Paper P2 - SAMPLE SOLUTIONS

ORGANISATION AND CONTROL OF MANUFACTURING SYSTEMS

1

(a) (i) some of the main responses are captured in the table below

Issue	*Reduce Source*	*Reduce Effects*
Static	*Lighter weight components*	*More rigid components* *Thicker materials* *X sectional shape*
Dynamic	*Design machine, tool for materials* *Externalise vibration sources*	*High damping* *Insultation* *Design natural frequency*
thermal	*Reduce heat sources* *Externalise heat sources*	*Expansion joints* *Differential wall sizes*

Reasons that not all of the deflections can be dealt with in design:

- *Static*

- unknown mass size, shapes
- different loading positions

- *Dynamic*

-different vibrations for different materials/tools combination – cant allow for all of them
-different external vibration sources

- *Thermal*

- unknown heat sources
- difficult to model heat paths & thermal responses exactly

(b)

(i) Stiffness, k, is related to natural freq by $\omega_n = \sqrt{k/m}$ *and hence a 20% decrease in stiffness will lead to a* $(1-\sqrt{0.80}) \cong 10\,\%$ *decrease in natural frequency.*

(ii) The first mode is given by

$$G_1(j\omega) = \frac{\omega_{n1}{}^2}{-\omega^2 + 2c_1\omega_{n1}\omega j + \omega_{n1}{}^2} \qquad (1)$$

and with the new reduced natural frequency, denoted $\overline{\omega}_{n1}$*, where* $\overline{\omega}_{n1} = 0.9\omega_{n1}$*, we have*

$$\overline{G}_1(j\omega) = \frac{\overline{\omega}_{n1}{}^2}{-\omega^2 + 2c_1\overline{\omega}_{n1}\omega j + \overline{\omega}_{n1}{}^2} \qquad (2)$$

Note: we are assuming that damping has not been affected by the material change.

Considering feedback, the closed loop system is

$$G_{C/L}(j\omega) = \frac{\overline{G}_1}{1 + K\overline{G}_1}$$

And substitution for G_1 *gives*

$$G_{C/L}(j\omega) = \frac{\overline{\omega}_{n1}^{\,2}}{-\omega^2 + 2c_1\overline{\omega}_{n1}\omega j + \overline{\omega}_{n1}^{\,2}(1+K)} \qquad (3)$$

Hence, the revised natural frequency y, denoted $\overline{\overline{\omega}}_{n1}$ *of this closed loop system is given by*

$$\overline{\overline{\omega}}_{n1}^{\,2} = \overline{\omega}_{n1}^{\,2}(1+K)$$

As we are seeking K such that $\overline{\overline{\omega}}_{n1} = \omega_{n1}$ *-i.e. the original natural frequency is restored - it can be immediately seen that K=0.25 gives the desired result.*

(iii) Although damping was assumed not to change with the new material, with the feedback adjustment to natural frequency, the effective damping of the closed loop system is changed in that the closed loop equation is now

$$G_{C/L}(j\omega) = \frac{\alpha\overline{\overline{\omega}}_{n1}^{\,2}}{-\omega^2 + 2\overline{\overline{c}}_1\overline{\overline{\omega}}_{n1}\omega j + \overline{\overline{\omega}}_{n1}^{\,2}} \qquad (4)$$

And equating (3) and (4) we now have that $2\overline{\overline{c}}_1\overline{\overline{\omega}}_{n1}\omega j = 2c_1\overline{\omega}_{n1}\omega j$ *and hence damping factor is reduced by approximately 10% - i.e.* $\overline{\overline{c}}_1 = 0.9c_1$.

To restore this, we might for example consider an amended controller, $K = K_P + K_D j\omega$ *and then in (4)*

$$G_{C/L}(j\omega) = \frac{\alpha\overline{\overline{\omega}}_{n1}^{\,2}}{-\omega^2 + (2\overline{\overline{c}}_1\overline{\overline{\omega}}_{n1} + \overline{\overline{\omega}}_{n1}^{\,2}K_D)\omega j + \overline{\overline{\omega}}_{n1}^{\,2}(1+K)}$$

And then the derivative feedback K_d *can be selected to achieve* $2\overline{\overline{c}}_1\overline{\overline{\omega}}_{n1} + \overline{\overline{\omega}}_{n1}^{\,2}K_D = 2c_1\overline{\overline{\omega}}_{n1}$

2 *(a)*

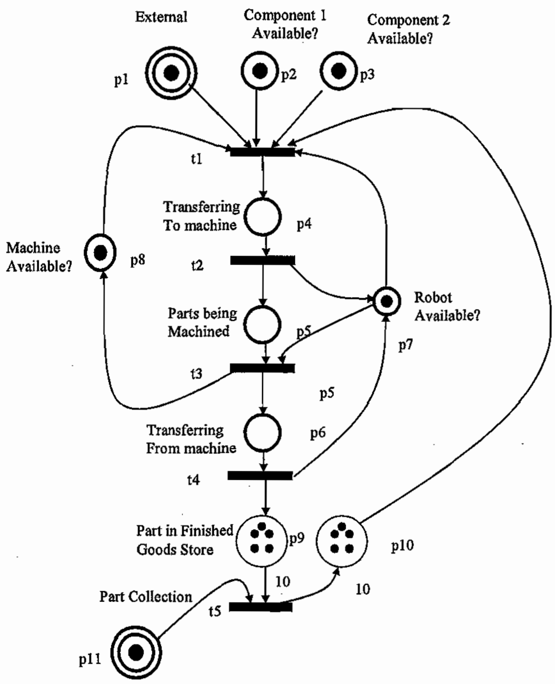
(i) This is more or less straight from the notes:

- *for simple systems: PLC coding can be intuitive and written as boolean expressions or as ladder logic directly by the engineer*
- *for complex systems: require some form of methodology*
    - *Approach 1: a simple methodology based on state diagrams to identify internal variables*
    - *Approach 2: a more formal approach based on Petri Nets*
- *Petri Nets are a graphical tool which can be used for the modelling, planning, control design and evaluation of manufacturing systems*
- *Advantages: capture state and action information, systematic, good for analysis, compatible with PLC programming, can be used to directly generate PLC code*

(ii) Inappropriate under the following conditions

- *simple situations*
- *where there is existing PLC code in existence which hasn't been modelled with a Petri net*
- *generally: PNs have a high initial overhead so only used when benefits above are likely to outweigh extra effort*

b) A possible revised and extended PN is given below: the key is to include 2 resource loops and the pair of PN places to accommodate storage locations full and available:



In this case we have specifically made the following changes

(i) Machine Tool: a single place is added to represent availability of the machine once parts have been machined

(ii) SCARA robot: a single place p7 represents robot availability. Note that the robot is used in 2 locations but will always give priority to unloading because of the unavailability of the machine prior to firing of t3

(iii) Finished Goods Storage: p9 represents the part in finished store and p10 the number of available places. When there are 10 parts in store transition t5 is activated and p10 is returned to 10 allowing production to proceed.

c) *the two key issues required to turn the Petri Net model into fully operational Ladder Logic code for a PLC are*

- *to covert the Petri net into ladder code: a latch/unlatch model can be used for this (described in lecture)*
- *to add in communications between the cell control and the physical world – sensors in and actuations out.*

Other issues which might be mentioned are to analyse the net for ambiguities, to simulate the Petri net operations etc

3 (a)

(i) The EOQ model considers two types of cost: holding cost and ordering cost. The basic assumption of the EOQ model is that – with increasing order size – the cost of holding inventory increases. At the same time, the fractional cost of ordering per item decreases with increasing order size. The EOQ model marks the minimum of the total cost curve, which is the sum of the holding cost and ordering cost.

(ii) After differentiation, the optimal Q is determined to

$EOQ = Q^* = sqrt(2*D * C_O / C_H)$.

Back in the cost equation, the total cost is therefore:

$C_{total} = C^* = ½ Q^* \times C_H + (D / Q^*) \times C_O$

and substituting for the optimal $Q^* = sqrt(2*D * C_O / C_H)$ *gives*

$C^* = sqrt(D \times C_O \times C_H / 2) + sqrt(D \times C_O \times C_H / 2)$

$= sqrt(2 \times D \times C_O \times C_H)$

$= C_H Q^*$

(b) (i)

D - Annual demand is 360 units.

C_O *– Ordering cost is £1000*

- Holding cost is 0.25 x 500 = £125

$EOQ = sqrt[2 * 360 * 1,000 / (500 * 0.25)] = 76$,

i.e. 76 units and the resulting total cost is

$C_{total} = C_H Q^* = 76 \times 125 = £ 9500$

(ii) practical issues might include

- *fixed quantity sizes*
- *fixed ordering periods*
- *economic delivery sizes*
- *other factors influencing total cost*
- *production requirements*
- *volume discounts*

(c)

$C^*(1+dC) = ½ Q^*(1+dQ) \times C_H + (D / Q^*(1+dQ)) \times C_O$

And for small dQ <<1, we approximate that

$1 / (1+dQ) = (1-dQ)$

And hence

$C^*(1+dC) = ½ Q^*(1+dQ) \times C_H + (D(1-dQ) / Q^*) \times C_O$

And eliminating C from each side, we get*

$C^*dC = \frac{1}{2} Q^* dQ\, C_H - D\, dQ\, C_O / Q^*$

Or

$$dC / dQ \quad = \tfrac{1}{2} Q^* \; C_H - D \; C_O / Q^*$$
$$= 0$$

*After substituting for Q**

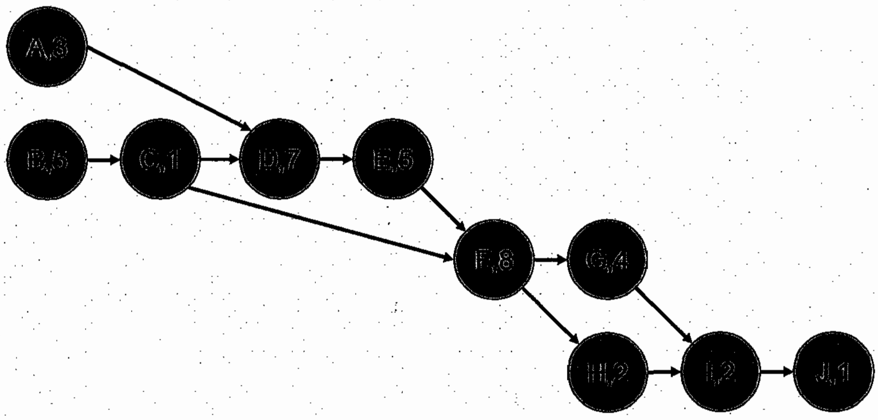
Hence for very small perturbations in Q away from Q there is very little impact on the overall cost so the famous robustness appears to be true.*

There are other ways to do this analysis, the main issue is for the student to demonstrate that the change in Q has only negligible effect on C.

4

a.)

i)



ii)
The work content = Σp_i = 38 minutes
*Cycle time = (8 hours * 60) / 60 units = 8 minutes/unit*
The line balancing can be achieved by either the ***"longest sequential chain of followers"*** *or* ***"total number of followers"*** *heuristics. Both heuristics yield the same solution. In either case, the minimum number of stations can be achieved by grouping them as:*
Worker 1: (A,B)
Worker 2: (C,D)
Worker 3: (E)
Worker 4: (F)
Worker 5: (G,H,I)
Worker 6: (J)

iii)
Minimum number of stations = Σp_i / cycle time = 38/8 = 4.75, i.e. min. 5 stations
*The balancing loss = 1- Σp_i / (number of workers * cycle time) = 1- (38/48) = 20.83%*

iv)
Even a small demand increase will have a significant impact as many of the workers in the above balancing are at maximum capacity. The organisation may need to significantly increase labour or completely re-examine the distribution of operations or both.

b)

i) *In this case, a large alpha (e.g. 0.3) should be selected, as this puts more weight on recent data, and thus increases the responsiveness to the trend.*
ii) *Moving average forecasts give little flexibility with regards to adjusting the characteristics of the forecast. In presence of a trend, however, it is required to create a forecast that is sensitive enough to project this trend. By altering the smoothing factor*

alpha, the exponential smoothing forecast has the ability to be responsive to trends, and is therefore better suited than the moving average.

iii) *In the light of the observed seasonality, a proper time series model should be developed instead of relying simply on moving averages or simple exponential smoothing. In principle, time series analysis decomposes demand into four (multiplicative model) or five (additive model) components:*

- *Level (additive model only)*
- *Trend*
- *Seasonality*
- *CyclicNoise*
- *irregular*

5 (a)

(i) A dispatching rule provides a guideline for the selection of orders to release onto the manufacturing shop floor and in particular is used for the prioritisation of tasks on an individual workstation

EDD – release of the orders such that those with the earliest due date are always released first
FIFO – a simple JIT like strategy in which orders are processed in the order they arrive
LCC – the next order for release is selected on the basis of the current machine configuration and the cost to change over to the next order

(ii)
EDD – when there are severe lateness penalties
FIFO – when there is little storage space, a visual rather than computer based control system
LCC – when machine changeovers are expensive

(b)
(i) Using FIFO rules on each station

Time	1	2	3	4	5
0	MA	-	-	-	-
10	MA	-	-	-	-
20	MA	MB	-	-	-
30	WB	MB	-	-	-
40	WB	MB	WB	MA	-
50	WB	MB	WB	MA	-
60	MB	WA	WB	MA	WB
70	MB	WA	WB	MA	WB
80	Finished	MA	MB	WB	WB
90		MA	WA	WB	MB
100		MA	WA	WB	MB
110		Finished	MA	MB	WA
120			MA	MB	WA
130			MA	MB	WA
140			Finished	Finished	MA
150					Finished

Product 1: 70 days early
Product 2: 20 days early
Product 3: 20 days late
Product 4: 30 days late
Product 5: 60 days late

Average lateness is 4 days (giving credit for early delivery) or 22 days (no credit for early delivery.)
3 products are late

And then using EDD rules:

Time	1	2	3	4	5
0	MA	-	-	-	-
10	MA	-	-	-	-
20	MA	MB	-	-	-
30	WB	MB	-	-	-
40	WB	MB	WB	MA	-
50	WB	MB	WB	MA	-
60	WB	WA	WB	MA	MB
70	WB	WA	WB	MA	MB
80	WB	WA	WB	MB	MA
90	WB	MA	WB	MB	Finished
100	WB	MA	WB	MB	
110	WB	MA	MB	Finished	
120	MB	Finished	MA		
130	MB		MA		
140	Finished		MA		
150			Finished		

M – make, W – waiting, A, B – assembly stations

Product 1: 10 days early
Product 2: 10 days early
Product 3: 30 days late
Product 4: on time
Product 5: on time

Average lateness is 2 days (giving credit for early delivery) or 6 days (no credit for early delivery.)
One product is late.

(ii)

The factory managers decision seems entirely justified with the current data. It would also be useful to get information about setup costs, available inventory and WIP storage and the availability of control systems to support the EDD approach. The schedules generated here are simply the ideal ones. Further order data would be needed to support the change of policy as it will have significant impact on operations

(c) In order to consider moving to a LCC policy a detailed study of the relative costs of asset utilisation, delivery delays, inventory holding would need to be carried out. Only where the changeover costs are substantial compared with the other two costs should the shift to an LCC policy be considered. LCC policies are used in operations where a key bottleneck asset must be maximally utilised.
[20%]

6. A small company has been assembling and supplying a limited range of simple sub-assemblies for a major computer manufacturer for several years. The computer manufacturer is located nearby and the supplier has established an office within the site to organise deliveries and monitor any issues that arise. In turn, the suppliers for the sub assembler are local and well known to the company. Because of stringent time pressures and cost constraints, the sub-assembly company has deployed a JIT approach to their business – both in terms of production planning and supplier management. This approach has worked well and the company has been able to consistently meet the demands and quality expectations of their customer.

(a) Why has a JIT approach worked well for this company? State any assumptions you make.

Key features of company situation
- time pressure
- cost constraint
- nearby, tight link to OEM
- Simple sub assemblies
- close relationship with a few suppliers
Also assume
- computer manufacturer also using a JIT type of approach at supplier end at least.
- - high level of visibility of WIP and finished goods

Note from lectures key characteristics of JIT

- *reacts to demand*
- *best for simple products and simple routings*
- *requires level scheduling*
- *PULL*

b)
i)
Challenges will be
Increased <u>range</u> of subassemblies

- *greater product mix*
- *new production facilities – more complex overall*
- *more complex BOM*
- *less visible operations*
- *more suppliers (some not local perhaps)*

Increased and more frequent variation in subassemblies
- more frequent changeovers on machines
- more rush jobs
- frequently changing BOM requirements – harder to forecast

Good students will be able to elaborate significantly on these base issues.

(ii) Again noting from lectures the relative merits of MRP and JIT and their combination:

Characteristics of MRP

- *anticipates future demand*
- *copes with product and process complexity*

(TURN OVER)

- *OK even for infrequent, low-volume parts*
- *PUSH*

Characteristics of JIT

- *reacts to demand*
- *best for simple products and simple routings*
- *requires level scheduling*
- *PULL*
- *MRP for overall control, JIT for internal control*

Combining MRP and JIT

- *MRP creates supplier schedules, shopfloor production controlled by kanban*
- *Advantages*
  - *no need for internal works orders*
  - *in process inventory only monitored between cells rather than for each activity*
  - *simpler BoM*
  - *simpler process routing information*
  - *simpler work centre planning and control*
  - *lead time and WiP reduced*

It would seem that in this situation a combined MRP and JIT strategy would be most appropriate, retaining JIT to ensure that customer interface is maintained under time and cost pressures while using MRP to manage increasingly complex production, BOM and supply base issues.

7

a) activities at each stage
Initiation *- Active and/or passive scanning of organisational problems/opportunities and IT solutions are undertaken. Pressure to change evolves from either organisational need (pull), technological innovation (push), or both.*
Adoption *- Rational and political negotiations ensue to get organisational backing for implementation of the IT application.*
Adaptation *- The IT application is developed, installed, and maintained. Organisational procedures are revised and developed. Organisational members are trained both in the new procedures and in the IT application.*
Acceptance *- Organisational members are induced to commit to IT application usage.*
Routinisation *- Usage of the IT application is encouraged as a normal activity.*
Infusion *- Increased organisational effectiveness is obtained by using the IT application in a more comprehensive and integrated manner to support higher level aspects of organisational work.*

b) potential issues
Issues in IS implementation
Technical issues
- *appropriate design*
- *systems integration*
- *developing and maintaining accurate databases*

People issues –
- *top management support*
    - *awareness and evaluation of opportiniies*
    - *committing resources*
    - *understanding implications*
- *the IS department*
    - *project planning*
    - *communication*
- *shopfloor*
    - *changed skill requirements*
    - *job (re)design*
    - *discipline*

c) advantages and disadvantages of implementation and customisation strategies

Implementation strategy big-bang vs phased implementation
Big bang (entire suite implemented at once)
- *Advantages*
    - *No need for temporary interfaces*
    - *Limited need to maintain and revise legacy systems*
    - *Lower risks?*
    - *Functionality linkage*
    - *No going back?*
    - *Shorter implementation time*

(TURN OVER)

- *Disadvantages*
    - *Large peak resources required*
    - *Fewer resources available for particular module*
    - *Longer development time*
    - *No demonstration effect*

Phased implementation

- *Advantages*
    - *Peak resource requirements lower*
    - *More resources can be devoted to a particular module*
    - *Lower risks*
    - *Legacy system fallback*
    - *Learning*
    - *Demonstration effect*
- *Disadvantages*
    - *Heavy use of temporary interfaces*
    - *Need to maintain and revise legacy systems*
    - *Higher risk of uninvolved and uncoordinated personnel*
    - *Higher risk of personnel turnover*
    - *May not achieve full functionality*
    - *Competition with legacy system*
    - *Longer time to install*
    - *Higher total cost*

Customisation (vanilla vs customised implementation)
Vamilla implementation

- *Minimal software change and minimal organisational change*
    - *Requires company processes to be well-matched to ERP models*
    - *May not deliver much improvement or savings*
- *Minimal software change and significant organisation change*
    - *Facilitates future software upgrade*
    - *Reduces development costs*
    - *Don't need to maintain changes*
    - *Opportunity for process improvement*
    - *Value creating processes may be lost*
    - *Organisational change difficult*

Customised implementation

- *Extensive software change and minimal organisational change*
    - *May be appropriate if company processes are considered superior to competitors or high value-adding*
    - *Incurs future costs for upgrading and maintenance*
    - *Creates idiosyncratic solutions*
- *Extensive software and organisational change*
    - *Can achieve significant performance improvement*
    - *Can be very expensive*
    - *High risk*

d) choices may be affected by

- *rate of change of market*

  - *rapid change suggests faster implementation, lower sunk costs, greater flexibility,*
- *positioning strategy – differentiation vs cost leadership*
  - *differentiation suggests customisation*
- *resources available – big bang/extensive customisation are resource intensive*
- *state of current technical/organisational systems*
  - *big bang avoids depends on legacy technology*
  - *vanilla implementation may be opportunity to adopt best practice*

(TURN OVER)

8 a)
Simulation
- *Advantages*
    - *Attempts to model actual system behaviour*
    - *Can use to explore different scenarios*
- *Disadvantages*
    - *Can be expensive*
    - *Can be complex*
    - *Can be difficult to interpret results*

Optimisation
- *Advantages*
    - *Should identify optimal solution*
    - *Well-established methods*
- *Disadvantages*
    - *Usually involves simplifying assumptions*
    - *More realistic models can be complex (and require specialist methods)*
    - *Can be difficult to interpret results*
    - *Can be difficult to understand how results obtained*

Heuristics
- *Advantages*
    - *Easy to understand (treat problem in common sense, holistic way)*
    - *Can be efficient*
    - *Lots of tried and tested example available*
- *Disadvantages*
    - *May not be optimal*
    - *May not be evident why they work*

8. b) LP formulation
minimise 7AX+8AY+2AZ+5BX+4BY+6BZ+3CX+6CY+9CZ
Subject to:
AX+BX+CX=40
AY+BY+CY=40
AZ+BZ+CZ=40
AX+AY+AZ=50
BX+BY+BZ=40
CX+CY+CZ=30

Students who add constraints that all values should be non-negative could get bonus marks, but this is not necessary

c) NW corner heuristic
1) Set initial allocation from NW corner
2) Fulfil as much of demand from first destination from first source as possible
3) If supply from first source > demand from first destination, allocate excess to second destination
4) If supply from first source < demand from first destination, fulfil demand from second source (and so on)

5) *Calculate cost of moving one unit to empty cell preserving demand/supply rim conditions*
6) *Reallocate maximum quantity to cheapest cell along path evaluated (subject to rim conditions)*

Initial NWC allocation:

	X	cost	Y	cost	Z	cost	
A	*40*	*7*	*10*	*8*		*2*	*50*
B		*5*	*30*	*4*	*10*	*6*	*40*
C		*3*		*6*	*30*	*9*	*30*
	40		*40*		*40*		
Cost							
	280		*80*		*0*		
	0		*120*		*60*		
	0		*0*		*270*		

cost for each location = volume cost per unit ie AX=40*7=280*
Total cost = sum of costs for each allocated cell = 810

evaluation of costs of moving loads to empty cells

	x	y	z
A			2-6+4-8=-8
B	5-7+8-4=2		
C	3-7+8-4+6-9=-3	6-4+6-9=-1	

calculations are change in cost of adding 1 unit to target cells, and consequent subtraction/addition from other cells on the evaluation path to maintain rim conditions.
ie if add 1 unit to AZ, need to take 1 from BZ, add 1 to BY, take 1 from AY to match supply/ demand at each location
presence of cells with negative values shows original allocation not optimal
AZ has largest cost saving, => move as large a load as possible to AZ (while maintaining rim conditions). So add 10 to AZ, => take 10 from BZ, add 10 to BY, take 10 from AY (can only move 10, because more would require changes to other cells). The heuristic is "short-sighted", but should eventually find the optimum.

If students do not come up with the allocation below they are not following the heuristic and should lose marks (even if their calculations are correct and they obtain greater cost savings).

d) *New allocation*

	X		Y		Z		
A	40	7	0	8	10	2	50
B	0	5	40	4	0	6	40
C	0	3		6	30	9	30
	40		40		40		
	280		0		20		

(TURN OVER)

0	*160*	*0*
0	*0*	*270*

Total cost =730 => saving =810-730=80