Market-driven Systems (FRTN20)

Exercise 8

Solutions

Define site structure and use of utilities

1. From the flowchart of the product flow we get

$$A_d = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 1 \end{bmatrix}$$

2. The area-utility matrix becomes

$$A_u = \begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 1 \\ 0 & 0 & 1 \end{bmatrix}$$

when utilities are ordered: steam, cooling water, electricity.

3. A utility dependence flowchart for the concerned utilities is shown in Figure 1.

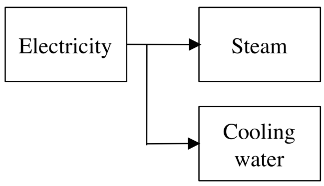

Figure 1 Utility dependence flowchart.

The utility dependence matrix becomes

$$U_d = \begin{bmatrix} 1 & 0 & 1 \\ 0 & 1 & 1 \\ 0 & 0 & 1 \end{bmatrix}$$

with the same ordering of utilities as before.

4. The utility operation matrix is obtained by comparing the measurements to the disturbance limits. We get

$$U = \begin{bmatrix} 1 & 0 & 1 & 1 & 0 & 0 & 0 & 1 \\ 1 & 1 & 0 & 1 & 0 & 0 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 \end{bmatrix}$$

with the same ordering of utilities as before.

5. With U from problem 4 and U_d from problem 3, we get

$$U_{ud} = \text{sign}\left(U + \text{sign}\left((I - U_d)(U - \mathbf{1}\mathbf{1}^T)\right)\right) =$$
$$= \text{sign}\left(U + \text{sign}\left(\begin{bmatrix} 0 & 0 & -1 \\ 0 & 0 & -1 \\ 0 & 0 & 0 \end{bmatrix}\begin{bmatrix} 0 & -1 & 0 & 0 & -1 & -1 & -1 & 0 \\ 0 & 0 & -1 & 0 & -1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 \end{bmatrix}\right)\right) =$$
$$= \text{sign}\left(\begin{bmatrix} 1 & 0 & 1 & 1 & 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 & 0 & 0 & 2 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 \end{bmatrix}\right) = \begin{bmatrix} 1 & 0 & 1 & 1 & 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 & 0 & 0 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 \end{bmatrix}$$

The matrix can also be obtained directly by switching the zeros of U to ones in the first two rows (i.e. for steam and cooling water) at samples where electricity did not operate (i.e. when there is a zero in the third row).

Calculate key performance indicators

6. The utility availabilities are given by $U_{av} = U \cdot \mathbf{1}/n_s$

a.

$$U_{av} = U \cdot \mathbf{1}/n_s = [4 \quad 5 \quad 7]^T/8 = [0.5 \quad 0.625 \quad 0.875]^T$$

b.

$$U_{av}^{ud} = U_{ud} \cdot \mathbf{1}/n_s = [5 \quad 5 \quad 7]^T/8 = [0.625 \quad 0.625 \quad 0.875]^T$$

The availabilities of utilities that are dependent on other utilities could increase when removing utility dependence. In this case, the availability of steam increases whereas the availability of cooling water remains unchanged.

7. The total area availabilities are the availabilities when both utility disturbances and connections of production areas are considered. These are given by

$$A_{av}^{tot} = A_{tot} \cdot \mathbf{1}/n_s$$
$$A_{tot} = \mathbf{1}\mathbf{1}^T + \text{sign}\left(A_d(A_{dir} - \mathbf{1}\mathbf{1}^T)\right)$$

for the four production areas. We get

$$A_{av}^{tot} = A_{tot} \cdot \mathbf{1}/n_s = [4 \quad 3 \quad 3 \quad 3]^T/8 = [0.5 \quad 0.375 \quad 0.375 \quad 0.375]^T$$

Consequently, area 2, 3, and 4 have the lowest total area availabilities.

Estimate losses using on/off production modeling

8. An estimate of the total revenue loss of each product is given by

$$J_p^{tot} = \left(\mathbf{1} - A_{av}^{tot}\right) .* q^m .* p n_s t_s$$

We get

$$J_p^{tot} = [0.5 \quad 0.625 \quad 0.625 \quad 0.625]^T .* [3 \quad 2 \quad 0 \quad 2]^T \frac{\mathrm{m}^3}{\mathrm{h}} .* \\ .* [2 \quad 3 \quad 6 \quad 6]^T \frac{\mathrm{kr}}{\mathrm{m}^3} \cdot 8 \cdot \frac{1}{6}\mathrm{h} = [4 \quad 5 \quad 0 \quad 10]^T \, \mathrm{kr}$$

Consequently, product 4 seems to stand for the greatest total revenue loss at the site, when both utility disturbances and the connections of production areas are considered.

9. An estimate of the total revenue loss due to each utility at the site is given by

$$J_u^{tot} = \mathrm{diag}\left[\mathbf{1} - U_{av}^{ud}\right] \cdot \mathrm{sign}\left(A_d A_u\right)^T \left(q^m .* p\right) n_s t_s$$

We get

$$J_u^{tot} = \mathrm{diag}\left[\mathbf{1} - U_{av}^{ud}\right] \mathrm{sign}\left(\begin{bmatrix} 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 1 \end{bmatrix} \begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 1 \\ 0 & 0 & 1 \end{bmatrix}\right)^T \left(q^m .* p\right) n_s t_s =$$

$$= \mathrm{diag}\left[\mathbf{1} - U_{av}^{ud}\right] \mathrm{sign} \begin{bmatrix} 0 & 1 & 1 & 1 \\ 1 & 1 & 2 & 2 \\ 1 & 2 & 2 & 3 \end{bmatrix} \left(q^m .* p\right) n_s t_s =$$

$$= \begin{bmatrix} 0.375 & 0 & 0 \\ 0 & 0.375 & 0 \\ 0 & 0 & 0.125 \end{bmatrix} \begin{bmatrix} 0 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} 3 \cdot 2 \\ 2 \cdot 3 \\ 0 \cdot 6 \\ 2 \cdot 6 \end{bmatrix} \frac{\mathrm{m}^3}{\mathrm{h}} \cdot \frac{\mathrm{kr}}{\mathrm{m}^3} \cdot 8 \cdot \frac{1}{6}\mathrm{h} =$$

$$= [9 \quad 12 \quad 4]^T \, \mathrm{kr}$$

Consequently, the cooling water utility seems to cause the greatest losses at the site. The recommendation for next year's maintenance schedule is to focus maintenance efforts on this utility.

Define model and constraints for continuous production modeling

10. The mass balance equations are given by

$$\begin{aligned} V_1(t+1) &= V_1(t) + q_1(t) - q_1^m(t) - q_2(t)y_{12} - q_3(t)y_{13} \\ V_2(t+1) &= V_2(t) + q_3(t) - q_3^m(t) - q_4(t)y_{34} \end{aligned}$$

11. The buffer tanks are of limited volume, i.e. the level must be kept between maximum and minimum limits at all times:

$$\begin{aligned} V_1^{\min} &\le V_1(t) \le V_1^{\max} \\ V_2^{\min} &\le V_2(t) \le V_2^{\max} \end{aligned}$$

In addition, the production areas have limited production capacity, i.e.

$$q_i^{\min} \le q_i(t) \le q_i^{\max}, \quad i = 1, 2, 3, 4$$

12. The continuous utilities give the constraints

$$\begin{aligned} \frac{1}{c_{12}} q_2(t) + \frac{1}{c_{13}} q_3(t) \le U_1(t) \\ \frac{1}{c_{21}} q_1(t) + \frac{1}{c_{23}} q_3(t) \le U_2(t) \end{aligned}$$

where steam is utility 1 and cooling water utility 2.
Electricity (utility 3) gives the constraint

$$q_j(t) \le \begin{cases} q_j^{\max} & \text{if } U_3(t) = 1 \qquad j = 1, 2, 3, 4 \\ 0 & \text{if } U_3(t) = 0, \end{cases}$$