1. Continuous: Often fluid-based, continuous product outflow, the equipment operates in steady state, often fluids, often invisible.

Discrete: Assembly-oriented, discrete units = pieces and parts, the equipment operates in an on-off manner, often visible.

Batch: Production in batches, production run determined by time, the production goes through stages of operation, both fluid and dry processing.

2.

a. See figure 1.

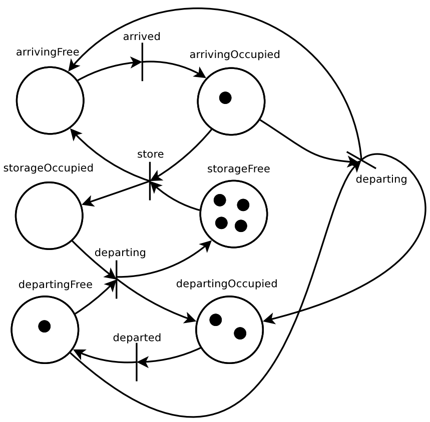

Figure 1

b. Bounded: Yes, the number of tokens in each place is limited.

Live: Yes, from any valid state there exists a sequence of firings which include firing all transitions.

Dead-lock free: Yes, since it is live it is also dead-lock free.

3. The bugs are that the transition conditions are not mutually exclusive. One bug is triggered by a button being released at the exact same time as the down position is reached, the other by the up position being reached at the exact same time as both buttons are pressed.

The undesired behavior occurs when the down position is reached, the application will jump between movingUp and movingDown until one of the buttons is released. This is not desirable since this will cause unnecessary wear of the splitter.

For a corrected Grafchart application, see figure 2.

4. The General Recipe describes how the product is produced. The Site Recipe adds site local information to a General Recipe, e.g. language and details about local materials. The Master Recipe adds equipment specific information to a Site Recipe, e.g. what kind of equipment is used and how it is coordinated. The Control Recipe adds information about the conditions of the specific batch to the Master Recipe, e.g. production time, set points, logged control data.

- One General Recipe per product - Equipment independent
- One Site Recipe per site and product - Equipment independent

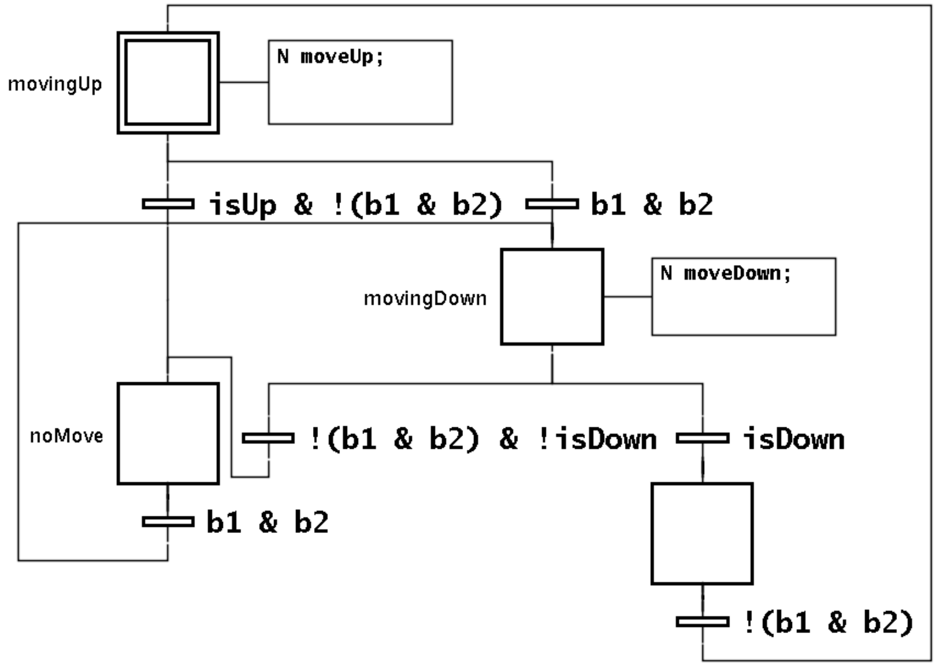

Figure 2

- One Master Recipe per process cell and product - Equipment dependent
- One Control Recipe per batch - Equipment dependent

5. No solution

6.

a. Denote the number of rolls of with 0.75m and 1.5m by x_1 and x_2 respectively. The matrices for this problem are then

$$A = \begin{pmatrix} 0.75 & 1.5 \\ 1 & 1 \end{pmatrix}$$
$$b = \begin{pmatrix} 9 \\ 8 \end{pmatrix}$$
$$c = \begin{pmatrix} p_1 - 0.75(c_u - c_w) - c_h \\ p_2 - 1.5(c_u - c_w) - c_h \end{pmatrix}$$

b. The optimal value is always in one of the corners of the feasible area (see figure 3), i.e. $v_0 = \begin{pmatrix} 0 \\ 0 \end{pmatrix}, v_1 = \begin{pmatrix} 0 \\ 6 \end{pmatrix}, v_2 = \begin{pmatrix} 8 \\ 0 \end{pmatrix}, v_3 = \begin{pmatrix} 0.75 & 1.5 \\ 1 & 1 \end{pmatrix}^{-1} \begin{pmatrix} 9 \\ 8 \end{pmatrix} = \begin{pmatrix} 4 \\ 4 \end{pmatrix}$.

These costs give

$$c = \begin{pmatrix} 3 \\ 5.5 \end{pmatrix}$$

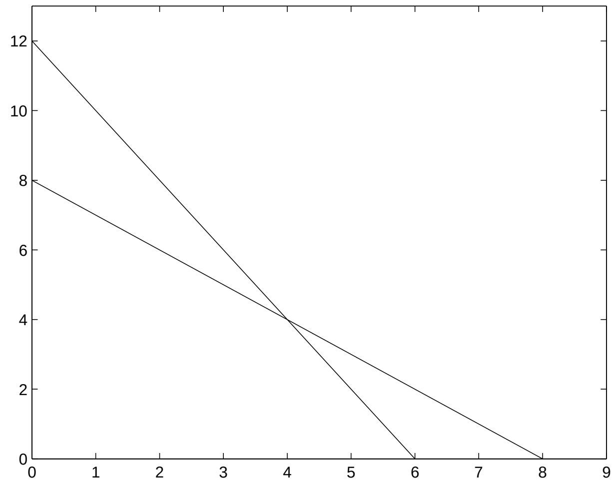

Figure 3 Feasible area.

which give the values $v_0 : 0, v_1 : 33, v_2 : 24, v_3 : 34$, meaning that v_3 is optimal.

7.

a. The utility operation matrix is

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

Considering first the utility operation matrix before removing utility dependence (U), the utility availability becomes:

$$U_{av} = U \cdot \mathbf{1}/n_s = \begin{pmatrix} 4 & 4 & 4 \end{pmatrix}^T /6 = \begin{pmatrix} 4/6 & 4/6 & 4/6 \end{pmatrix}^T$$

In case one considers the utility operation matrix when utility dependence is removed (U_{ud}), the utility availability becomes:

$$U_{av}^{ud} = U_{ud} \cdot \mathbf{1}/n_s = \begin{pmatrix} 4 & 4 & 6 \end{pmatrix}^T /6 = \begin{pmatrix} 4/6 & 4/6 & 1 \end{pmatrix}^T$$

where U_{ud} can be obtained directly by switching the zeros of U to ones of the second and third rows (for instrument air and vacuum system) at samples where electricity did not operate, the same applies for the third row where the zeros are changed to ones at the samples where instrument air did not operate in the right range.

$$U_{ud} = \begin{pmatrix} 1 & 0 & 1 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 \end{pmatrix}$$

When comparing U_{av} and U_{av}^{ud}, one can see that the availabilities of utilities that are dependent on other utilities can increase when the utility dependence is removed. Thus, the availability of the vacuum system increases, while the availability of the instrument air remains the same.

b. The area dependence matrix is

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

The area-utility matrix is

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

The total revenue loss due to each utility can be calculated using:

$$\begin{aligned} J_u^{tot} &= \text{diag}(\mathbf{1} - U_{av}^{ud}) \cdot \text{sign}(A_d A_u)^T (q^m \cdot * p) n_s t_s \\ &= \text{diag}\begin{pmatrix} 2/6 \\ 2/6 \\ 0 \end{pmatrix} \text{sign}\begin{pmatrix} 1 & 1 & 3 & 2 \\ 1 & 0 & 2 & 0 \\ 1 & 1 & 2 & 1 \end{pmatrix} (q^m \cdot * p) n_s t_s \\ &= \begin{pmatrix} 2/6 & 0 & 0 \\ 0 & 2/6 & 0 \\ 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 \\ 1 & 1 & 1 & 1 \end{pmatrix} \begin{pmatrix} 2 \cdot 3 \\ 0 \cdot 1 \\ 4 \cdot 6 \\ 5 \cdot 2 \end{pmatrix} \frac{\text{m}^3}{\text{h}} \cdot \frac{\text{kr}}{\text{m}^3} \cdot 6 \cdot \frac{1}{5}\text{h} \\ &= \begin{pmatrix} 16 & 12 & 0 \end{pmatrix}^T \text{kr} \end{aligned}$$

The utility that causes the greatest losses at the site is electricity.

8.

a. The dual solution, λ^*, tells you the *cost* of violating each constraint. For example it can be interpreted as marginal price for resources.

b. Yes, for a maximization problem the value of the dual problem is required be higher than that of the primal problem.

No, they cannot be the optimal values since strong duality always holds for an LP meaning that $p^* = d^*$.

c. $g(\lambda) = \max_x (c^T x + \lambda^T (b - Ax)) =$

$$\max_x \left(\begin{pmatrix} 3 & 1 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} \lambda_1 & \lambda_2 & \lambda_3 \end{pmatrix} \begin{pmatrix} 3 - 2x_1 - x_2 \\ 1 - x_2 \\ \frac{5}{4} - x_1 \end{pmatrix} \right) =$$

$$\max_x \left(3x_1 + x_2 + \lambda_1(3 - 2x_1 - x_2) + \lambda_2(1 - x_2) + \lambda_3(\tfrac{5}{4} - x_1)\right)$$

9.

a. From the game one can see that the unique pure-strategy equilibrium is (D,R) which has a payoff of (3,3). In case Player 1 would like to change his game from D to U, his payoff will remain the same, that is, “3”. In case Player 2 would like to change his game from R to L, his payoff will reduce to “2”. This fulfils the condition for a pure Nash equilibrium, where the players do not have any incentive (a better payoff) to change their games.

b. Game of Player 1

Player 1	U	-2q + 3
	D	q + 3

Player 1 will play the pure strategy $p = 0$ against any $q \in (0, 1]$ and he is willing to mix against $q = 0$. Player 1 best response can be seen in Figure 4 and corresponds to $B_{Player1}(q)$.

Game of Player 2

Player 2	
L	R
2 - p/2	3 - 2p

Player 2 will play the pure strategy $q = 0$ against any $p \in [0, 2/3)$, will play the pure strategy $q = 1$ against any $p \in (2/3, 1]$, and will be free to mix for $p = 2/3$. Player 2 best response can be seen in Figure 4 and corresponds to $B_{Player2}(p)$.

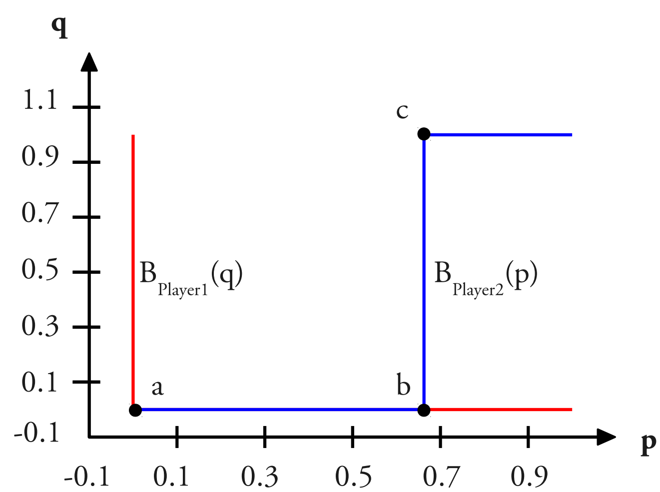

Figure 4 Player 1 and 2 best-responses, and equilibrium payoffs.

The Nash equilibria are given by the intersection between the blue and the red line in Figure 4, i.e. the line segment $q = 0$, $p \in [0, 2/3]$.

c. Player 1 is indifferent to mixing between U and D, given that Player 2 is playing R. However, this mixing hurts Player 2. When using the strategy defined by "a", both players get a payoff of 3. In case Player 1 chooses the strategy defined by "b" (mixes between U and D), his payoff will be the same, but the payoff of Player 2 declines to 5/3.

d. If Player 1 chooses U he will receive 1 (since Player 2 will choose L). If Player 1 chooses D he will instead receive 3, and hence he prefers this. Player 2's response will then be R. The outcome will thus be (3,3).