0.1 Study 2: seasonal effects

Part A. To address the seasonal effects of the mobilization costs d_t, the following mobilization costs (in thousands of USD) for different months in a year are used:

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
15	13	11	9	7	5	5	7	9	11	13	15

The mobilization costs for different months are different, but for the same month at different years are the same. The average mobilization cost is $\bar{d} = 10$. These numbers are obtained based on a discussion with the experts within the Swedish Wind Power Technology Centre (SWPTC). Table 1 summarises the results produced by the NextPM algorithm applied to the following three settings:

the winter start scenario (i.e. the wind turbine start function at Jan) with

$$d_1 = 7.5, d_2 = 6.5, \ldots, d_{12} = 7.5, d_{13} = 7.5, d_{14} = 6.5, \ldots,$$

the summer start scenario (i.e. the wind turbine start function at Jul) with

$$d_1 = 2.5, d_2 = 3.5, \ldots, d_{12} = 2.5, d_{13} = 2.5, d_{14} = 3.5, \ldots,$$

the constant mobilization cost scenario with $d_1 = 5, d_2 = 5, d_3 = 5, \ldots$

Component j	1	2	3	4	Corresponding month	Monthly maintenance cost
Winter start	54	54	54	54	Jun	5.010
Summer start	49	49	49	49	Jul	4.979
Constant mobilization cost	52	52	52	52	–	5.061

Table 1. Summary of the NextPM results for $\bar{d} = 10$.

They suggest (as a consequence of high mobilization costs) to perform PM to all four components at a certain time, irrespective of the scenario. With the summer start setting, the average monthly maintenance cost is somewhat lower. Notice that in all of the seasonal settings, the proposed PM activities are scheduled for summer months (having lower mobilization costs).

Part B. In this section, the mobilization costs are halved to contrast the results of Part A, so that $\bar{d} = 5$ and d_t take the following values depending on which month of the year lies behind the time parameter t:

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
7.5	6.5	5.5	4.5	3.5	2.5	2.5	3.5	4.5	5.5	6.5	7.5

The new results presented in Table 2 are drastically different from the results of Part A.

Component j	1	2	3	4	Corresponding month	Monthly maintenance cost
Winter start	x	x	43	x	Jul	4.876
Summer start	48	x	48	x	Jul	4.863
Constant mobilization cost	50	50	50	50	–	4.964

Table 2. Summary of the NextPM results for $\bar{d} = 5$.

According to Table 2, in the Winter start setting, the optimal next PM plan suggests a PM activity on month 43 only for the component 3, the gearbox. With the seasonal mobilization cost, the next PM is always planned during the summer since the mobilization cost is low then. Again, the most economic among the three scenarios is to start in the summer time, with the optimal plan being to perform the next PM activity on month 48 by replacing the components 1 and 3.

Part C. A simple wind turbine maintenance strategy is to ignore the PM option and perform a CM activity whenever a turbine component breaks down. This leads to the question: how much can one save by introducing PM planning? The total cost associated with the pure CM strategy is estimated based on the random number of failures over the time interval $[0,T]$ for all n components

$$F(T) = \sum_{j=1}^{n} \mathrm{E}\left(\sum_{i=1}^{\infty} 1_{\{V_i^j \le T\}}(d_{V_i^j} + b_j)\right) = \sum_{j=1}^{n} \int_0^T (d_u + b_j) dH_j(u), \tag{1}$$

where H_j are the corresponding renewal functions

$$H_j(t) = \mathrm{E}\left(\sum_{i=1}^{\infty} 1_{\{V_i^j \le t\}}\right), \quad t > 0,\ j = 1, \dots, n. \tag{2}$$

According to the standard renewal theory, see for example Grimmett et al. (2020), for the large values of T,

$$\frac{F(T)}{T} \approx \sum_{j=1}^{n} \frac{1}{T\mu_j} \int_0^T (d_u + b_j) du = \sum_{j=1}^{n} \frac{\bar{d} + b_j}{\mu_j}, \tag{3}$$

where $\bar{d} = \frac{d_1 + \ldots + d_T}{T}$. Applying this approximation to the four-component model of the wind turbine, the monthly maintenance costs for the pure CM strategy are computed to be 7.396 for $\bar{d} = 5$, and 7.618 for $\bar{d} = 10$. Comparison of the costs produced by the NextPM algoritms in Parts A Table 2 and part B Table 1, shows that implementation of the PM planning results in 35% cost saving.

References

Grimmett, G. S. et al.: Probability and random processes, Oxford university press, 2020.