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Energy-SmartOps Integrated Control and Operation of Process, Rotating Machinery and Electrical Equipment

Optimization based maintenance planning

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Introduction

- Energy saving is a growing concern for industry and society.
- The connection between maintenance and energy savings has been widely shown.
- Optimization of maintenance planning in process and manufacturing industry represents a great opportunity for energy saving.

Business motivation

WHAT

- Increase plant revenue by optimizing system maintenance plan
- “Turn a threat into an opportunity”

HOW

- Optimally combine several maintenance activities during a single plant stop or a partial shutdown
- Exploit plant layout flexibility and benefit from asset dependencies
- Explicitly account for real time asset health condition information

System overview

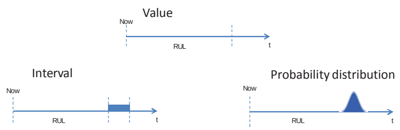
MAINTENANCE DEPENDENCIES

- Economic dependence
- Structural dependence
- Stochastic dependence

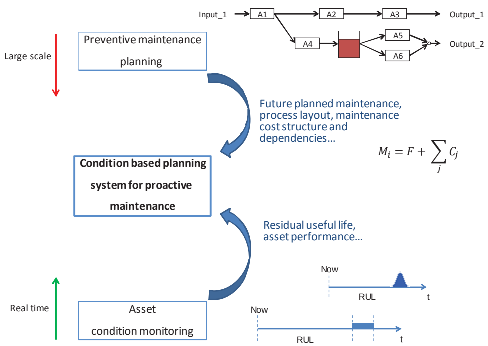
Plant topology can also be exploited to reduce system downtime

ASSET HEALTH INFORMATION

Residual Useful Life (RUL) of an asset can be provided as:



MAINTENANCE SYSTEM OVERVIEW



Modeling

A MILP DETERMINISTIC MODEL

$$x_{it} = \begin{cases} 1 & \text{if component } i \text{ maintained at time } t \\ 0 & \text{else} \end{cases} \qquad i \in N, t \in T$$

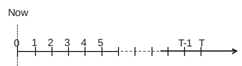
$$y_t = \begin{cases} 1 & \text{if any component is maintained at time } t \\ 0 & \text{else} \end{cases} \qquad t \in T$$

C = maintenance setup cost

c_i = maintenance cost of component i

r_i = maximum life of component i

r_i^0 = residual life of component i at time slot 0, $r_i^0 > 0$



$$\min_{(x,y)} \sum_{t \in T} \left(\sum_{i \in N} c_i x_{it} + C y_t \right)$$

$$\text{s.t.} \quad \sum_{t=1}^{r_i^0} x_{it} \geq 1, \quad \forall i \in N$$

$$\sum_{t=k+1}^{k+r_i} x_{it} \geq 1, \quad \forall i \in N, k = 0, \ldots, T\text{-}r_i$$

$$x_{it} \leq y_t, \quad \forall i \in N, \forall t \in T$$

$$x_{it}, y_t \in \{0,1\}$$

FROM DETERMINISTIC TO STOCHASTIC

$$x_{it}{}^{\omega} = \begin{cases} 1 & \text{if component } i \text{ maintained at time } t \\ 0 & \text{else} \end{cases} \qquad i \in N, t \in T, \omega \in \Omega$$

$$x_{st}{}^{\omega} = \begin{cases} 1 & \text{if "special" component maintained at time } t \\ 0 & \text{else} \end{cases} \qquad t \in T, \omega \in \Omega$$

$$y_t{}^{\omega} = \begin{cases} 1 & \text{if any component is maintained at time } t \\ 0 & \text{else} \end{cases} \qquad t \in T, \omega \in \Omega$$

$$\tilde{x}_{st}{}^{\omega} = \begin{cases} 1 & \text{if "special" component is maintained} \\ & \text{for the first time at } t \\ 0 & \text{else} \end{cases} \qquad t \in T, \omega \in \Omega$$

r_i = lifetime of component i

r_s = lifetime life of component s

$\tilde{r}_s^{\omega}$ = first lifetime of component s, $\forall \omega \in \Omega$

$$\min \sum_{\omega \in \Omega} p(\omega) \left[\sum_{t \in T} \left(\sum_{i \in N} c_i x_{it}{}^{\omega} + c_s x_{st}{}^{\omega} + C y_t{}^{\omega} \right) + \sum_{t=0}^{\tilde{r}_s^{\omega}} c_s \tilde{x}_{st}^{\omega} \right]$$

$$\text{s.t.} \quad \sum_{t=l}^{r_i+l-1} x_{it}^{\omega} \geq 1, \quad l = 0, \ldots, T - r_i, \forall i \in N, \omega \in \Omega$$

$$x_{it}^{\omega} \leq y_t^{\omega}, \quad \forall t \in T, \forall i \in N, \omega \in \Omega$$

$$\sum_{t=l}^{r_s+l-1} x_{st}^{\omega} + \sum_{t=l}^{\tilde{r}_s^{\omega}} \tilde{x}_{st}^{\omega} \geq 1 \quad l = 0, \ldots, \tilde{r}_s^{\omega}, \omega \in \Omega$$

$$\sum_{t=l}^{r_s+l-1} x_{st}^{\omega} \geq 1 \quad l = \tilde{r}_s^{\omega} + 1, \ldots, T - \tilde{r}_s, \omega \in \Omega$$

$$x_{st}^{\omega} \leq \sum_{k=0}^{t-1} \tilde{x}_{sk}^{\omega} \quad t = 1, \ldots, \tilde{r}_s, \omega \in \Omega$$

$$\tilde{x}_{st}^{\omega} \leq y_t, \quad t = 1, \ldots, \tilde{r}_s^{\omega}, \omega \in \Omega$$

$$x_{st}^{\omega} \leq y_t, \quad \forall t \in T, \omega \in \Omega$$

Conclusion

- The use of MILP optimization techniques for maintenance planning is still limited in applications.
- Models have to be extended to account for asset dependencies and the uncertainty of the degradation/breakage process.
- A decomposition approach is foreseen to keep the problem tractable and in order to be able to address real-size problem from applications.

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