LUNDS TEKNISKA
HÖGSKOLA
Lunds universitet

Institutionen för
REGLERTEKNIK

Market-driven System

Exam, May 27 2011 at 14–19

Points and grades

All answers must include a clear motivation. The total number of points is 25. The maximum number of points is specified for each subproblem. Preliminary grades:

Betyg 3: 12 – 16.5 points
4: 17 – 21.5 points
5: 22 – 25 points

Accepted Aid

Accepted aids are: Standard mathematical tables and authorized “Formelsamling i reglerteknik”, as well as pocket calculator.

Results

The result will be available Tuesday June 7 2011. The results will be shown on the notice-board at the Department of Automatic Control, 1st floor M-building.

1. Industrial production processes can be classified as being; continuous, discrete and batch. In breif, continuous processes have a continuous outflow, discrete processes have a discrete output, and the output of a batch process is refered to as a batch or lot. Present and explain two additional characteristics of each production type (3 p)

Solution

Continuous production processes:

- Continuous flow of material (often fluid-based)
- Open-ended production runs
- The process is most often ”invisible”
- Disassembly-oriented production is not unusual.
- The equipment operates in steady-state

Discrete production processes:

- The product is a discrete entity.
- Assembly-oriented production.
- Staged production through work cells
- Well-defined production runs.
- The process is most often ”visible”.
- The equipment operates in on-off manner.

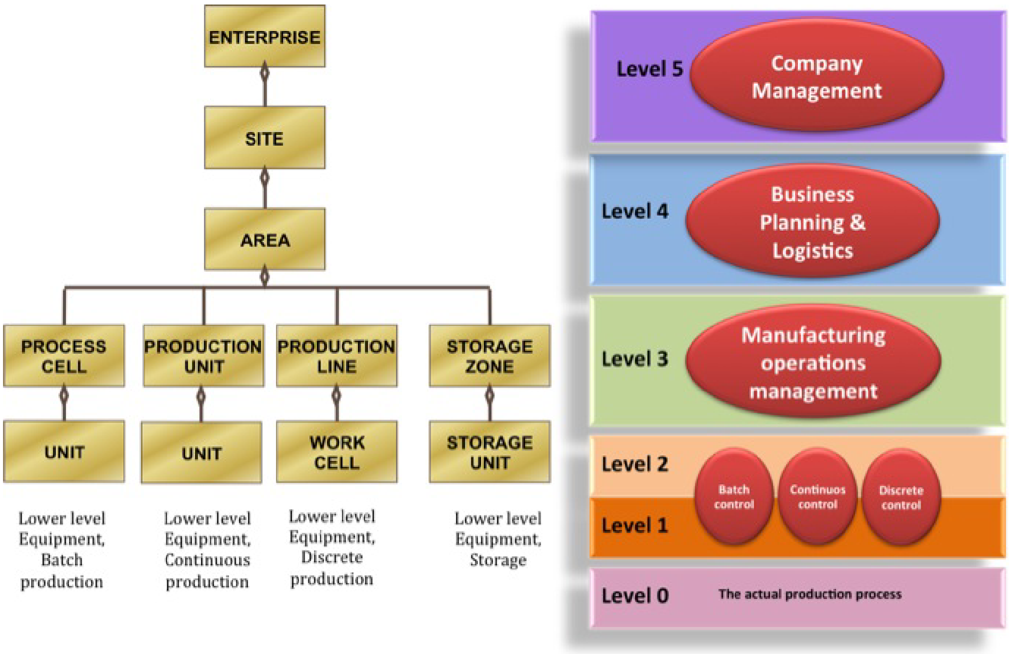
Batch production processes:

- Production of products in batches
- Discontinuous flow of materials.
- Production run determined by time/end point.
- Production goes through steps of operations.
- Fluid and dry processing.

2. In order to help select software products and information systems in a company, a framework is needed. The framework can be used to structure the company and, among other things, locate where various functions should reside. A framework used for this purpose is the Purdue Enterprise Reference Architecture (PERA). PERA gives a structure to the physical hierarchies in a company, see figur 1 (left), the organizational hierarchies (not shown here) and the functional hierarchies, see figur 1 (right).

a. Describe the five functional levels. The description should contain explainations of at least two typical functionalities at each level. (2,5 p)

b. This problem is ONLY for the members of the project-group ”Rockwell”.
In this project a laboratory session was set up using hardware and software from Rockwell Automation (Allan Bradley). The task was to control a servo motor and/or a DC-motor. The software modules used in the project were; RSLinx Classic, RSLogix5000 and Factory Talk View Studio ME. Where in the functional hierarchy would you place thses software modules? Do not forget to motivate your answer. (1 p)



Figur 1 The physical hierarchy (left) and functional hierarchy (right) of the PERA model.

Solution

a.
- Level 5 = Business. What types of products should be produced? Where should they be produced? Are tehy profitable?
- Level 4 = ERP. takes care about inventories, customer relations, shipping and billing, customer orders, etc.
- Level 3 = MES. Takes care about production, maintenance, inventory and quality operations
- Level 2-1 = Process control. Actuators and sensors
- Level 0 = actual production process

b. (This problem is ONLY for the Rockwell project group)
The three modules reside within level 1-2.

- RSLogix 500 = logic based programming environment for programming the control of the production process.
- RSLinx Classic = module used to connect and managem the connections to the hardware (equipments).
- Factory Talk View Studio ME = used to create a GUI for operators.

3.

a. Simplify the expression below as far as possible using Boolean algebra,

$$\overline{AB}(\overline{A}+B)(\overline{A}+A)$$

(1 p)

b. Prove your solution of **a** using a truth table. (1 p)

Solution

a.

$$
\begin{aligned}
&\overline{AB}(\overline{A}+B)(\overline{A}+A)\\
=&\overline{AB}(\overline{A}+B)\\
=&(\overline{A}+\overline{B})(\overline{A}+B)\\
=&\overline{A}+\overline{B}B\\
=&\overline{A}
\end{aligned}
$$

b.

A	B	Expression	$\overline{A}$
0	0	1	1
0	1	1	1
1	0	0	0
1	1	0	0

4. Two robots in a factory are grinding steel parts for cars. Their work cycles can be described as

1. Pick up steel part from incoming conveyer belt.
2. Grind steel part.
3. Put steel part on outgoing conveyer belt.

Each robot has its own incoming conveyer belt but the outgoing conveyer belt is shared and thus only one robot at the time may put its finished part on it. The outgoing conveyer belt is thus a *shared resource*.

a. Draw a Petri net that solves the problem with the shared resource. You may have to include more states in the work cycle than above to solve the problem. (2 p)

b. This problem is ONLY for the members of the project-group ”Tetra Pak Packaging”
In this project the state-model of ISA88 was compared with the state-model currently used by Tetrapak Packaging. Explain what the state-model is used for and what the main differences between the two models are. (1 p)

Solution

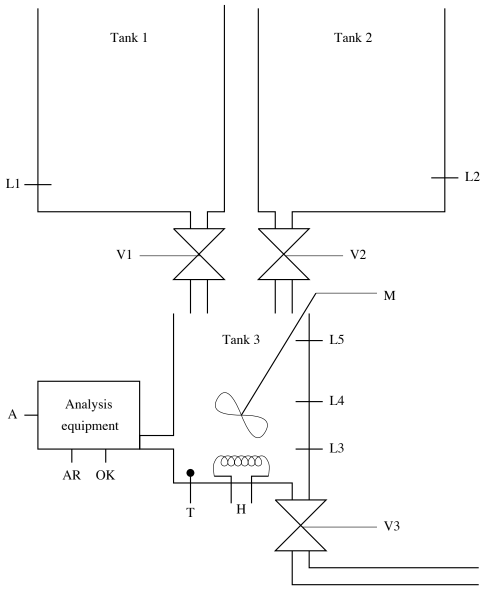
a. This is an example of implementation of mutual exclusion using semaphores in a Petri net. The states of each robot are

1. Pick up steel part from incoming conveyer belt.
2. Grind steel part.
3. Wait on semaphore to be free, i.e., wait for other robot.

4. Put steel part on outgoing conveyer belt. (when having the semaphore)

b. (This problem is ONLY for the Tetra Pak Packaging project group)
State models are used to describe logical states of a machine. Each state can have separate logic taking care of what should happen in this state. The main difference between the ISA88 state model and the state model used by TetraPak is the number of states used. TetraPak has fewer states but instead submits parameters to the states that are used interanlly by the state. Solution for project group TetraPak Packaging.

5. The process XYZ consists of three tanks, see figure 2. Two of the tanks contain raw-materials and one tank takes care of the chemical reaction.



Figur 2 The process XYZ.

The two tanks with the raw materials are each equiped with a levelsensor (L1 and L2) that indicate when a tank has enough raw material for running a batch.

The tank taking care of the chemical reaction has three levelsensors (L3, L4 and L5), a heater (H), a temperaturesensor (T), an agitator (M) and instrumentation for analysis (A, AR and OK). The signal AR indicates that the analysis is done, OK indicates that the product is ready. The analysis, which is very quick, is started with the signal A.

The flows from tank-1 and tank-2 to tank-3 is controlled by the valves V1 and V2. The outflow of tank-3 is controlled by valve V3.

The operator interface is very simple and consists of two buttons (Start and Ack) and one error-indicator (Error).

A batch is started when the operator pushes the button Start. The production is then coordinated by a recipe impleneted by a Grafcet, see figure 3.

a. Explain what is happening during the execution of the batch.
Hint: All signals are boolean except for the temperature T which is real. In the Grafcet there is also a signal S9.T which is a timer that is resumed and started when the state S9 becomes active. (2 p)

b. This is a problem ONLY for the members of the project-group ABB.
In this project the task was to control a double-tank process using the harware and software supplied by ABB. The AC800M Controller Unit was used to implement the program. Explain what advantages/disadvantages you see in using a graphical language compared with a textual langage for implementing this program. (1 p)

Solution

a.
- When the operator has pushed the START button and both tanks contain enough substance then valve V1 is opened, otherwise the operator can push the ack button and the sequence returns to the initial state.
- When Tank3 has reached level L4, valve V1 is closed and the heater (H) and the agitotor (A) are switched on.
- When the temperature has reached 60 degrees the agitator and teh heater are turned off and the valve V2 opens.
- When teh level in Tank 3 has reached L5, the valve V2 is closed and the heater and agitator are turned on again.
- When teh temperature has reached 80 degrees the heater and agitator are turned off and teh analysis A is started.
- When the analysis is ready and the result is ok, valve V3 is opened and the tank is emptied until level L3 when a new batch is started. When the analysis is ready and the result is not-ok, there is a waiting period of 60 time-units until the analysis is done again.

b. (This problem is ONLY for the ABB project group)
The advantages for using a graphical language for implementing this program is that it is very easy to understand (intuitive) and you do not need any programming skills. Disadvantages with a graphical language may be that it takes a lot of place on teh screen. If you know what you want you would probably program faster in a textual langauge

6. Assume that you are working at a smaller production company as overall-responsible for the production (e.g., COO = Chief Operations Officer). The company is producing wooden furnitures. You are aware of how the production of wooden furnitures is done in general, but would like to get feedback from the actual production more often. As it is now, you only get weekly reports telling how successful/unsuccessful the production was during the last week. You have heard about Key Performance Indicators (KPIs) but the company is not using it today.

a. Explain the idea of Key Performance Indicators (KPIs). Also explain how you, as the COO, can use KPIs to get feedback from the production. (1 p)

b. You decide to introduce three (3) KPIs. Select and define three KPIs. You should also motivate why these three KPIs are of relevance for you as COO. (1,5 p)

c. Select one (1) out of the three (3) KPIs you presented in b). Explain how you would like to see this KPI being presented to you (e.g., in a graphical or textual way). (0,5 p)

d. This problem is ONLY for the members of the project group ”Alfa-Laval”. In this project the task was to focus on the Overall Equipment Effectiveness (OEE). The definition of OEE is given in the standard-draft ISO 22400. Explain how OEE is calculated according to the this standard and where the main difference is compared with the currently definition used by AlfaLaval. (1 p)

e. This problem is ONLY for the members of the project group ”Tetra Pak Processing”'.
In this project the task was to suggest Green KPIs for Tetra Pak Processing. Tetra Pak would like use their KPIs to measure something of relevance for the Plant, Unit and/or Line. Give an example of one Green KPI and explain how it could be use at Plant, Unit and Line level. (1 p)

Solution

a. KPIs are Key performance indicators. It should be possible to measure and quantify a KPI.

b.
- Yield = material in end-product / total material submitted.
- lead-time = the time period between a customer's order and delivery of the final product
- cycle-time = time per unit produced (time needed to produce one product/entity).
- throughput= quantity produced per time unit (PQ/TPT)
- occupancy-ratio (beläggningsgrad) = time used for production / total time
- down-time = the time a machine is not running even though the machine is available
- quality rate = number of good products / total number of products produced to exercise 6.

c. Motivate your answer. Illustrations are good.

d. (This problem is ONLY for the Alfa-Laval project group)
OEE = Availability*Effectiveness*Quality
There are two main difference between the definition of OEE used in ISO 22400 vs that used by Alfa-Laval:

- Since Alfa-Laval have difficulties measuring the quality directly, instead they use 1 as a default value for quality.
- Alfa Laval treats planned maintenance as a production stop (i.e. scheduled time) whereas ISO 22400 sees it as unscheduled time. This means that the availability for Alfal-Laval becomes lower than that calculated using teh ISO definition.

e. (This problem is ONLY for the Tetra pak Processing project group)
An example of a green KPI could be Unitfootprint. Unit footprint could be applied at differnet levels (unit, line, areas) but is most easily understood at the line level. Unitfootprint (CO2) = produced units (x)*carbon footpring (CO2/kg)*used rawmaterial (kg)
Another example of a green KPI could be total energy consumption / time.

7. A company manufactures two different kinds of wooden furniture, tables and chairs, that are sold for prices,p_1 and p_2. The products are manufactured by sawing and assembling. The sawing for each table takes s_1 hours while the sawing for each chair takes s_2 hours. The assembling takes a_1 hours for each table and a_2 hours for the each chair. The total weekly amount of man hours available for sawing and assemling is t_s and t_a hours respectively.

a. State the linear program that maximizes the profit. (1 p)

b. Solve the problem in a) using the following parameters; $p_1 = 11$, $p_2 = 9$, $s_1 = 10$, $s_2 = 12$, $a_1 = 14$, $a_2 = 11$, $t_s = 20$, $t_a = 20$. (1 p)

c. Set $p_2 = \alpha p_1$ and solve resulting linear program in a) for all $\alpha >= 0$ using the parameters in b). (1 p)

d. From one week to the next the maximum increase in production is limited by Δ_1 and Δ_2 for the two products respectively. State the linear program that maximizes the profit over the following three weeks, taking this limitation into account. Denote the amount of products produced the previous week by x_1^0 and x_2^0 respectively. (2 p)

Solution

a. Denote by x_1 the number of tables produced and by x_2 the number of produced chairs. The resulting LP becomes

$$\begin{array}{rl} \min & p_1x_1 + p_2x_2 \\ \text{s.t.} & s_1x_1 + s_2x_2 \leq t_s \\ & a_1x_1 + a_2x_2 \leq t_a \\ & x_1 \geq 0, x_2 \geq 0 \end{array}$$

b. The solution must be in a vertex. Insertion of parameters; $p_1 = 11$, $p_2 = 9$, $s_1 = 10$, $s_2 = 12$, $a_1 = 14$, $a_2 = 11$, $t_s = 20$, $t_a = 20$ gives the following vertices with corresponding values:

vertex	value
(0,0)	0
(20/14,0)	$\frac{11\times20}{14} \approx 15.7$
(0,20/12)	$\frac{9\times20}{12} = 15$
(20/58,80/58)	$\frac{11\times20}{58} + \frac{9\times80}{58} \approx 16.2$

The last vertex, (20/58,80/58), is where both constraints are active, i.e. where x satisfies

$$\begin{pmatrix} 10 & 12 \\ 14 & 11 \end{pmatrix} x = \begin{pmatrix} 20 \\ 20 \end{pmatrix}$$

The point (20/58,80/58) is the optimal solution.

c. Set $p_2 = \alpha p_1$. We have the same constraints as in the previous problem. Thus, the vertices are the same but the values depend on α as in the following table

vertex	value
(0,0)	0
(20/14,0)	$\frac{20p_1}{14}$
(0,20/12)	$\frac{20p_1\alpha}{12}$
(20/58,80/58)	$\frac{20p_1}{58} + \frac{80p_1\alpha}{58}$

For small α, $\frac{20p_1}{14}$, is the largest value and for large α, $\frac{20p_1\alpha}{12}$, is the largest value. The solution may change when the cost function is aligned with the constraints, i.e. when $\alpha = 12/10$ and $\alpha = 11/14$. Inserting this into the values gives that the optimal solution is

$$x^* = \begin{cases} (20/14,0) & 0 \le \alpha \le 11/14 \\ (20/58,80/58) & 11/14 \le \alpha \le 12/10 \\ (0,20/12) & \alpha \ge 12/10 \end{cases}$$

When $\alpha = 11/14$ and when $\alpha = 12/10$, i.e. when the cost is aligned with the one constraint, all solutions on the line connecting the optimal solutions are optimal.

d. Introduce variables for the amount of tables and chairs produced each week over the following three week, i.e. x_1^1, x_1^2, x_1^3 for the tables and x_2^1, x_2^2, x_2^3 for the chairs. We get the following LP

$$\begin{array}{ll} max_x & \sum_{i=1}^{3} p_1 x_1^i + p_2 x_2^i \\ \text{s.t.} & s_1 x_1^i + s_2 x_2^i \le t_s \\ & a_1 x_1^i + a_2 x_2^i \le t_a \\ & x_1^i \ge 0, x_2^i \ge 0 \\ & x_1^i \le x_1^{i-1} + \Delta_1 \\ & x_2^i \le x_2^{i-1} + \Delta_2 \end{array}$$

where x_1^0 and x_2^0 are the amounts of tables and chairs produced the previous week.

8. Two persons sharing a house needs to decide how much time to spend on cleaning. The rest of the time is spent watching TV. The payoff function for person i is given by

$$u_i = (t_1 + t_2) + (9 - t_i) + (9 - t_i)(t_1 + t_2)$$

Here t_i the time spent on cleaning for person i (where $0 \le t_i \le 9$ hours), the term $t_1 + t_2$ models the happiness from living in a clean house, the term $9 - t_i$ the TV time, and the last term the extra happiness of watching TV in a clean house.

a. Determine the best response functions $B_1(t_2)$ and $B_2(t_1)$ describing how much time should be spent on cleaning when knowing the other person's action. (1 p)

b. Find all pure Nash equilibria. (1 p)

c. Calculate cleaning time (t_1, t_2) optimizing the "total welfare", i.e. $u_1 + u_2$. Is the solution the same as in b? (1 p)

Solution

a. The players want to maximize their payoff function. The payoff function is concave, we compute the maximum by computing the derivative and finding the t_i for which the derivative is 0. The following holds for player 1.

$$\frac{\partial u_1}{\partial t_1} = -(t_1 + t_2) + (9 - t_1) = 0$$
$$\Leftrightarrow 2t_1 + t_2 = 9$$

The computations for player 2 are equivalent. We get

$$t_1 = \frac{9 - t_2}{2} \qquad\qquad t_2 = \frac{9 - t_1}{2}$$

b. We need to find t_1 and t_2 such that the respective best respons functions do not change. That is, we need to find t_1 and t_2 such that

$$\begin{pmatrix} 1 & 1/2 \\ 1/2 & 1 \end{pmatrix} \begin{pmatrix} t_1 \\ t_2 \end{pmatrix} = \begin{pmatrix} 9/2 \\ 9/2 \end{pmatrix}$$

We have that $t_1^* = t_2^* = 3h$.

c. Compute the "total welfare"

$$u_1 + u_2 = 2(t_1 + t_2) + (18 - t_1 - t_2) + (18 - t_1 - t_2)(t_1 + t_2)$$

Set $T = t_1 + t_2$ and we get

$$u_1 + u_2 = 2T + (18 - T) + (18 - T)T$$

Differentiation w.r.t T and setting to 0 gives

$$2 - 1 + (18 - T) - T = 0$$
$$\Leftrightarrow T = 19/2$$

If we divide equally, a solution is $t_1 = t_2 = 19/4$. The total welfare in this situation is

$$u_1 + u_2 = 19 + (18 - 19/2) + (18 - 19/2)19/2 = 108.25$$

The total welfare for the solution in **b** is found by inserting $T = t_1 + t_2 = 6$ in the total welfare formula

$$u_1 + u_2 = 12 + 12 + (18 - 6)6 = 96.$$

9. Find the mixed equilibrium to the following zero-sum two player game

	Left	Right
Top	1	0
Bottom	0	3

where the row player tries to minimize and the column player to maximize. What is the value of the game? (1,5 p)

Solution

Denote by p the probability that the column player chooses "Left" and denote by q the probability that the row player chooses "Top". The game for the row player becomes

Top	p
Bottom	3(1-p)

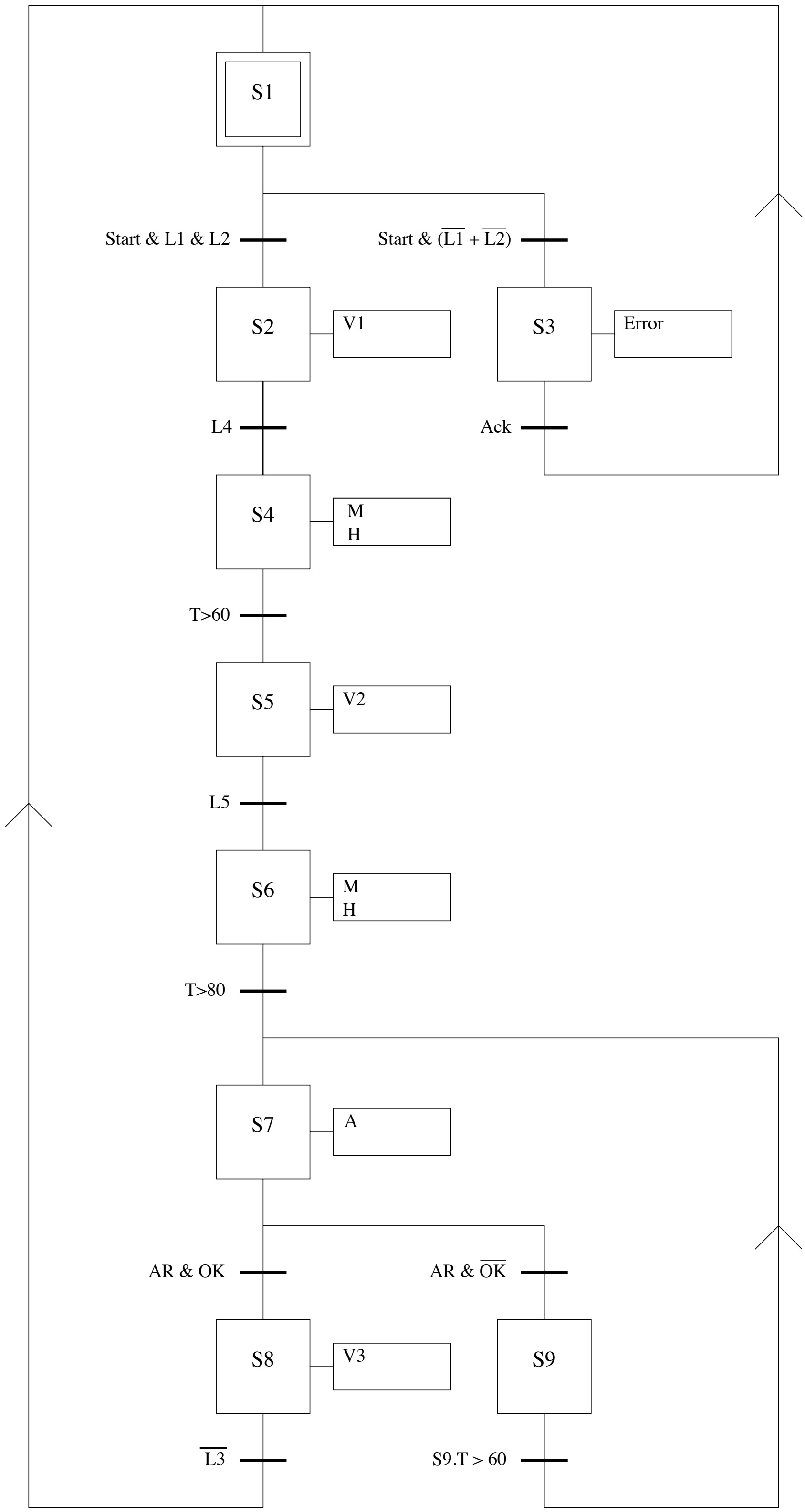
The row player would like to minimize and chooses the one which gives the smalles value. The optimal strategy for the column player becomes the p such that the payoffs for choosing "Top" and "Bottom" are equal. Thus

$$\begin{aligned} & p^* = 3(1-p^*) \\ \Leftrightarrow\ & p^* = 1/4 \end{aligned}$$

The situation is symmetric when analysing the game from the column-players perspective which gives $q^* = 1/4$.

The value of the game is

$$\begin{pmatrix} q^* & (1-q^*) \end{pmatrix} A \begin{pmatrix} p^* \\ (1-p^*) \end{pmatrix} = 1/16 \begin{pmatrix} 1 & 3 \end{pmatrix} \begin{pmatrix} 1 \\ 9 \end{pmatrix} = (1+27)/16 = 7/4.$$



Figur 3 The recipe, presented as a Grafcet, for the process XYZ.