Aalto University
School of Science

Application: Comparison of maintenance policies with help of fault simulations

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Presentation *19*
20.11.2020

MS-E2191 Graduate Seminar on Operations Research
Fall 2020

Maintenance scheduling

- Goal is to schedule preventive maintenance for machine components to minimize costs and ensure reliability
- Components may have e.g. economic dependencies
- Presentation 14: Application of policy iteration
  - Group component maintenance to cut costs
  - Minimize average costs **in the long run**

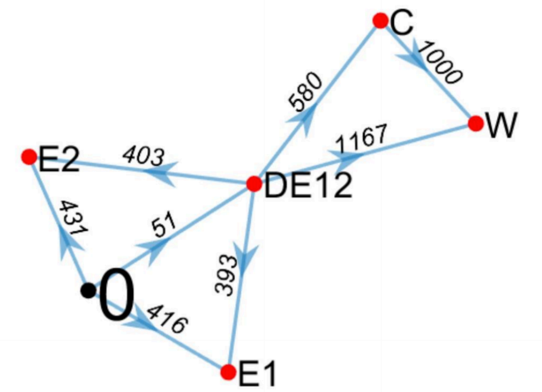


Figure 5.1: Cost structure of the system where the root node is on the left

Leppinen, J. (2020)

Motivation

- Solve same problem with a different approach
  - Perform optimizations and make decisions based on the current state and events
  - Minimize costs both on long-term and short-term
    $\Rightarrow$ Rolling horizon approach

- Introduce three fairly simple dynamic maintenance policies
  - 2 policies include maintenance grouping

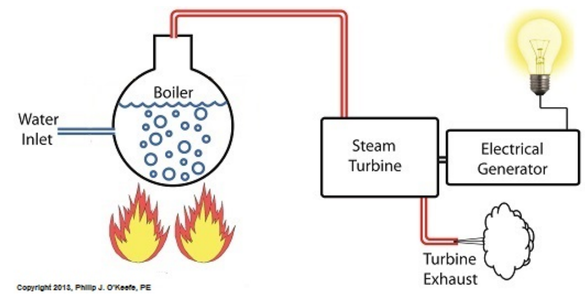
- Do a simulation study to support decision making on maintenance policies

Agenda

- Introduce a multi-component system to maintain
- Introduce maintenance policies
- Results of a Monte Carlo simulation comparison of maintenance policies

The machine

- Consider a machine with N connected, critical components
- Components have different life-times and repair costs
- Broken components and maintenance prevents use of the machine, causing losses in production



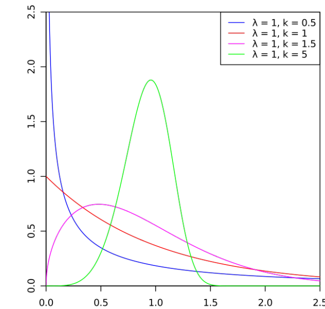
http://www.engineeringexpert.net/Engineering-Expert-Witness-Blog/tag/coal-power-plant-training-seminars

The model

- Two types activities for each component i: preventive maintenance (PM) and corrective maintenance (CM)
- Cost of preventive maintenance $C_i^P = c_i^P + C_{sys}^P d_i$
- Cost of corrective maintenance $C_i^C = c_i^C + C_{sys}^C d_i$
    - Replacement cost c_i
    - Cost of missed production: coefficient C_{sys} ($/time), duration of activity d_i
- Set-up cost S for starting maintenance on any number of components

The model

- Probability of component breaking down taken from Weibull distribution



https://en.wikipedia.org/wiki/Weibull_distribution

- Minimize expected cost over infinite horizon to determine optimal preventive maintenance interval for each component

$$x_i^* = \lambda_i \sqrt[\beta_i]{\frac{C_i^p + S}{C_i^C(\beta_i - 1)}}$$

⇒Schedule preventive maintenances for each component with interval x_i^*

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Grouping costs and savings

- Scheduled activities in planning horizon can be grouped together
- Savings of group G^k, when $|G^k|$ is the group size

$$U_{G^k} = (|G^k| - 1)S$$

- Penalty function $\Delta H_{G^k}{}^*$ for shifting activities based on increased costs caused by deferring from optimal schedule

⇒ Optimize groupings by maximizing savings while also considering penalties

Three policies

1. Minimal repair policy (MRP)
   - no grouping
   - maintain components according to their individual schedule or when they break
2. Adaptive grouping policy (GPa)
   - group maintenances
   - upon component failures, fix broken component immediately
3. Opportunistic grouping policy (OGP)
   - group maintenances
   - upon component failures, grouping structure is optimized again

     $\Rightarrow$ allow grouping corrective and preventive maintenances together

Simulations

- Tested the three policies for 1 year in simulation time in a Monte Carlo simulation of a machine with 6 components

- 1000 simulations for each policy for each setup cost in $S \in \{0,50,100,150,...,600\}$

- Calculate average cost of maintenance and availability for each set-up cost - policy combination

Results

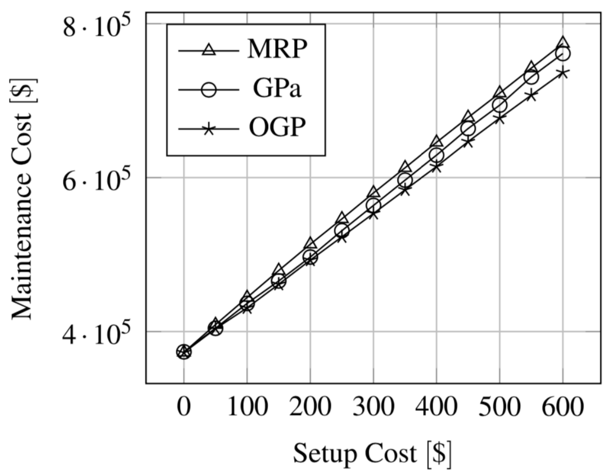

FIGURE 7. The average cost of maintenance with different policies with respect to different set-up costs.

Urbani et al. (2020)

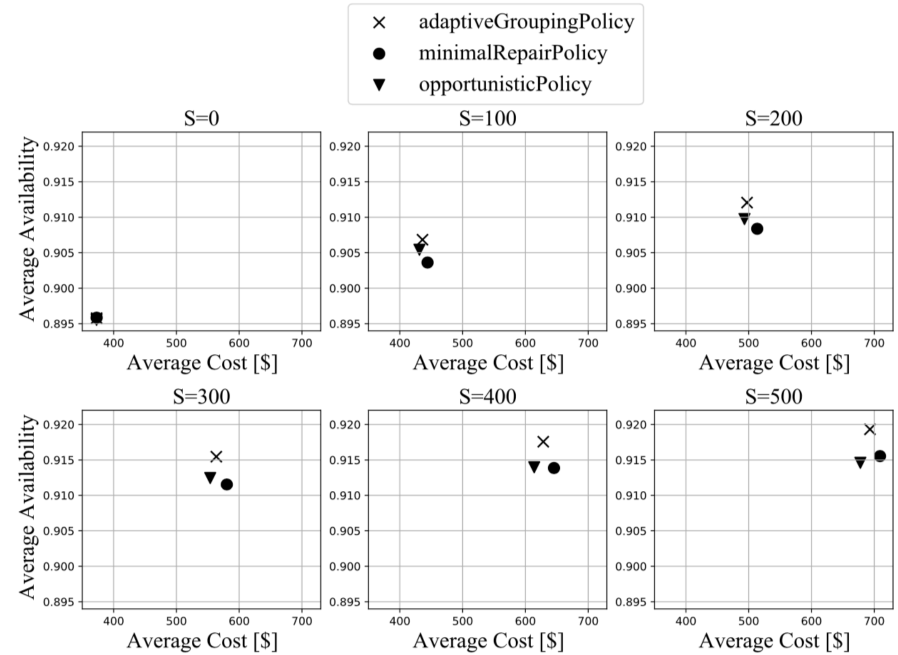

FIGURE 9. Bi-objective (cost vs. availability) comparison of policies for different setup costs ($N = 6$). Costs are expressed in 1,000 units.

Urbani et al. (2020)

Conclusions

- An opportunistic model minimizes costs, but can lead to excessive preventive maintenances on long term causing lower availability
- Simulation study showed that out of these policies, no best policy could not be chosen without trade-offs
- All in all, simulations provided a good tool for comparison of maintenance policies

References

Leppinen, J.,2020, “A Dynamic Optimization Model for Maintenance Scheduling of a Multi-Component System”, Master’s thesis, Aalto University.

Urbani, J. et al., 2020, ”A Comparison of Maintenance Policies for Multi-Component Systems Through Discrete Event Simulation of Faults," *IEEE Access*, vol. 8, pp. 143654-143664.

Homework

Recap slide 8 and read subsections **B. Decomposition and D. Grouping maintenance activities** from section **II. Model** of the Urbani paper**.**

Briefly explain what economic profit of a grouping $EP(G^k)$ is comprised of and what is the intuition behind the two parts of the penalty function for shifting maintenance times.

Submissions to tuuli.aaltonen@aalto.fi by 27.11. 09.00.

Grouping costs and savings

- Scheduled activities in planning horizon can be grouped together
- Savings of group G^k, when $|G^k|$ is the group size

$$U_{G^k} = (|G^k| - 1)S$$

- Penalty function for shifting activities composed of two parts (when Δt_i = shift of maintenance time):
    1. increase in expected cost of the maintenance cycle
       $E[x_i^* + \Delta t_i] - E[x_i^*]$
    2. cost of interference to future activities $\Delta t_i \phi^*$
- Optimize groupings by maximizing savings while also considering penalties

Simulation for OGP