Dynamic and Adaptive Maintenance Policies for Complex Systems based on Real-Time Data

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Technische Universiteit **Eindhoven** University of Technology

DINALOG Dutch Institute for Advanced Logistics

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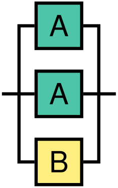
Dynamic & Adaptive Residual Life Distributions



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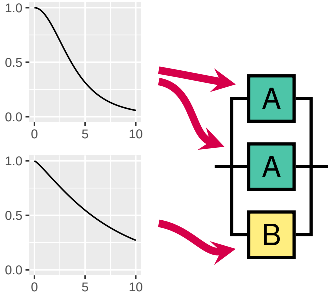

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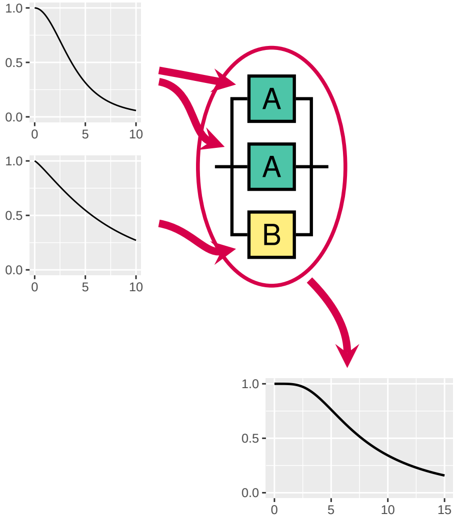

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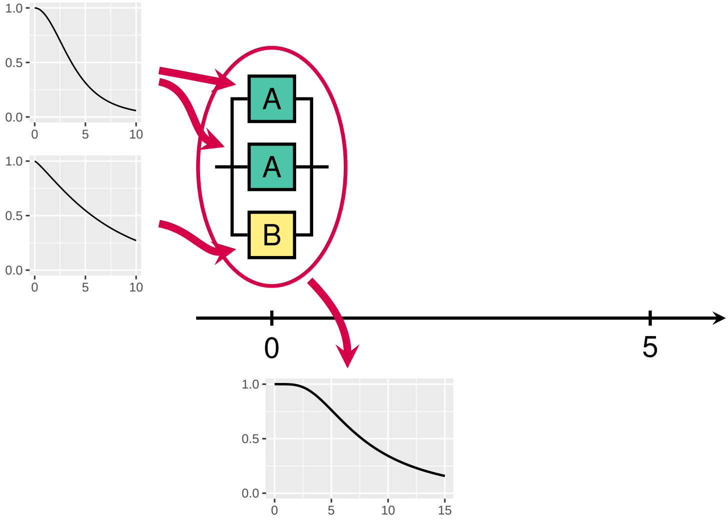

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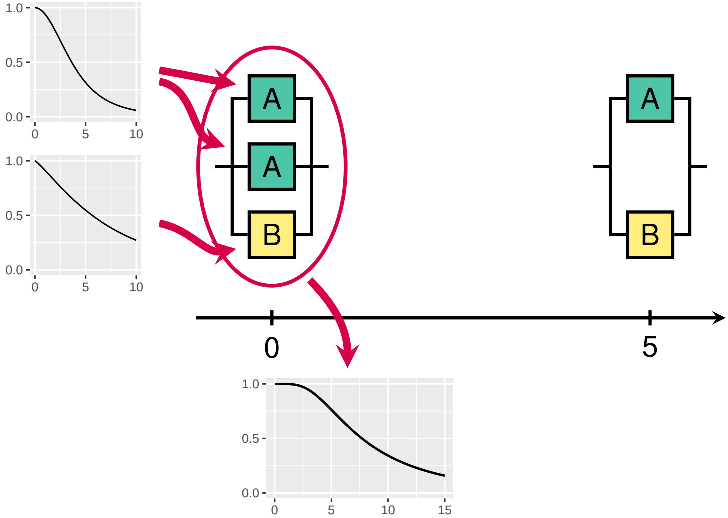

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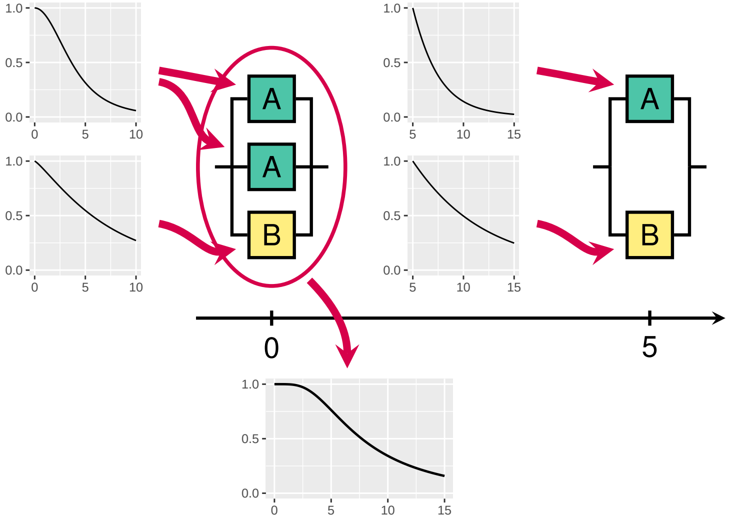

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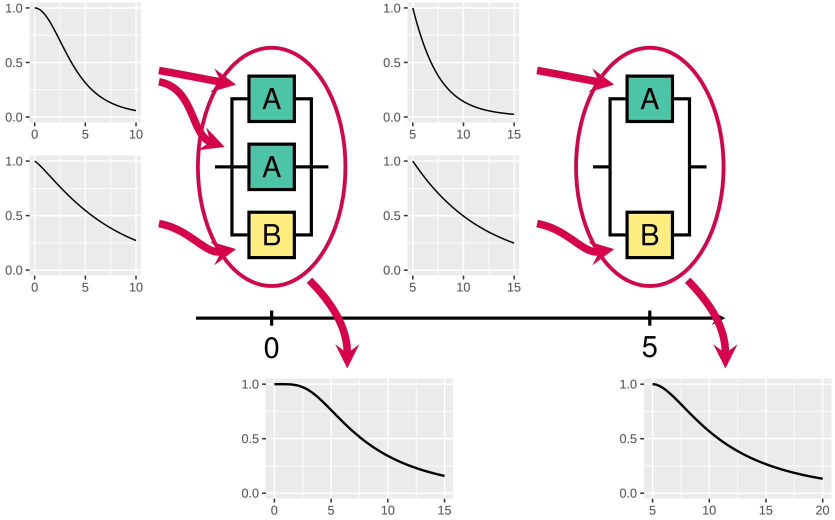

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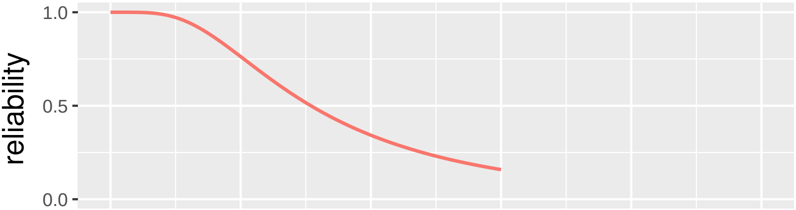

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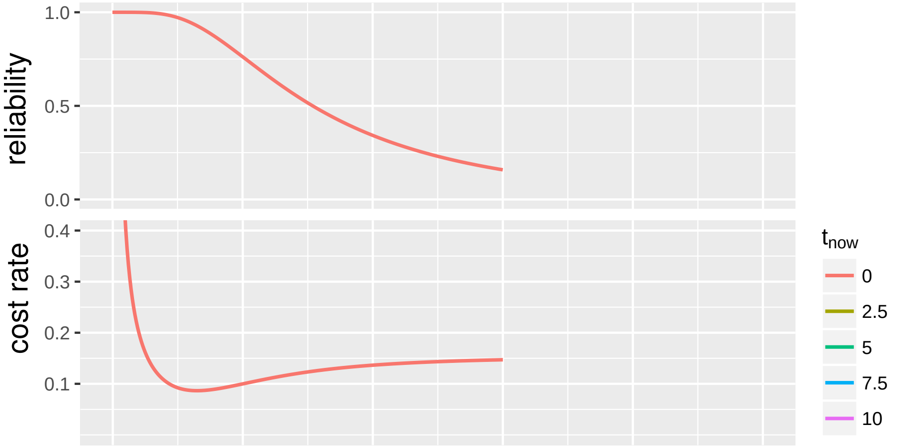

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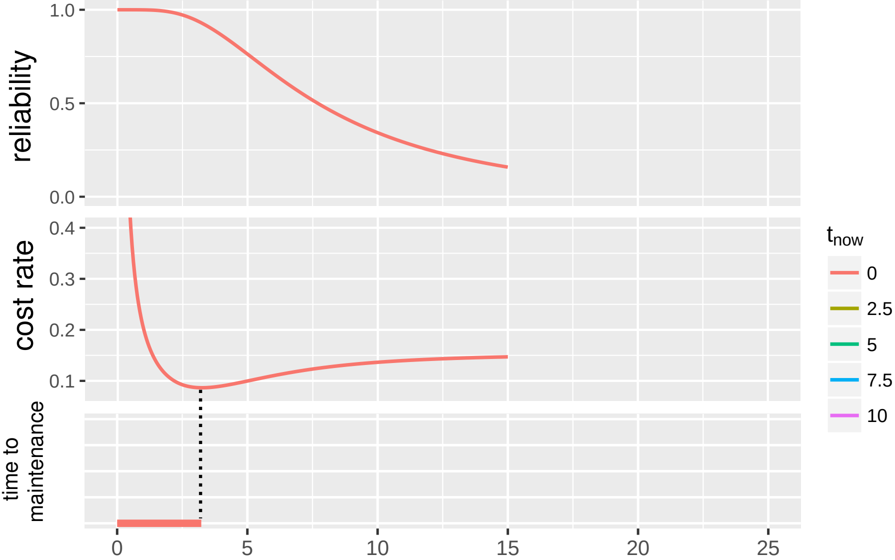

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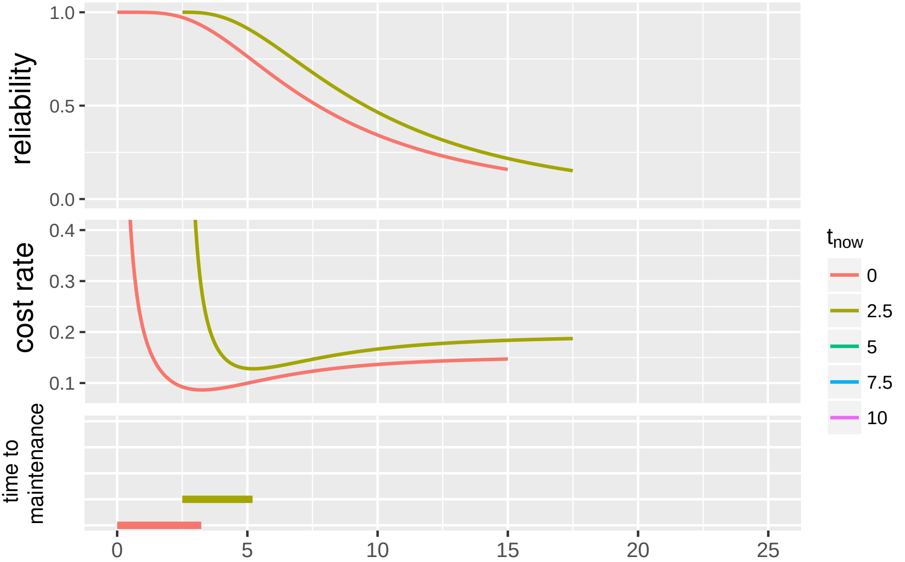

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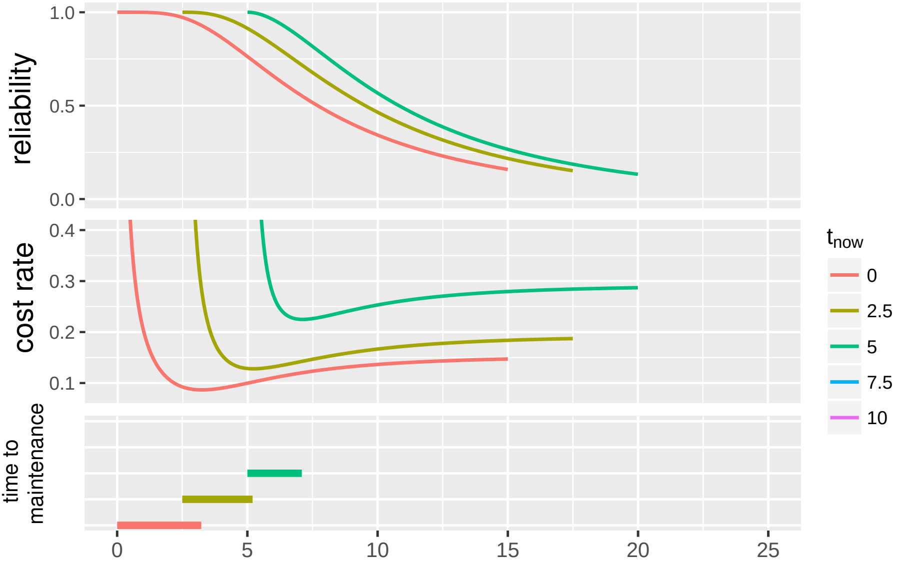

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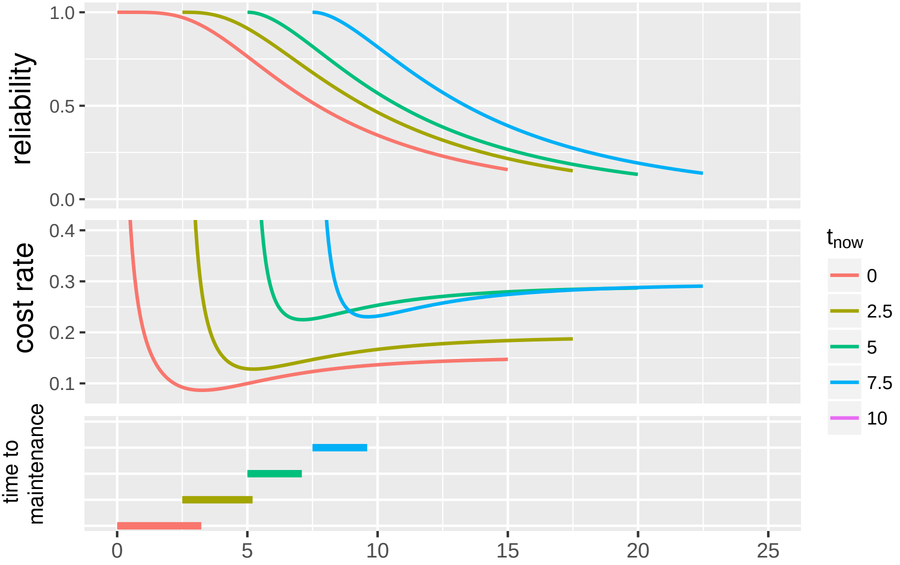

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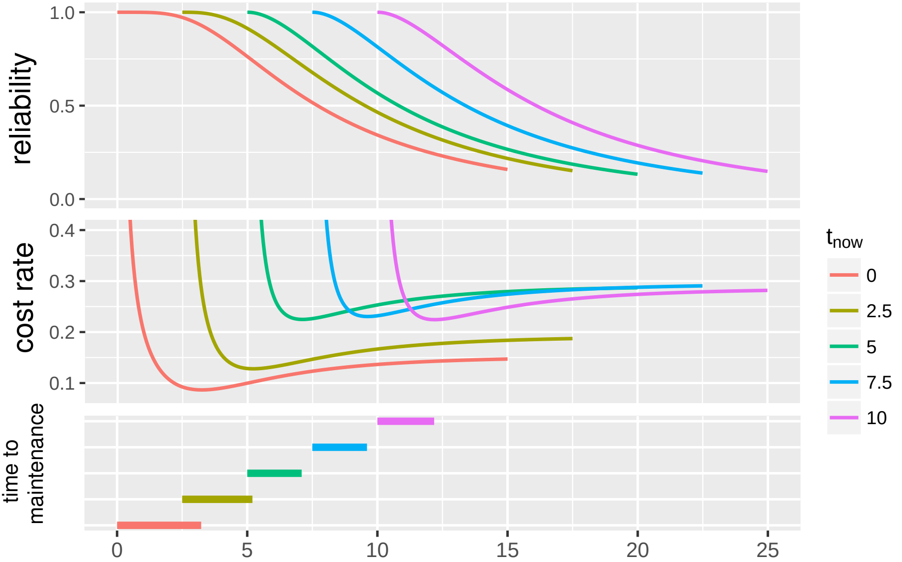
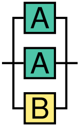


Input & Output

Inputs before start-up:

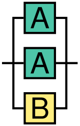
- system reliability block diagram

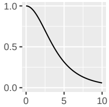


Input & Output

Inputs before start-up:

- system reliability block diagram
- for each component type:
  - Weibull shape parameter & MTTF from expert
  - expert confidence (how sure about MTTF)
  - optional: test data





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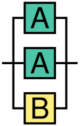

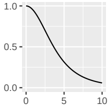

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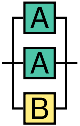

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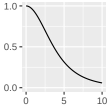

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Input during run-time (preferred automatic):

- which components still work and which not

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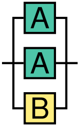

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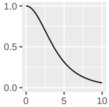

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Input during run-time (preferred automatic):

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Output:

- for any time during run-time:
  cost-optimal moment to repair the system (dynamic & adaptive)

System Reliability using the Survival Signature

$T_{\text{sys}}^{(t_{\text{now}})}$ (random) time of system failure given all info. at time t_{now}

$R_{\text{sys}}^{(t_{\text{now}})}(t)$ corresponding reliability function

$c_k^{(t_{\text{now}})}$ number of type k components functioning at time t_{now}

K number of component types

$$R_{\text{sys}}^{(t_{\text{now}})}(t) = \sum_{l_1=0}^{c_1^{(t_{\text{now}})}} \cdots \sum_{l_K=0}^{c_K^{(t_{\text{now}})}} \underbrace{\Phi^{(t_{\text{now}})}(l_1, \ldots, l_K)} \prod_{k=1}^{K} \underbrace{P(C_t^k = l_k \mid n_k^{(0)}, y_k^{(0)}, \boldsymbol{t}_k^{(t_{\text{now}})})}$$

survival signature
$= P(\text{system functions} \mid \{l_k \text{ k's function}\}^{1:K})$

Probability that l_k of the $c_k^{(t_{\text{now}})}$ k's function

Expected One-cyle Unit Cost Rate

τ decision variable (when to do maintenance?)

$T_{\text{sys}}^{(t_{\text{now}})}$ (random) time of system failure,

with density $f_{\text{sys}}^{(t_{\text{now}})}(t)$ and reliability function $R_{\text{sys}}^{(t_{\text{now}})}(t)$

c_p cost of planned maintenance action

c_u cost of unplanned maintenance action

$$g(\tau \mid T_{\text{sys}}^{(t_{\text{now}})} = t) = \begin{cases} c_p/\tau & \text{if } t \geq \tau \qquad \text{(cost rate if failure after } \tau\text{)} \\ c_u/t & \text{if } t < \tau \qquad \text{(cost rate if failure before } \tau\text{)} \end{cases}$$

$$g^{(t_{\text{now}})}(\tau) = \mathrm{E}[g(\tau \mid T_{\text{sys}}^{(t_{\text{now}})})] = \frac{c_p}{\tau} R_{\text{sys}}^{(t_{\text{now}})}(\tau) + c_u \int_0^\tau \frac{1}{t} f_{\text{sys}}^{(t_{\text{now}})}(t)\,\mathrm{d}t$$

$$\tau_*^{(t_{\text{now}})} := \arg\min g^{(t_{\text{now}})}(\tau)$$