Automation – EIEF45 (former MIE080)

Exam Friday March 22, 2019

You may bring the course book and the hardcopy of the chapter on HMI, but *not* the solutions to problems nor your own solutions to simulation tasks, lecture slides, home works or other personal notes. A calculator (memory cleared), TEFYMA, formula sheet from the Automatic Control department and a dictionary are permitted. You may answer in **Swedish** or in **English**.

Grading: There are 30 points all together. The following grades will apply:
Grade 3: at least 15 points
Grade 4: at least 20 points
Grade 5: at least 25 points

Note that all answers should be complete and well motivated. Your line of thought should be easy to follow and hand calculations should be provided for all mathematical problems. Corrections will be completed not later than *Tuesday **April 16,** 2019*.

Good Luck!

Problem 1 (5 points)
Four completely mixed tanks with constant volumes are connected according to Figure 1 (initially filled with pure water). The external inputs to the first tank are the flow rate (Q_1) and the concentration of a specific soluble compound in that flow (C_{in1}). The external inputs to the second tank are the flow rate (Q_2) and a concentration of the *same* compound in that flow (C_{in2}). The volumes of the tanks are V_1, V_2, V_3 and V_4. 50% of Q_2 is directed to tank 3 whereas the remaining 50% exits the system. 50% of the input flow rate to tank 3 goes on to tank 1 and the remaining 50% to tank 4. V_1 is twice as large as V_2 and V_3 is 10 times larger than V_2. V_1 and V_4 are the same volumes. The output flows from tanks 1, 2 and 4 simply exit the process (note: constant liquid volume in all tanks at all times).

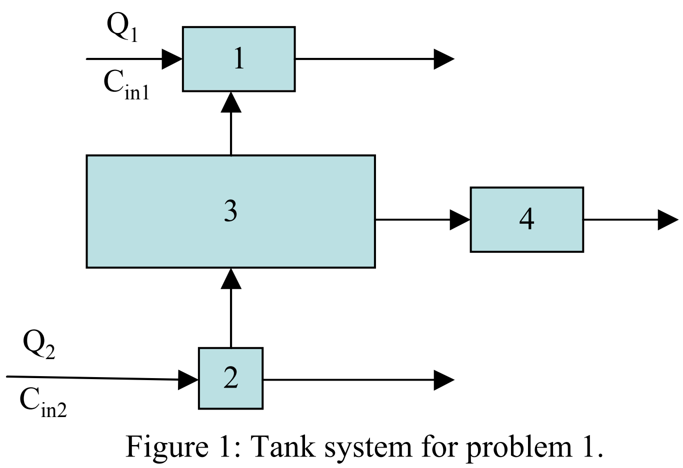


Figure 1: Tank system for problem 1.

a) Set up the differential equations for the concentrations C_1, C_2, C_3 and C_4 to represent the above process (define all variables you use). (**1 p**)
b) Transform the equations into state-space form (assume you can measure three things: C_1, $C_{in2}+C_2$ and C_4), $\mathbf{u} = [\,C_{in1}\;\; C_{in2}\,]^T$. (**1 p**)
c) Draw in *one* diagram (concentration as a function of time) as detailed as you can and also explain in words the behaviour of how the concentrations will change over time in the four tanks, if all are initially filled with pure water (i.e. concentration = 0) and the input concentration C_{in1} at time 0 is set to 50 g/l and the input concentration C_{in2} at time 0 is set to 25 g/l. Assume both the influent flow rates and concentrations to remain constant from time = 0 and onwards. Use $Q_1 = 5$ l/h, $Q_2 = 20$ l/h, $V_1 = V_4 = 2$ l, $V_2 = 1$ l, $V_3 = 10$ l and discuss the details of the dynamic response. Clearly provide the steady state concentrations in all four reactors and discuss the time constants in the system. (**2 p**)
d) Suddenly the pipe between tanks 3 and 4 is blocked and the entire output flow from tank 3 is now diverted to tank 1. At the same time C_{in2} changes from 25 g/l to 40 g/l and Q_1 changes from 5 to 15 l/h. What will be the new steady state concentrations in tanks 1, 2 and 3? (**1 p**)

Solution

a) Using the variables defined in the task the mass balances give us the dynamic system, i.e.

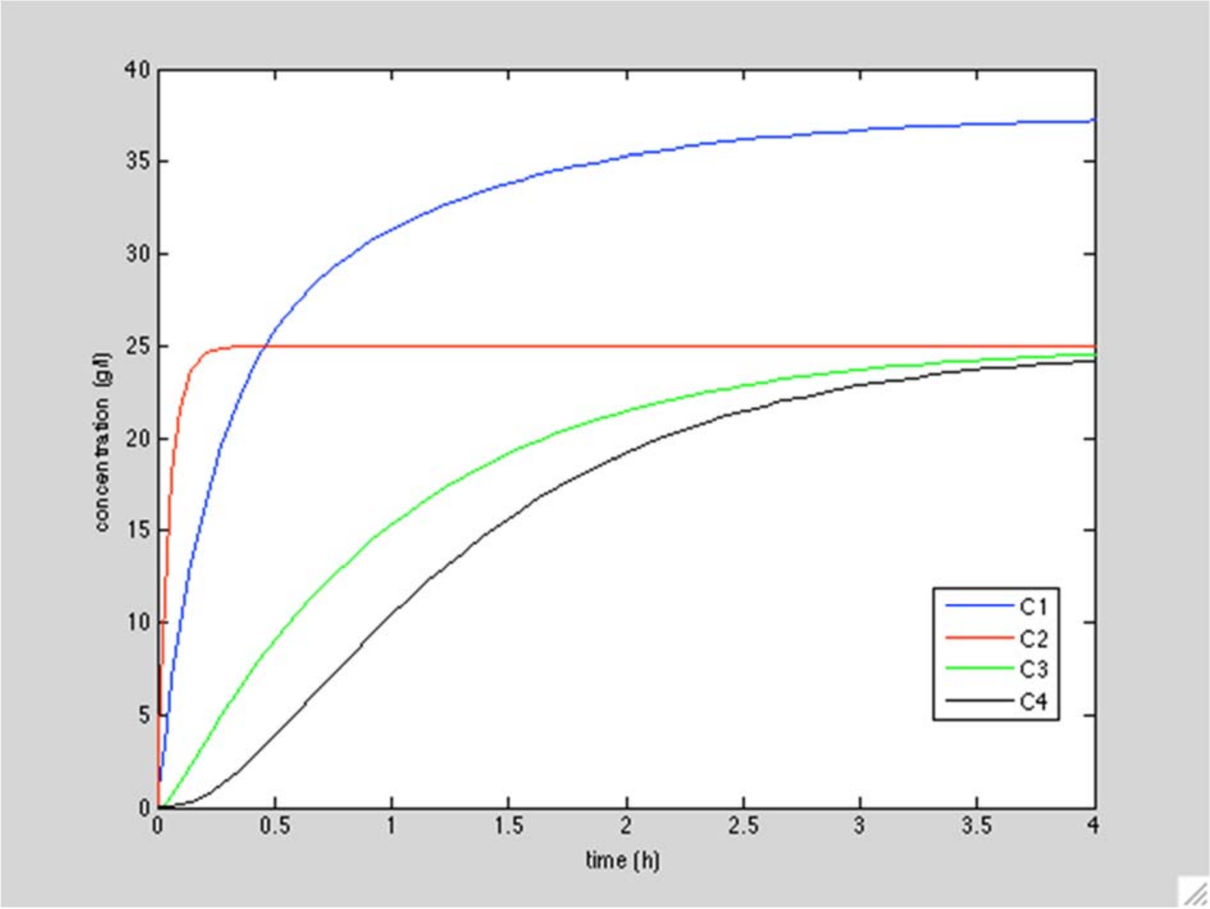
$$\begin{cases} \dfrac{dC_1(t)}{dt} = \dfrac{Q_1}{V_1}\cdot C_{in1} + \dfrac{0.25\cdot Q_2}{V_1}\cdot C_3 - \dfrac{(Q_1+0.25\cdot Q_2)}{V_1}\cdot C_1 \\ \dfrac{dC_2(t)}{dt} = \dfrac{Q_2}{V_2}\cdot C_{in2} - \dfrac{Q_2}{V_2}\cdot C_2 = \dfrac{Q_2}{V_2}(C_{in2}-C_2) \\ \dfrac{dC_3(t)}{dt} = \dfrac{0.5\cdot Q_2}{V_3}\cdot C_2 - \dfrac{0.5\cdot Q_2}{V_3}\cdot C_3 = \dfrac{0.5\cdot Q_2}{V_3}(C_2-C_3) \\ \dfrac{dC_4(t)}{dt} = \dfrac{0.25\cdot Q_2}{V_4}\cdot C_3 - \dfrac{0.25\cdot Q_2}{V_4}\cdot C_4 = \dfrac{0.25\cdot Q_2}{V_4}(C_3-C_4) \end{cases}$$

b) The state space representation (**A** and **B**) can be directly identified from the above equations and the **C** and **D** matrices are defined by the given available measurements as:

$$\begin{cases} \dfrac{d\mathbf{x}(t)}{dt} = \mathbf{Ax}+\mathbf{Bu} = \begin{bmatrix} -\dfrac{(Q_1+0.25\cdot Q_2)}{V_1} & 0 & \dfrac{0.25\cdot Q_2}{V_1} & 0 \\ 0 & -\dfrac{Q_2}{V_2} & 0 & 0 \\ 0 & \dfrac{0.5\cdot Q_2}{V_3} & -\dfrac{0.5\cdot Q_2}{V_3} & 0 \\ 0 & 0 & \dfrac{0.25\cdot Q_2}{V_4} & -\dfrac{0.25\cdot Q_2}{V_4} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} \dfrac{Q_1}{V_1} & 0 \\ 0 & \dfrac{Q_2}{V_2} \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} \\ \mathrm{y} = \mathbf{Cx}+\mathbf{Du} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 1 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} \end{cases}$$

where **x** represents $[C_1\; C_2\; C_3\; C_4]^T$ and **u** represents $[C_{in1}\; C_{in2}]^T$

c) The initial concentrations in all four tanks are equal to 0. Tank 2 is a normal first-order system with constant input and a time constant of V_2/Q_2 (= 0.05 h) and a steady state value equal to C_{in2} (= 25 g/l). Since the only input to tanks 3 and 4 comes from tank 2, the steady state values of these tanks must also be equal to C_{in2} (= 25 g/l). The steady state value in tank 1 will depend on its input C_{in1} and the input coming from tank 3. A simple calculation yields that this steady state value must be $(Q_1*C_{in1}+0.25*Q_2*25)/(Q_1+0.25*Q_2)$ = 37.5 g/l (based on the values given in the task). The steady state values can also be obtained by setting the derivatives in (a) equal to 0 and solving the resulting equation system. The answer is reasonable since the steady state concentrations must obviously be within the region defined by C_{in1} and C_{in2}. The small size of tank 2 and the high flow rate means that this tank will reach a steady state very quickly compared to the other tanks. A good approximation for tank 3 is therefore to assume that the input to that tank is constant with $Q_{in} = 0.5*Q_2$ = 10 l/h and an input concentration of 25 g/l and therefore its dynamic behaviour will be that of a first-order system with a time constant of V_3/Q_{in} = 1 h. Since it will take a small amount of time for tank 2 to react, the actual response for tank 3 will be slightly slower. The dynamic behaviour of tank 4 will closely follow that of tank 3 but somewhat delayed since the input concentration to tank 4 will depend on tank 3. If the concentration input to tank 4 was constant then the concentration change would just follow the time constant for tank 4, i.e. $V_4/0.25*Q_2$ = 0.4 h. If tank 1 was not connected to tank 3, its time constant would be V_1/Q_1 (= 0.4 h) and the steady state value equal to C_{in1} (= 50 g/l). However, the input from tank 3 will have an impact on tank 1 and bring the steady state concentration in tank 1 to 37.5 g/l in the end although this will take a while due to the delay from the tank 3 output. Initially, we can expect the concentration in tank 1 to increase quickly up to about 25 g/l (the resulting concentration for the Q_1 input with concentration C_{in1} and an input flow of $0.25*Q_2$ with zero concentration) and then follow the behaviour of tank 3. However, the time constant of tank 1 based on these initial input flows is only 0.2 h so it will initially increase its concentration fast and later on follow the change of tank 3. Tanks 2 and 4 will be the last tanks to reach steady state. Based on this discussion it is now possible to plot the dynamic behaviour of the tanks fairly accurately. A detailed plot of the simulated system is shown below.



d) The steady state values in tanks 2 and 3 are only affected by C_{in2} and will after some time be equal to the new C_{in2} (= 40 g/l). The steady state value in tank 1 will depend on its input Q_1, C_{in1} and the input coming from tank 3. A simple calculation yields that this steady state value must be $(Q_1 * C_{in1} + 0.5 \cdot Q_2 * C_3)/(Q_1 + 0.5 \cdot Q_2) = 46$ g/l (total input mass/total flow, where $C_3 = C_{in2}$, other values given in the task). The steady state values can also be obtained by modifying the equations in (a) and setting the derivatives equal to 0 and solving the resulting equation system.

Problem 2 (1 point)
Input and corresponding output data from an industrial process is given in the table below. As always there is some noise in the measurements. Is the process behaviour linear? Motivate! Is there any off-set in the output signal, i.e. what is the output value when the input = 0?

Input data	Output data
4.1	11.7
5.0	14.7
8.9	24.3
12.2	32.0
16.0	41.7
16.9	44.5
24.0	62.3

Solution
The simplest way is to plot the input vs the output and check if we get a fairly straight line and determine where it intersects the y-axis. We can also use superposition. If the system is linear there may be an offset. If we make a hypothesis that the system is linear then the offset ≈ y – ((y2–y1)/(x2-x1))*x (we can for example use x1 = 4.1, x2 = 24, y1 = 11.7, y2 = 62.3). The average offset can then be calculated to 1.39 and if we include that when calculating the ratio between input and output we get the table below:

Input data	Output data	Ratio (if no offset is taken into account)	Offset	Ratio (taking into account offset)
4.1	11.7	2.85	1.27	2.51
5.0	14.7	2.94	1.99	2.66
8.9	24.3	2.73	1.67	2.57
12.2	32.0	2.62	0.98	2.51
16.0	41.7	2.6	1.02	2.52
16.9	44.5	2.63	1.53	2.55
24.0	62.3	2.60	1.27	2.54

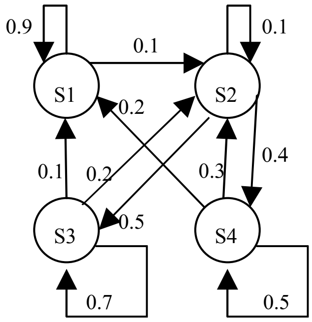
Since there is some noise on the measurements we can quite safely conclude that the system is behaving in a linear fashion and the output ≈ 2.5*input + 1.4

Problem 3 (4 points)
A machine can be described as being in four different states: (1) under repair, (2) waiting for a new job, (3) working mode 1, and (4) working mode 2. While the machine is working in mode 1 the probability to break down is 0.1 and the probability to get finished (go to waiting) is 0.2. While the machine is working in mode 2 the probability to break is 0.2 and the probability to get finished (go to waiting) is 0.3. If the machine is under repair there is a 0.1 probability to get repaired, and then the machine will become waiting. A broken machine is never brought directly (in one step) to operation. If the machine is waiting there is a 0.5 probability to get into operation mode 1 and a 0.4 probability to get into operation mode 2. A waiting machine does not break and the machine does not change directly from one operating mode to the other.

a) Describe the system as a Markov chain, define the transition probability matrix and make a state diagram. (**1 p**)
b) What is the probability that the machine is under repair after two time steps (events)? Assume the system is in working mode 1 when started. (**1 p**)
c) What is the probability to be operating in mode 2 after a long time? Complete solution required. (**2 p**)

Solution

a) S1 = under repair; S2 = waiting; S3 = working mode 1; S4 = working mode 2



The transition probability matrix is $P = \begin{pmatrix} 0.9 & 0.1 & 0 & 0 \\ 0 & 0.1 & 0.5 & 0.4 \\ 0.1 & 0.2 & 0.7 & 0 \\ 0.2 & 0.3 & 0 & 0.5 \end{pmatrix}$

b) $\mathbf{p}(2) = \mathbf{p}(1)*\mathbf{P} = \mathbf{p}(0)*\mathbf{P}^2$. $\mathbf{P}^2 = \begin{bmatrix} 0.81 & 0.1 & 0.05 & 0.04 \\ 0.13 & 0.23 & 0.4 & 0.24 \\ 0.16 & 0.17 & 0.59 & 0.08 \\ 0.28 & 0.2 & 0.15 & 0.37 \end{bmatrix}$ and

$\mathbf{p}(2) = \begin{bmatrix} 0.16 & 0.17 & 0.59 & 0.08 \end{bmatrix}$ The probability that the machine is under repair (i.e. in state 1) at time = 2 is consequently 0.16 = 16%.

c) Use Gauss elimination to solve the equation system (p1 p2 p3 p4)*(**I** – **P**) = 0 together with the extra condition p1 + p2 + p3 + p4 = 1. This gives:

$$\begin{cases} 0.1p1 - 0.1p3 - 0.2p4 = 0 \\ -0.1p1 + 0.9p2 - 0.2p3 - 0.3p4 = 0 \\ -0.5p2 + 0.3p3 = 0 \\ -0.4p2 + 0.5p4 = 0 \\ p1 + p2 + p3 + p4 = 1 \end{cases}$$

Some further calculations (not shown here but must be provided) yield p1 = 0.4851, p2 = 0.1485 and p3 = 0.2475 and p4 = 0.1188. So the stationary probability to be in mode 2 is p4(∞) = 0.1188.

Problem 4 (2 points)

A transfer line consists of two machines (M1 and M2) with a buffer in between described as a Markov process. The machines can be either operating or broken and the buffer can hold 0, 1 or 2 items. With its current set of parameters (repair rates r_1 and r_2, failure rates f_1 and f_2, production rates μ_1 and μ_2, where index 1 represents M1 and index 2 M2) the stationary probabilities (rounded off values) are given in the table below:

State name	Machine 1 (0=broken,1=operating)	Machine 2 (0=broken,1=operating)	Buffer size (0, 1 or 2)	Stationary probability
S0	0	0	0	0.0278
S1	0	0	1	0.0080
S2	0	0	2	0.0118
S3	0	1	0	0.2354

S4	0	1	1	0.0334
S5	0	1	2	0.0169
S6	1	0	0	0.0212
S7	1	0	1	0.0233
S8	1	0	2	0.0507
S9	1	1	0	0.2711
S10	1	1	1	0.1754
S11	1	1	2	0.1250

a) What is the total system production rate (μ_1=0.5 time^{-1}; μ_2=0.7 time^{-1})? (**0.5 p**)
b) What is the average probability that M2 is starved? (**0.5 p**)
c) What is the average buffer size? (**1 p**)

Solution

a) Total system production rate P_S = μ_1 * E1 = μ_2 * E2, where E1 and E2 are the real efficiencies for machines 1 and 2, respectively. E1 = all states where machine 1 is producing = p(1,0,0) + p(1,1,0) + p(1,0,1) + p(1,1,1) = p(S6) + p(S9) + p(S7) + p(S10) = 0.491. E2 = all states where machine 2 is producing = p(0,1,1) + p(1,1,1) + p(0,1,2) + p(1,1,2) = p(S4) + p(S10) + p(S5) + p(S11) = 0.3507. Total system production rate = 0.5 * 0.491 = 0.7 * 0.3507 = 0.2455.
b) M2 is starved when M2 is operating but the buffer is empty = p(S3) + p(S9) = 0.5065
c) Average buffer size = 0 * (p(S0) + p(S3) + p(S6) + p(S9)) + 1 * (p(S1) + p(S4) + p(S7) + p(S10)) + 2 * (p(S2) + p(S5) + p(S8) + p(S11)) = 0.6489.

Problem 5 (2 points)

A process consists of a number of reactors where an inflow of cold tap water is mixed with chemical substances and chemical reactions take place. We want to control the temperature of the outflow from the reactor system and because of this, the transfer function for the system has been identified to relate the outflow temperature to the inflow temperature. This transfer function is used to make a simulation model and a PID-controller with unlimited actuator authority is tuned in the simulator.

In the real process, a flow through heater is applied to the inflow water. It is driven by a PWM-power electronic unit so that a time-proportional heating power is applied. The on/off switching frequency is so high that the process will see this heating as an analogue power source. Still we can expect some differences when we apply the PID parameters from the simulator. Describe these differences.

Solution

If an unlimited actuator signal has been used it means that unlimited power can be applied for both heating and cooling. Although the heater is controlled by PWM and can be considered analogue and linear, in the active operating region, it has a maximum heating power. This is a limitation. Furthermore is nothing said about any cooling equipment. The "normal" action is of course to heat the cold water but in the model it is very probable that the PID sometimes will have a negative output i.e. cooling. With limited positive and no negative control action it is likely that the real process control will differ a lot from the simulation.

Problem 6 (3 points)
In a real time system, several activities are running in parallel. Describe, and motivate, what resource protection is needed and how it can be implemented in the following scenarios:

a) Reading and writing of elements in a data structure containing PID-parameters for a controller that several activities are using and modifying. (**1 p**)
b) Reading and writing a real number that several activities read but only one activity writes. (**1 p**)
c) Reading and writing a character variable (one byte) that several activities read but only one activity writes. (**1 p**)

If the scenarios described above contain more than one possible solution, or if more specifications are needed, you should describe all main options.

Solution
a) The parameters in a PID controller are probably strongly related to each others. A change should therefore be made as an indivisible operation. To achieve this the data structure should be protected by e.g. a semaphore. Any process that would like to have access to the parameters should wait for the semaphore before the access and then signal the semaphore when access is no longer needed.
b) In this case we need to know if the reading and writing are indivisible operations. If they are then no protection is needed. However, if the number needs several memory words then an interrupt can take place when only a part of the number has been read or written. In this case the number has to be protected in the same way as described in a).
c) Almost all computers read and write at least one byte as an indivisible operation so it is very likely that we don't need any protection here.
It should be emphasized that the conclusion about no protection in the b) and c) cases depends on that only one process is writing. If for instance two processes can do a read-modify-write operation then the whole operation has to be made indivisible and this usually requires protection.

Problem 7 (2 points)
For personal desktop computers the wire bound network communication is almost always through Ethernet/IPS. (IPS=Internet Protocol Suite where TCP/IP is an important part.) However, for control equipment in industry, fieldbuses are more frequent. Compare Ethernet/IPS with fieldbuses and point out the differences between the features.

Solution
Fieldbuses in general are used for smaller local area networks and because of this they can usually only address rather few nodes, e.g. a couple of hundred. The noise and disturbance immunity is usually higher than with networks designed for office environments. This often means that shielded or even double shielded cables are used. The data throughput is often rather low for the fieldbuses e.g. 0.25-10 Mbit. On the other hand, most fieldbuses are deterministic by design or provide tools to make them deterministic. A drawback is that although the fieldbuses usually are well standardized there are very many fieldbus standards while Ethernet/IPS is almost totally dominating the market for personal computer LAN.

Problem 8 (1 point)
A measurement signal of 1200 Hz is sampled with 5 kHz. Suddenly there is an equipment failure and a sinusoidal disturbance signal of 29 kHz is added to the input measurement signal. Unfortunately no anti-alias filters have been included in the measurement system. How

does the disturbance signal affect the sampled signal (at what frequency does the disturbance appear)?

Solution

Use the graph in Figure 10.3 (page 361) in the book: the value $f/f_s = 29/5 = 5.8$, which will intersect the graph at the y-value 0.2, i.e. when $f_o/f_s = 0.2$. This means that the observed alias frequency will appear at $f_o = 1$ kHz = 1000 Hz.

Problem 9 (2 points)

A third-order exponential low-pass filter can be written as:

$$\hat{y}(kh) = 3\alpha \cdot \hat{y}((k-1)h) - 3\alpha^2 \cdot \hat{y}((k-2)h) + \alpha^3 \cdot \hat{y}((k-3)h) + (1-\alpha)^3 \cdot y(kh)$$

where $\hat{y}$ is the filter output, y is the measurement signal, h is the sampling time and k is an index.

a) What is the approximate time constant (T) of this filter in integer number of samples? Assume that α=0.5 and that the measurement signal is a step signal with the value 1 at sample number 0. y and $\hat{y}$ are both 0 before the step. (**1 p**)

b) What is the principle difference between a causal and non-causal filter? (**0.5 p**)

c) A median filter (e.g. y_out_filter(kh) = median_value[y(kh), y((k-1)h), y((k-2)h)] is often used to remove outliers. Explain why this is so (for example compare the median filter behaviour with a moving average filter) (**0.5 p**)

Solution

a) The time constant is the time by which the filter has reached 63% of its final output when exposed to a step change. Using α=0.5 means

$$\hat{y}(k) = 1.5 \cdot \hat{y}(k-1) - 0.75 \cdot \hat{y}(k-2) + 0.125 \cdot \hat{y}(k-3) + 0.125 \cdot y(k)$$

At sample 0 the measurement signal changes from 0 to 1 and we get the following sequence:

Filter output (sample 0) = 0.125
Filter output (sample 1) = 0.3125
Filter output (sample 2) = 0.5000
Filter output (sample 3) = 0.6562

Consequently the filter requires 4 samples to reach above 63% of its final output.

b) A causal filter may only use current and old measurement values, which means that it can be implemented in on-line applications but also that the output signal will always be somewhat delayed compared to the original signal. A non-causal filter is suitable for off-line analysis (using stored data) and time delays can then be avoided.

c) If for example an outlier in an otherwise slowly changing signal is only present for one sample then a median filter based on three measurements will completely remove it, as the median value will be one of the two other measurement values. A MA-filter will reduce the effect of the outlier but it can never completely remove the effect as it is included in the actual average calculation (unless the moving window is infinite). It there are two outliers next to each other a median filter of length 3 is not enough, instead a length of 5 is required, etc. Since the median filter is also an extremly simple filter it is popular for this fairly difficult task.

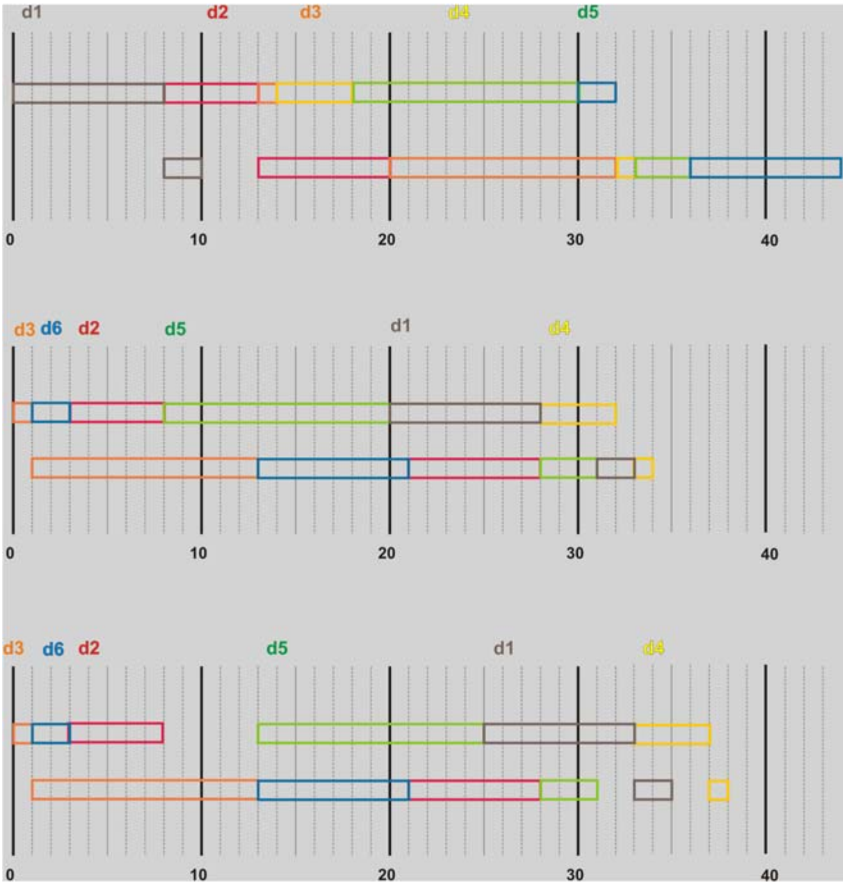
Problem 10 (3 points)
Consider a transfer line of two machines producing six different products. Every product has to be machined first in machine m_1 and then in machine m_2. Six designs (d1 – d6) have to be processed where the processing times are:

	d1	d2	d3	d4	d5	d6
m_1	8	5	1	4	12	2
m_2	2	7	12	1	3	8

a) Calculate the total manufacturing time if the designs are produced in the order given in the task with an unlimited buffer between the machines. (**1 p**)
b) Calculate the manufacturing order of the designs that will minimize the time to finish all products and calculate the production time for this order. (**1 p**)
c) Use the order in b) but assume that the buffer can hold **only one design at a time**. What is the production time now? (**1 p**)

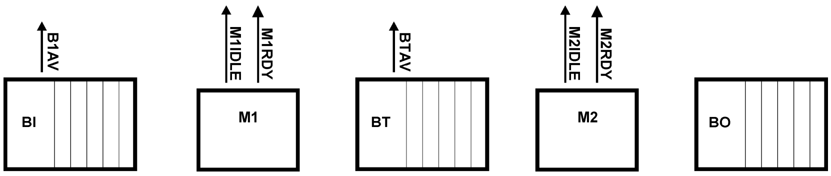
Graphical solutions showing the production flow should be presented for all three cases.

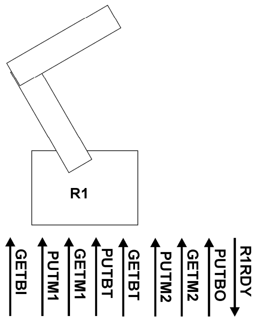
Solution



a) In the first diagram, we can read that the total time is 44 time units.
b) In the second diagram, we have changed the order according to Johnson's algorithm and the time is now reduced to 34 time units.
c) In the third diagram d5 cannot be started because d2 cannot enter the buffer. The single buffer position is taken by d6 until time unit 13. This makes the total time 38 time units.

Problem 11 (5 points)
A robot is controlling the transfer line in the previous problem. The production flow for each product is BI-M1-(BT-) M2-BO. The unlimited BT-buffer is of FIFO-type and the product order should be kept in the production. (No shuffling.) Unnecessary use of buffers is not allowed. BO is also unlimited.

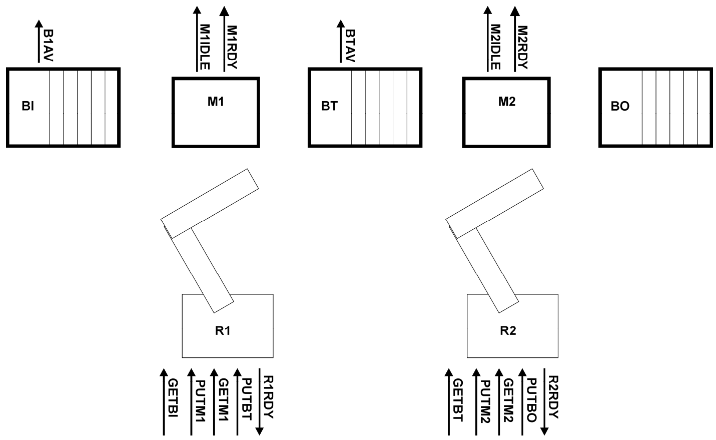




The status signal from the buffers, BxAV indicates that there is an object to pick up. The machines indicate that they are ready to receive a new object with the signals MxIDLE. If an object is processed in a machine and can be picked up, it is indicated with MxRDY.

The robot is controlled with GETxx and PUTxx commands to take and put objects from the buffers and machines. These commands are set to true to perform the action but when each action is completed, the command automatically returns to false and the signal R1RDY becomes true. R1RDY returns to false as soon as a new GET/PUT-command is given.

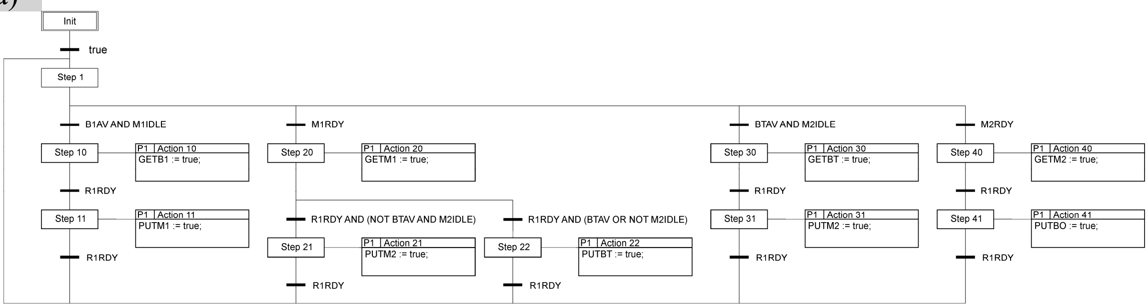
a) Write an SFC program that controls the robot for a production according to these specifications. (**3 p**)
b) After a redesign of the production line, it is not possible for one robot to reach over the whole line. Because of this, a second robot is installed. The first one handles the flow BI-M1-BT while the second robot handles BT-M2-BO. Now BT is always used for handing over the products. Modify your program to handle this new configuration. You can make blocks of parts of your solution in a) and only rewrite the changed code. The new robot now takes the four commands between GETBT to PUTBO and responds with R2RDY (**1 p**)



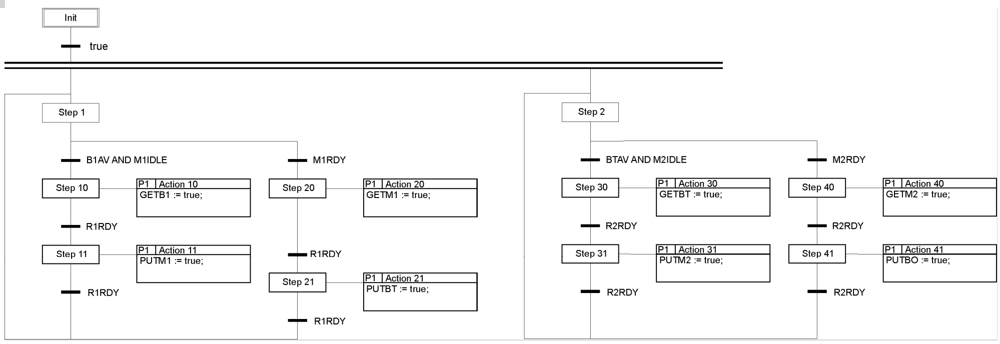
c) In b) you could assume that a PUTBT and GETBT could be executed simultaneously. If we now assume that the robots have to perform these commands mutually excluding to avoid a collision. How can this be solved in the program? You do not have to write the code but make a clear description of the functionality. (**1 p**)

Solution

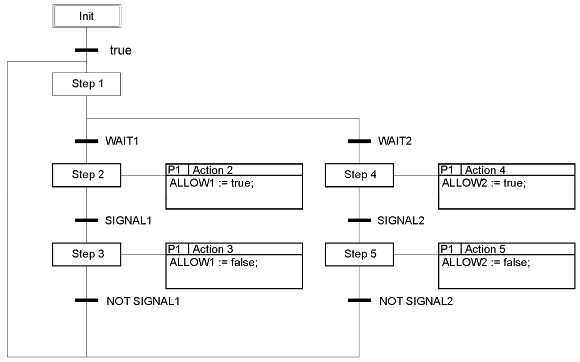
a)



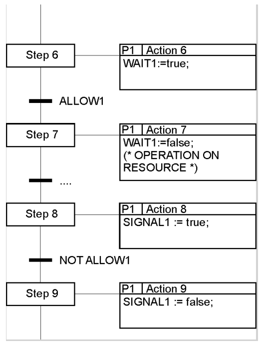
b)



c) Here we get the situation where two concurrent activities need access to a critical resource (only one at a time). In real time programming this could be solved with a semaphore. However, no such function is available in SFC/ST and in many cases this could be solved with a scheduler that initiates the operations. To keep the efficiency of the parallel activities in this case such a program should be very large and complicated. It is rather a resource allocating program that is needed to implement this "test-and-set" operation. We assume that the programs use the variables WAITX, SIGNALX, and ALLOWX where X is 1 or 2 for the two concurrent activities. The allocating program could then look something like this:



A use of the resource in activity 1 could look like this:



Please note that this is just one solution example. Many other, maybe smarter or simpler, could be created.