NTNU
Norwegian University of
Science and Technology

RAMS Seminar

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Lead Time Modeling for Optimization of an Alarm Threshold

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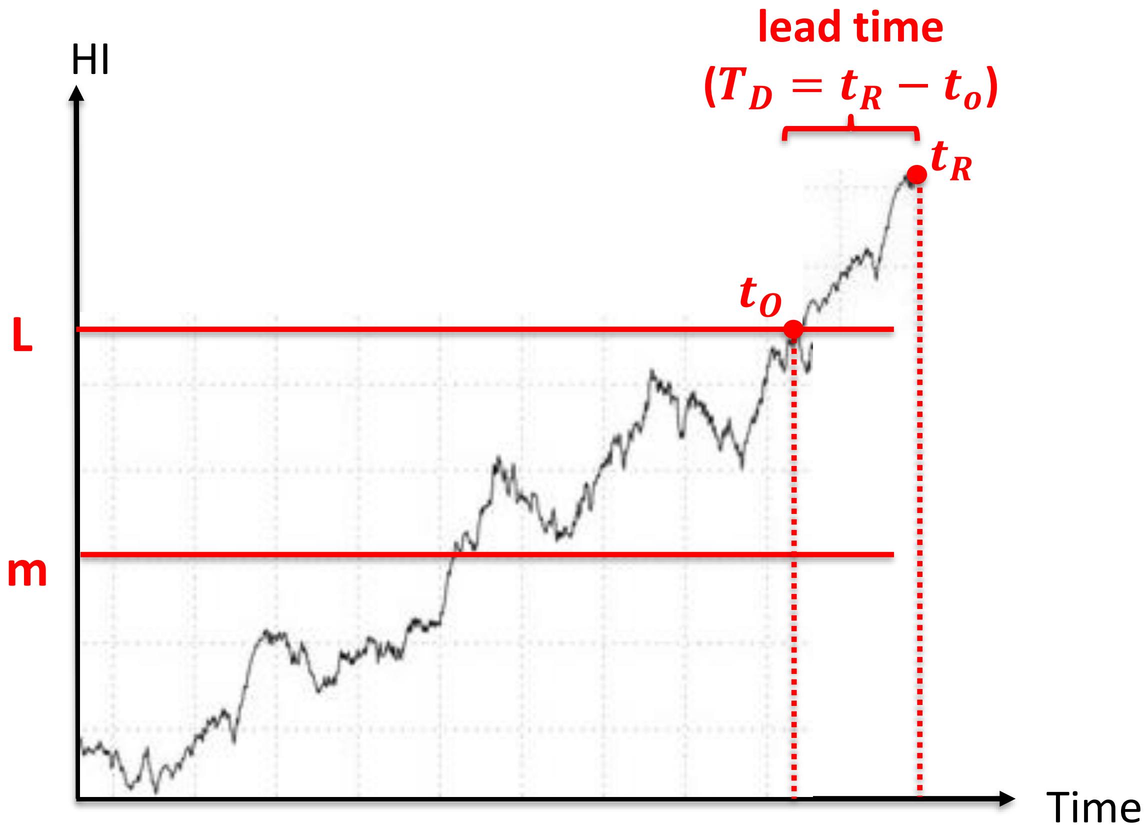
Agenda

- Introduction
- Objective
- Deterministic Lead Time
- Stochastic Lead Time
- Modeling and Some Results
- Further Work

Introduction

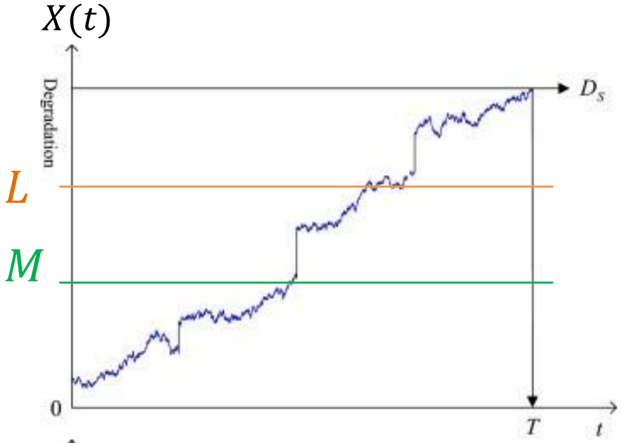
- Lead time: Time between placing an order and receiving the order/time from when a maintenance action is ordered until it is carried out.
- Lead time depends on many factors such as delivery time of an item, maintenance team availability, …
- Most literature works focus on deterministic lead time
- In reality, lead time is stochastic variable



Objective

- The objective is to find an appropriate alarm threshold (m) to minimize the expected cost

Deterministic Lead Time - Assumptions



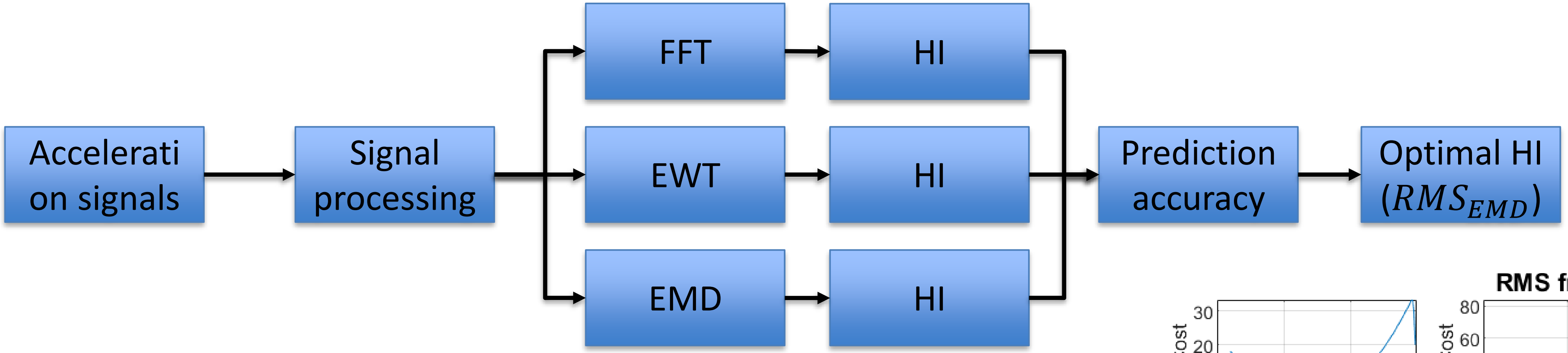
- The system is continuously monitored without any uncertainty:
  - Gradual degradation (aging) : **Wiener process**
  - Failure if $X(t) \geq L$
  - When $X(t) \geq L$, we place a request to replace the component with a new one

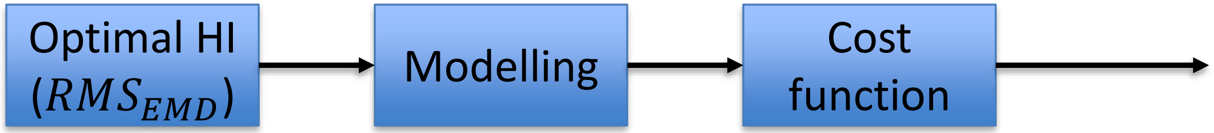
Deterministic Lead Time Modelling

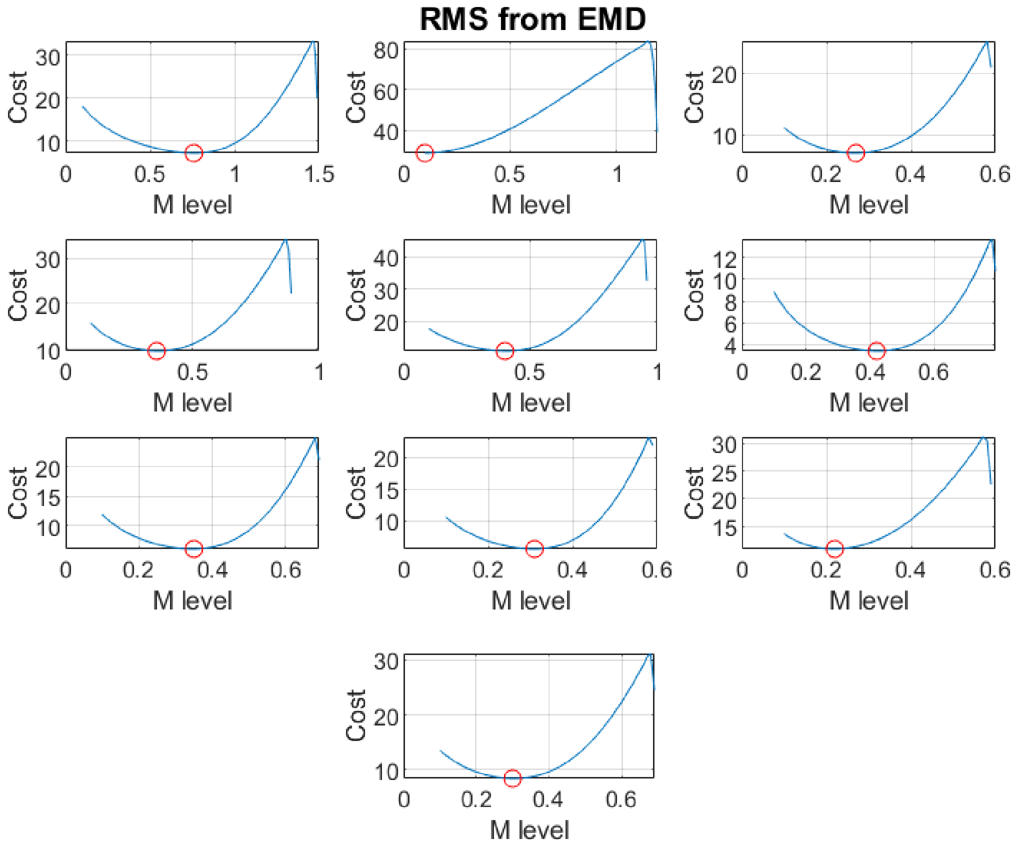
$$C(m) = \frac{C_R + C_F.F(T_L|\alpha_m, \beta_m) + C_U.\int_0^{T_L} f(t|\alpha_m, \beta_m)(T_L - t)dt}{\frac{m}{\mu} + T_L}$$

- C_R: replacement cost
- C_F: Failure cost
- C_U: Cost of per hour downtime
- $F(t; \alpha_m, \beta_m)$ and $f(t; \alpha_m, \beta_m)$ are the CDF and PDF of RUL
- MTBR in denominator is mean time between renewals
- $\alpha_m = \frac{L-m}{\mu}$
- $\beta_m = \frac{(L-m)^2}{\sigma^2}$

Case study: Bearings







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Stochastic Lead Time - Assumptions

- The system is continuously monitored without any uncertainty:
  - Gradual degradation (aging) : **Wiener process**
  - Failure if $X(t) \geq L$
  - When $X(t) \geq L$, we place a request to replace the component with a new one
  - $T_L \sim Weibull\ (2,5)$

Stochastic Lead Time - Modelling

$$C(m) = \frac{C_R + C_F . \int_0^{\infty} F(T_L|\alpha_m, \beta_m)\ g(T_L|m)\ dT_L + C_U . \int_0^{\infty} \int_0^{T_L} f(t|\alpha_m, \beta_m)\ g(T_L|m)\ (T_L - t)dt\ dT_L}{\int_0^{\infty} \left(\frac{m}{\mu} + T_L\right) g(T_L|m)\ \ dT_L}$$

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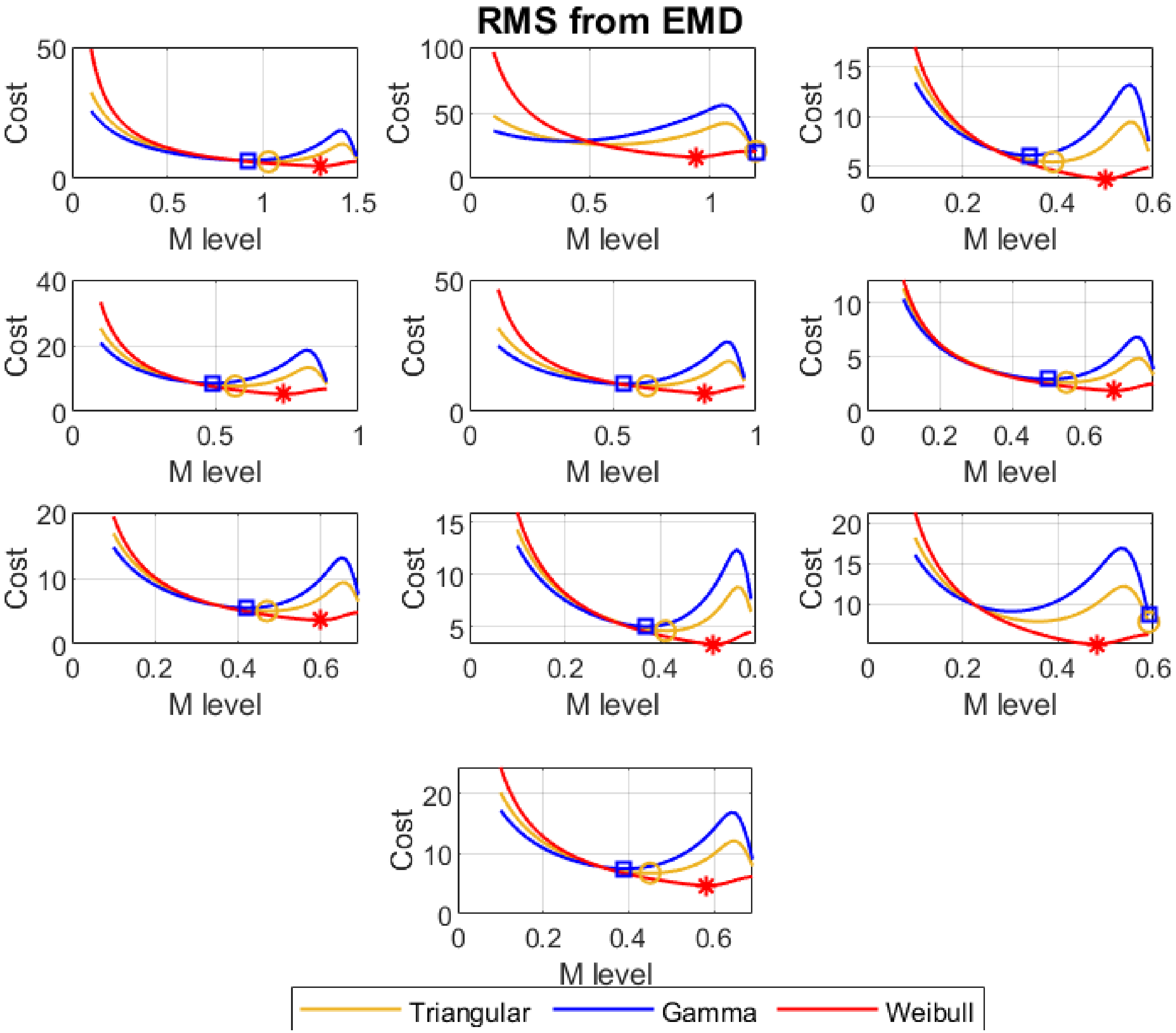
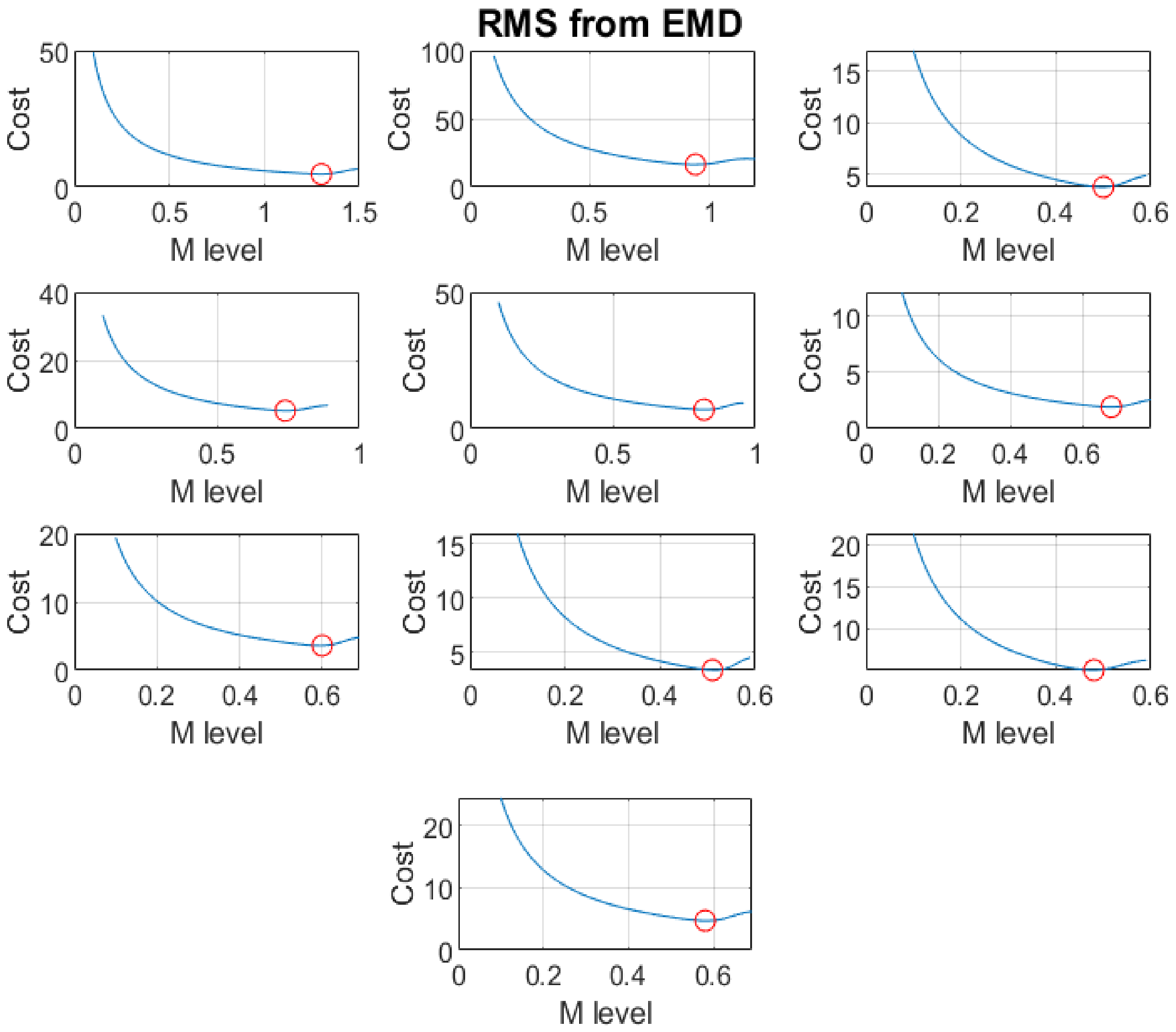
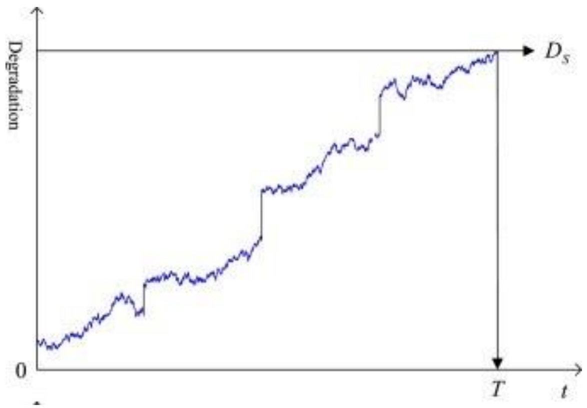
Case study: Bearings





Ideas for Further Work

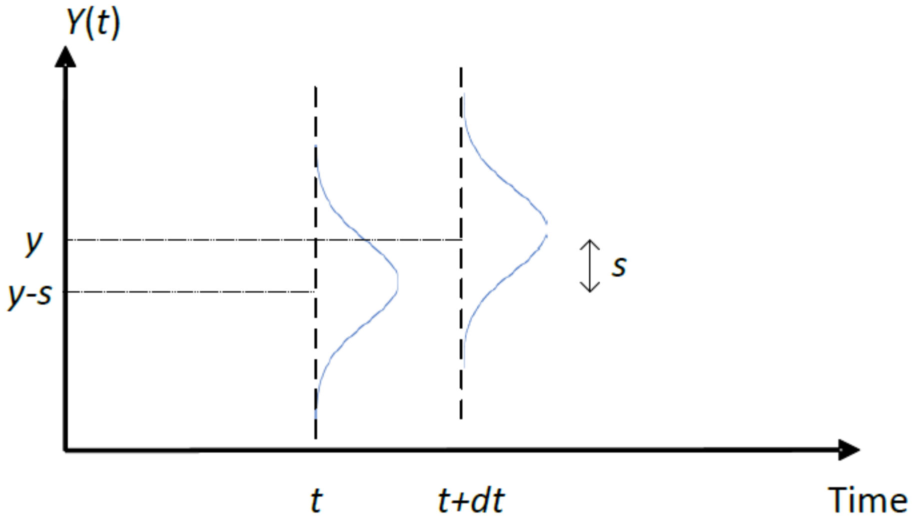
- Gradual degradation (aging) with Wiener process
- Random shock with homogeneous Poisson process (HPP) with intensity ρ
- Magnitude of the random shocks is random (gamma distribution)
- Deterministic lead time



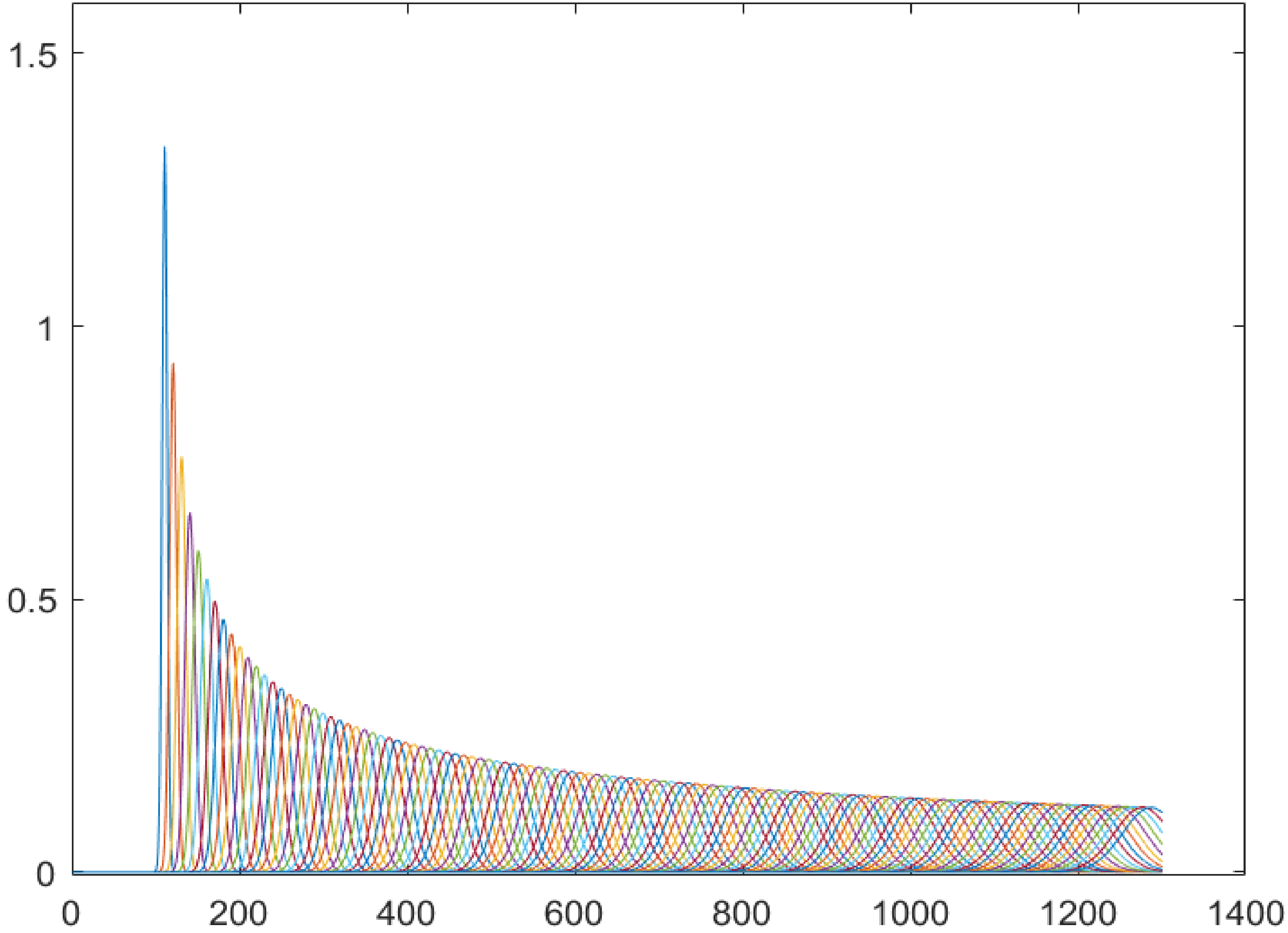
$$C(m) = \frac{C_R + C_F \cdot \int_0^{\infty} F(T_L|\alpha_m,\beta_m)\, g(T_L|m)\, dT_L + C_U \cdot \int_0^{\infty}\int_0^{T_L} f(t|\alpha_m,\beta_m)\, g(T_L|m)\,(T_L - t)\,dt\, dT_L}{\int_0^{\infty}\left(\frac{m}{\mu} + T_L\right) g(T_L|m)\; dT_L}$$

What can we do instead to derive the cost function?

- Numerical integration of the stochastic process (PK8207!)
- $y(t+dt) = y(t) + S$
- $f(y|t+dt) = \int_{-\infty}^{\infty} f(y-s|t)\, g(s)\, ds$
- $f(y|t+dt\,, \boldsymbol{and\ shock}) = \int_0^{\infty} f(y-s|t)\, h(s)\, ds$
- $f(y|t+dt) = (1-\rho dt)\, f(y|t) + \rho dt \int_0^{\infty} f(y-s|t)\, h(s|t)\, ds$



Probability mass shuffling



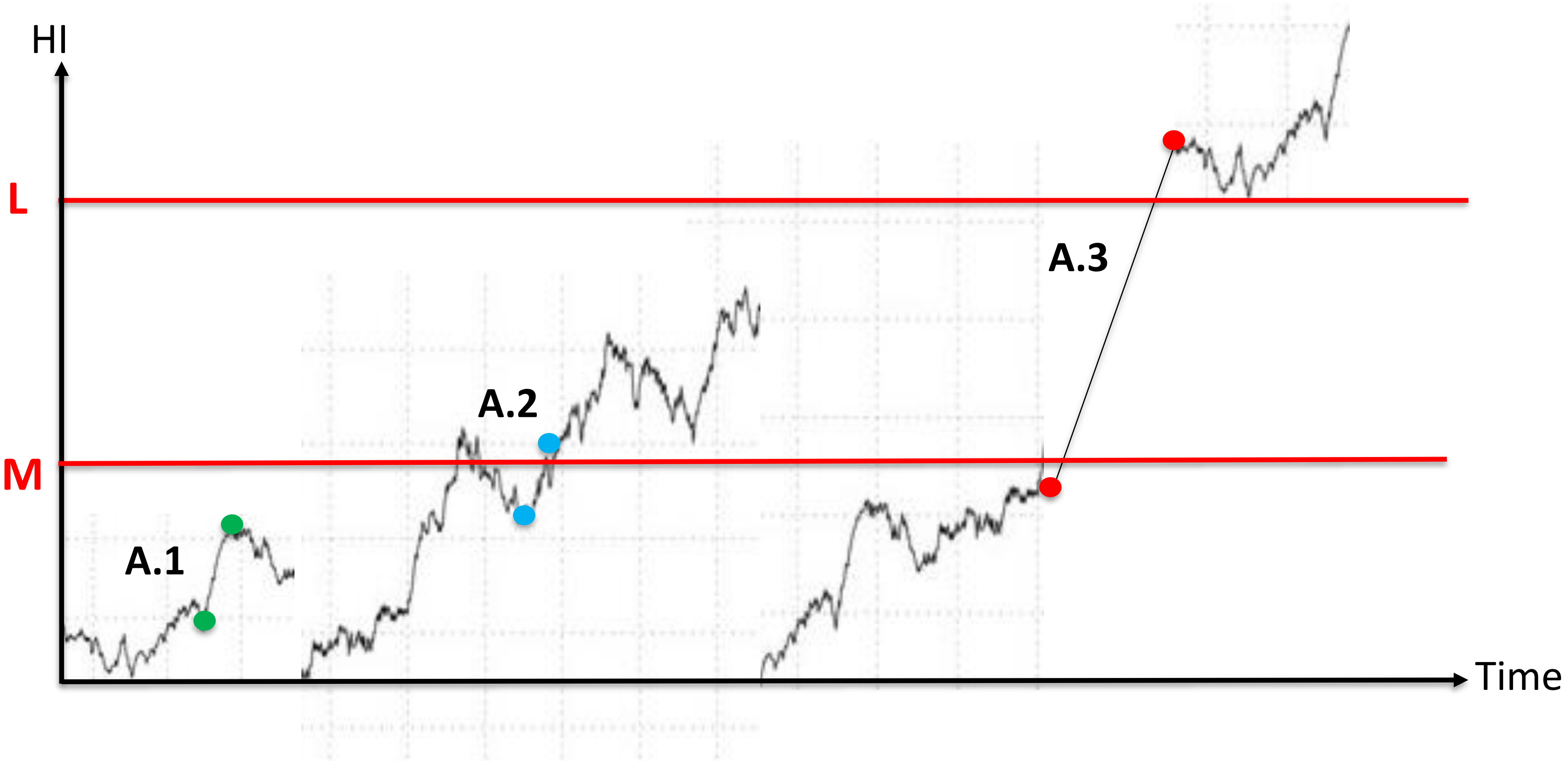
Random shock, possible cases

Case A: Shock occurs below the maintenance limit (M)

A.1 Low magnitude, degradation level remains below M

A.2 Medium magnitude, degradation level lies between M and L

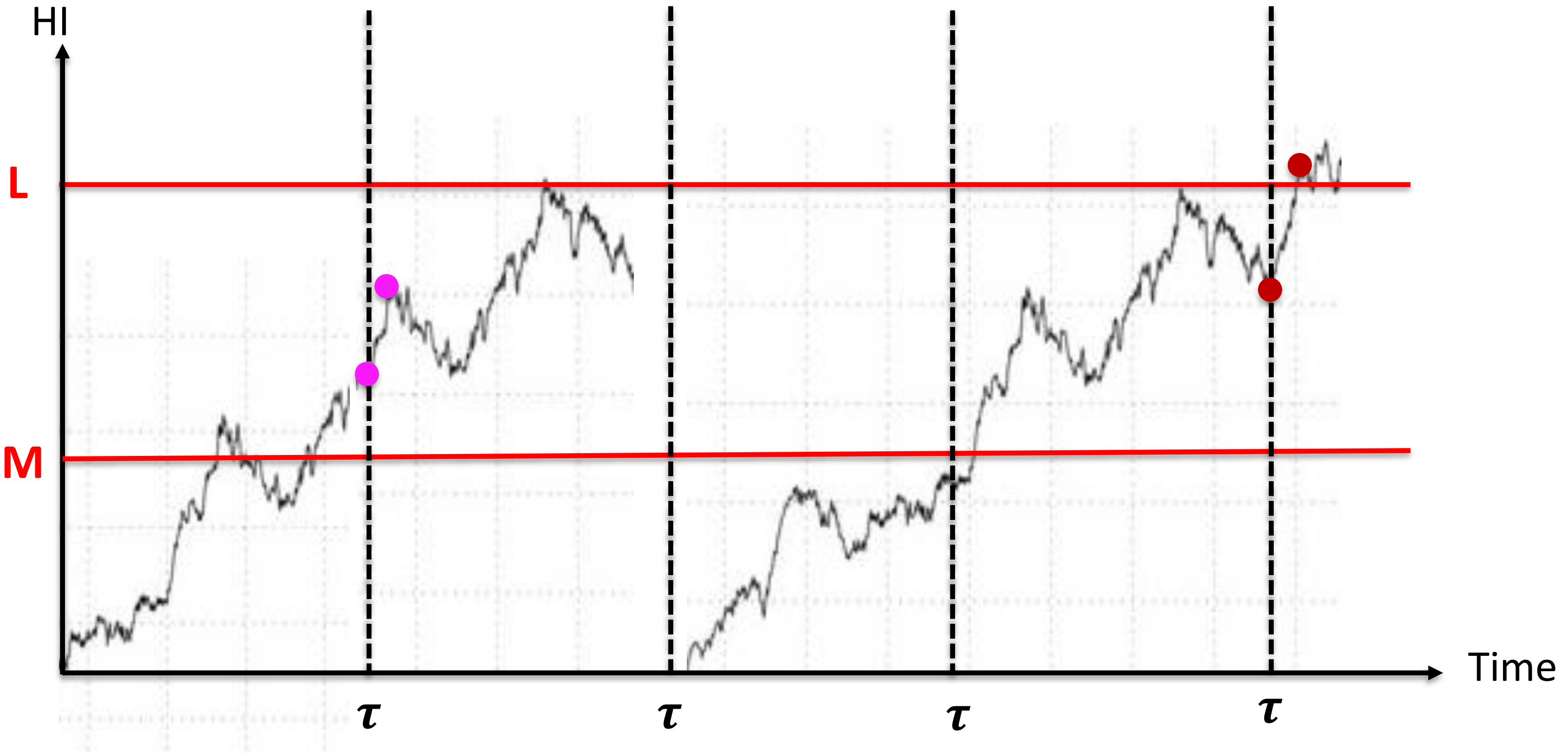
A.3 Large magnitude, degradation level goes above L



Imperfect Repair, possible cases

Case B: A shock occurs while we are waiting for a renewal (the degradation level is above M)

- B.1 low magnitude of shock, degradation level remains below L
- B.2 large magnitude, degradation level goes above L



Thank you!