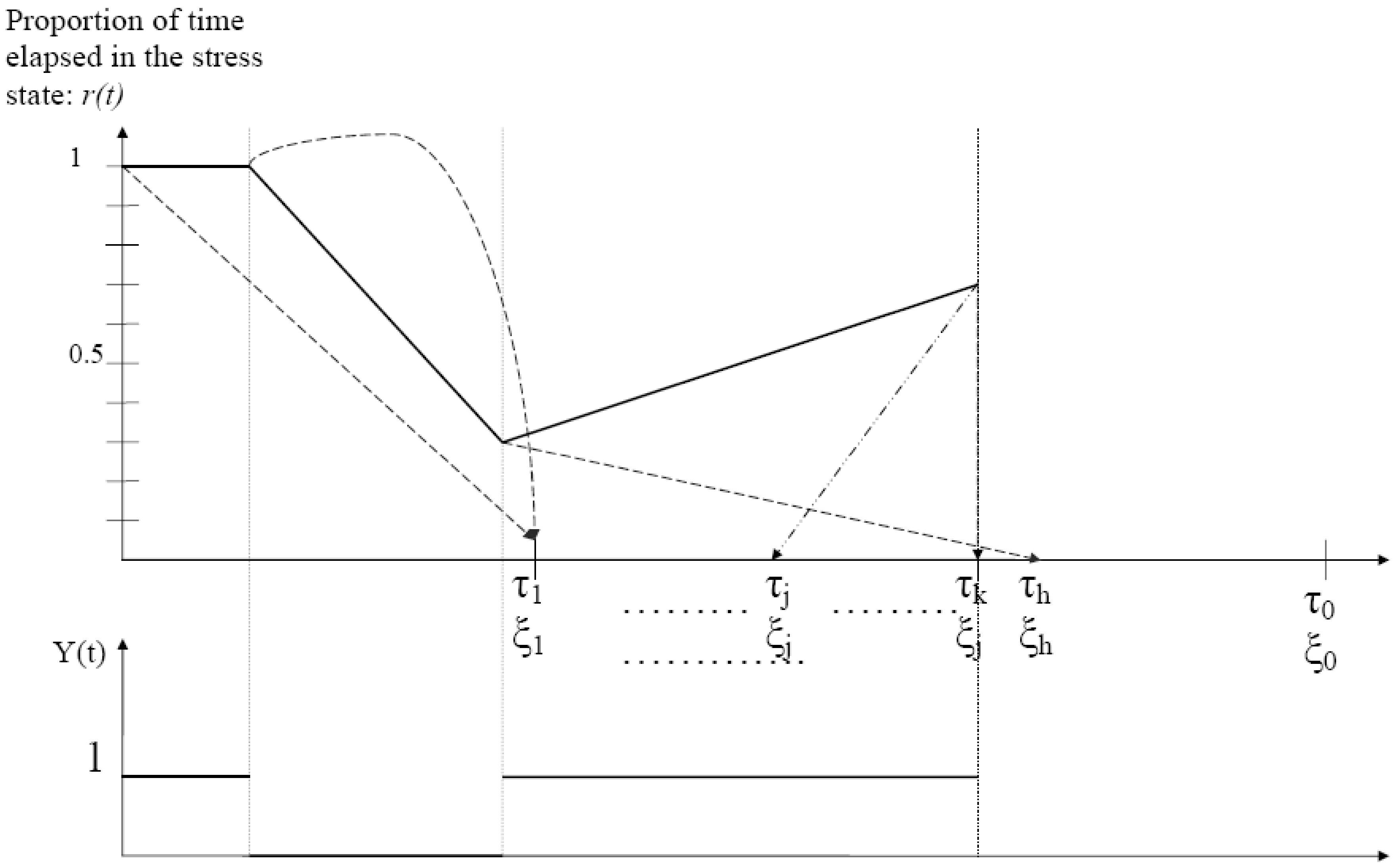
- Numerically evaluated

“Adaptive” maintenance policy

The stress covariate is continuously monitored

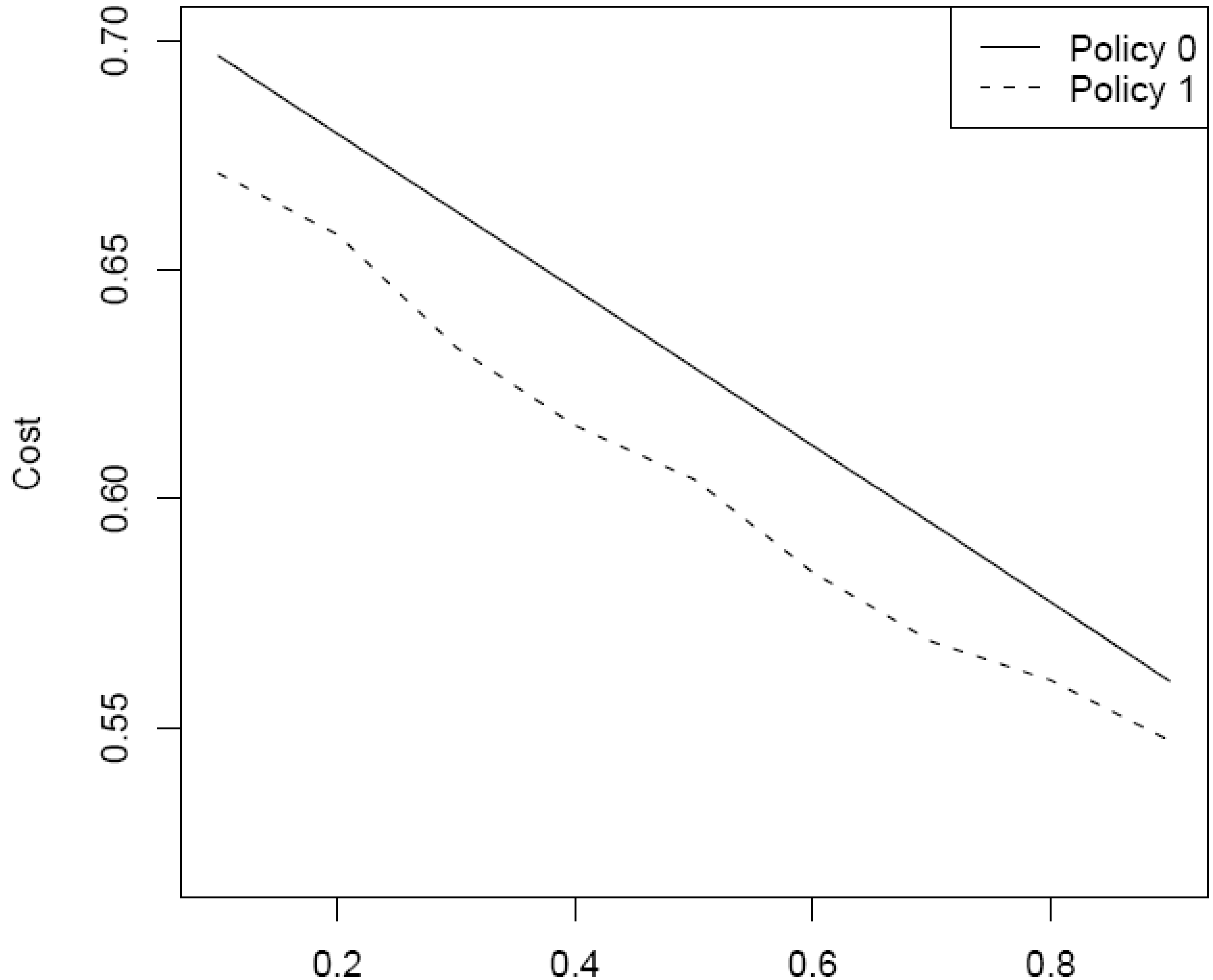
- r(t): the actual proportion of time elapsed in the stressed state
- $(\tau_{r(t)}, \xi_{r(t)})$the optimized decision parameters for stationary maintenance policy when $r(t) = \bar{r}$
- At each environmental state change: decision parameters are re-evaluated according to *r(t)* $(\tau_{r(t)}, \xi_{r(t)})$
  - If the new inspection period leads to an inspection time lower than the present time, the system is inspected immediately with the following decision parameters $(t, \xi_{r(t)})$
  - Limit cases:
    - System never stressed: r(t)=0 ; decision parameters (τ_0, ξ_0)
    - System always stressed: r(t)=1 ; decision parameters (τ_1, ξ_1)

Adaptive maintenance policy



Performance of the maintenance policy

4% cost saving with the adaptive maintenance policy (Policy 1)



Summary & conclusions

- Modelling of the relationship between the system performance and the associated operating environment

- Development of two maintenance strategies:
  - One based on the a priori knowledge of the stress process
  - One based on the continuous available information on the stress process

Next steps and future work

- Development of the mathematical model for the adaptive maintenance strategy
- Study of the model sensitivity analysis