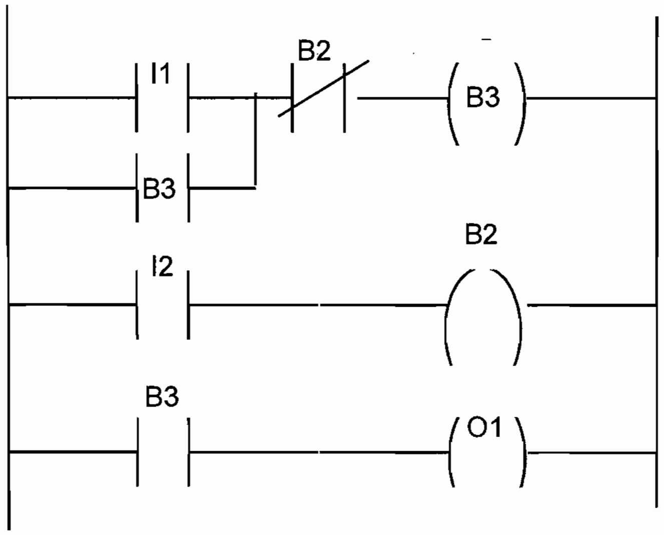
Paper P2 - SAMPLE SOLUTIONS

ORGANISATION AND CONTROL OF MANUFACTURING SYSTEMS

SECTION A
1

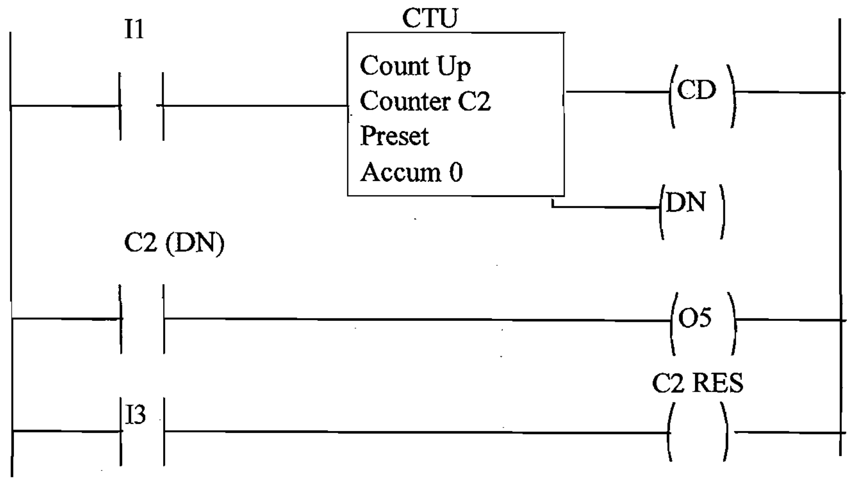
(a)

i. Many inputs such as push-buttons are momentary. In order to generate a permanent input from such momentary inputs, a latching function is used. However, when a latch is used, it is important to have an unlatch as well.

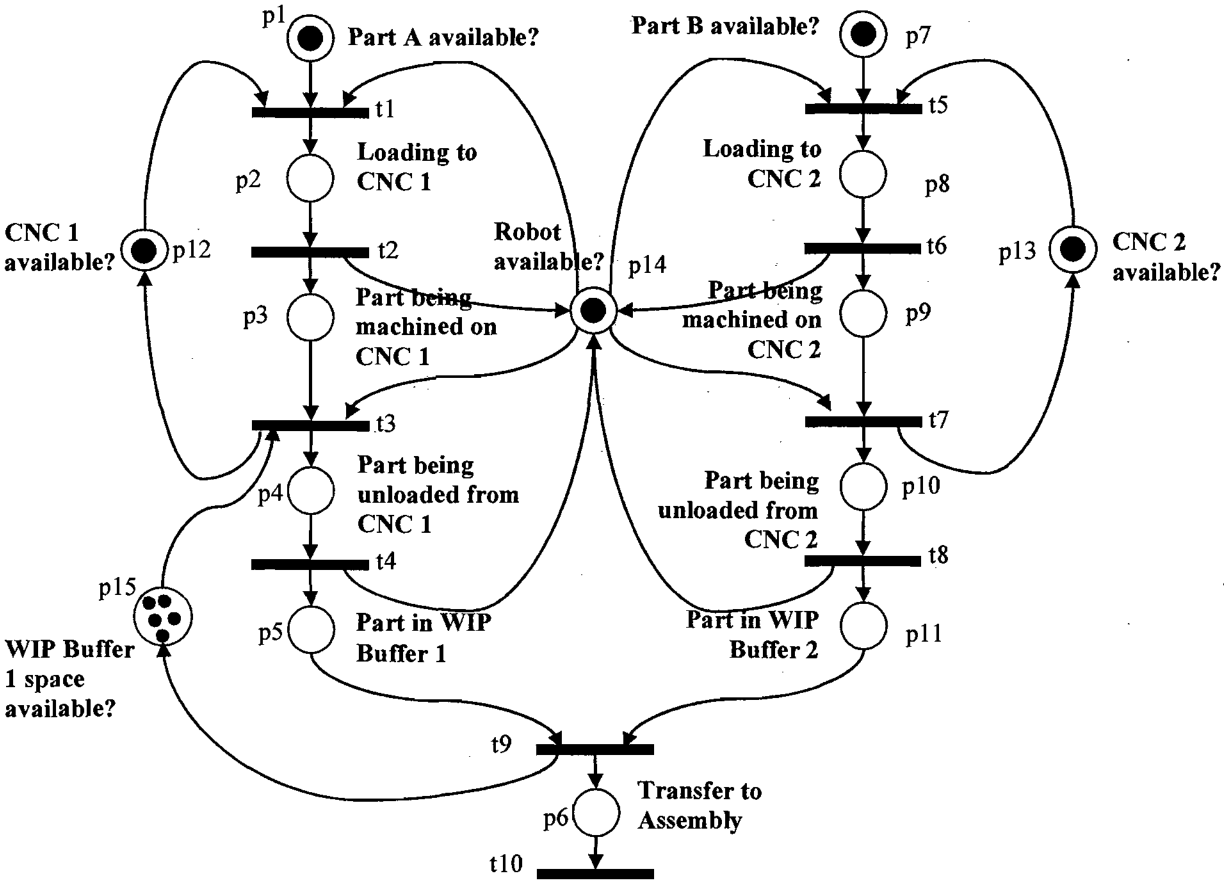


In the above figure, the temporary state B3 is used as a latch for the momentary input I1 that ensures output O1 remains on. B2 is the unlatch function that turns output O1 off, and this is activated by I2

ii. Upward and downward counters are used to monitor the accumulation of events (e.g. parts passing a particular point). Once the accumulated counter reaches the preset value the rung (DN) becomes "true" or "on" and can be used as an alarm or as part of a resetting sequence. CD indicates that the counter is counting.



(b)
(i) The extended Petri Net is as shown in figure below:



(ii) *In the Petri Net shown above, places p12 and p13 represents the availability of the two CNC machines, and p14 represents the availability of the robot. Place p15 represents the spaces in the buffer. The sum of the tokens in p5, p4 and p15 will always be 5.*

(iii) *The current marking of the Petri Net is given by*

$$M = (1,0,0,0,0,0,1,0,0,0,0,1,1,1,5)$$

(a) Some of the main responses are captured in the table below:

Advantages	***Disadvantages***
▪ *higher accuracy*	▪ *additional sensors required*
▪ *respond quicker to changes*	▪ *more complex control*
▪ *copes better with disruptions*	▪ *more maintenance*
▪ *less precision required in actuation*	▪ *potentially unstable*

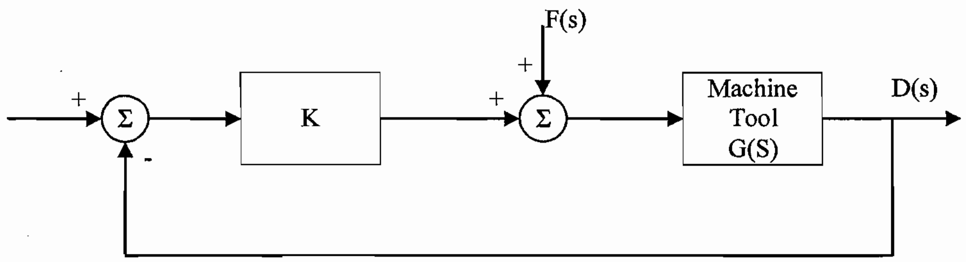
[60%]

(b)

(i) *This is a second order system. Hence the gain could be estimated either analytically or by using the databook.*

Using the mechanics databook, it is possible to read directly that for a 14 Hz (90 rad/s) disturbance, this system (with a damping factor 0.3 and natural frequency 120 rad/s) will have a gain of 1.6 mm/kN. Hence for a 1 kN vibration, the amplitude of the resulting deflection is 1.6mm.

(ii) *New block diagram is shown in figure below:*



Closing the feedback loop with controller K(s) results in the resulting transfer function from F(s) to D(s) being:

$$\frac{D(s)}{F(s)} = \frac{G(s)}{1+KG(s)}$$

Hence,

$$\frac{D(j\omega)}{F(j\omega)} = \frac{\omega_n^2}{-\omega^2 + 2c\omega_n\omega j + \omega_n^2(1+K)}$$

$$= \frac{1}{-(\omega/\omega_n)^2 + 2c\omega j/\omega_n + (1+K)}$$

$$= \frac{1}{\left((1+K) - (\omega/\omega_n)^2\right) + 2c\omega j/\omega_n}$$

The magnitude of the resulting deflection is therefore given by:

$$|D(j\omega)| = \frac{1}{\sqrt{\left[(1+K) - (\omega/\omega_n)^2\right]^2 + (2c\omega j/\omega_n)^2}} \cdot |F(j\omega)|$$

By setting the value of K =2, we can see that the feedback has reduced the amplitude of the resulting deflection to 0.403 ≈ 75%

(iii)

From the given equation:

$$G(s) = \frac{\omega_n^2}{s^2 + 2c\omega_n s^2 + \omega_n^2},$$

we can infer that the behaviour of the machine tool in the face of vibrations depends on two key design factors: (i) ***c****, the damping factor; and (ii)* $\boldsymbol{\omega_n}$*, the natural frequency. Recall that the natural frequency is given by the equation:*

$$\omega_n = \sqrt{\frac{k}{m}}$$

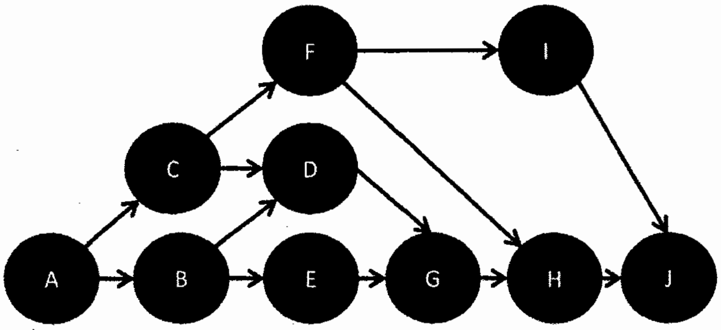
where k = stiffness and m = mass distribution.

Hence, the dynamic response of the machine tool can be improved by (i) increasing the stiffness, (ii) high damping factor; and (iii) improved mass distribution.

SECTION B

3

a) *The network is:*



The work content = Σp_i *= 46 minutes*
*Cycle_time = ((7.5 hours * 60) – 40) / 36 units = 11.39 minutes/unit*
Minimum number of stations = Σp_i */ cycle_time = 46/11.39 = 4.04, i.e. min. 5 stations.*

The line balancing can be achieved by either the ***"longest sequential chain of followers"*** *or* ***"largest 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,E)
Worker 2: (C,F)
Worker 3: (D,G)
Worker 4: (H,I)
Worker 5: (J)

The balancing loss = 1 - Σp_i */ (number of workers * cycle_time) = 1 - (46/56.95) = 19.2%*

*b) According to Little's Law, there is a minimum amount of stock in the system, which is determined by the processing lead-time and the throughput rate. In this case, the minimum amount of stock is n= (17.4 * 60min)*(36 units/410 min) = 91.67, i.e. 92 units. Hence the current WIP inventory can only be reduced by 34.3%.*

c) The main advantages of inventory holding at the raw material level:

- *Ability to buffer against supply uncertainty*
- *Ability to run at economical lot sizes, and thereby reduce the opportunity cost of machine setup*
- *Ability to respond faster to changes in customer demand, as one does not have to wait for the supplier to deliver the materials*
- *Ability to use price reductions in the raw material market to purchase at lowest cost*

The main disadvantages of inventory holding at raw material level:

- *Cost of capital to keep stock, and the cost of warehousing & associated labour, energy etc.*
- *Quality degradation due to stockholding and multiple handling*
- *Risk of obsolescence and depreciation of items in stock*
- *Stockholding masks problems, i.e. does not push people to improve manufacturing operations*

4

(a)

- *The EBQ model considers two types of cost: holding cost and machine setup cost. The basic assumption of the EBQ model is that – with increasing batch size – the cost of holding inventory increases, as the average inventory equals Q/2. At the same time, the fractional opportunity cost of setting up the machine per item decreases with increasing the batch size Q: the larger the batch, the more fractional productive time can used on the machine. The EBQ model marks the minimum of the total cost curve, which is the sum of the holding cost and setup cost.*
- *Mathematically, the cost curves are:*

  Holding cost $= \frac{1}{2} Q * C_H$
  Setup cost $= (D / Q) * C_S$

  With D = annual demand, and Q = batch size, C_S *= cost for one setup,* C_H *= cost for holding 1 item in store for 1 year.*
  The total cost is therefore: $C_{total} = \frac{1}{2} Q * C_H + (D / Q) * C_S$
  After differentiation, the minimal Q is $EBQ = sqrt\ (2*D * C_S / C_H)$
- *EBQ = sqrt [2 * 20,000 * 60 / (15 * 0.1)] = 1,264.9 i.e. 1,265 units.*

(b)

- *If the storage cost is considered, EBQ = sqrt [2 * 20,000 * 60 / (15 * 0.1 + 5)] = 607.6, i.e. 608 crates.*
- *In case of EOQ = 608, the total annual cost would be £3,949.70, using the total cost formula from a.)*

(c)

Main advantages of the EOQ:

- *Simplicity, easy to compute*
- *Stable solution, relatively insensitive to changes in input variables (i.e. inaccurate cost data)*

Main disadvantages:

- *Assumptions of stable demand, zero replenishment lead-times*
- *Tends to favour large batch sizes, in particular if the holding cost is based on interest rates only (i.e. omits warehousing, obsolescence, handling and quality cost).*

- *Does not consider interactions/synergies between parts sharing the same transportation equipment*
- *Does not consider any supply chain implications of the batches (synchronisation with suppliers etc)*

The EOQ model should be used for C-parts only (following the ABC analysis), as here the impact of a potentially higher stock level has less adverse financial consequences. It should not be applied to A- and B-parts.

Good students should be able to answer this last question, although this was not specifically discussed in class.

SECTION C

5 (a)

Generally high capacity systems will be dedicated to a small number of product designs (possible one only) so will give a lower unit cost than more flexible systems. So, high capacity inflexible systems will be appropriate to commodities with little product differentiation, stable markets, and where price is the main purchase driver. In contrast, for faster changing products or markets, where price is determined more by innovation, flexibility will be more valuable than capacity, to allow rapid response to market changes.

(b)

(i)

Maximum demand is 12,000 litres per month, so 12 tanks are required. Maximum output is thus 144,000 litres per year, where as demand adds to 84,000 litres per year. So capacity utilisation is 84/144 = 58%.

(ii)

Average demand is 7000 litres per month. End of month stocks are thus:

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Demand in 1000 litres	5	9	12	13	13	11	7	2	0	0	2	0

This gives an average stock of 6160 litres.

(iii) The manufacturer can try to manage demand or manage supply. To manage demand, he could:

- *Reduce the price or build other promotions to increase sales in low demand months*
- *Introduce a second product with a different cycle – apparently this is a summer beer, so could he make a winter beer with the same equipment?*
- *Enter new markets with a reversed buying cycle – for instance in the southern hemisphere.*

To manage supply, he could:

- *Find a way to increase the speed of fermentation in times of high demand*
- *Find other products that could be made by the same or similar equipment, perhaps where the equipment was redesigned for increased flexibility*
- *Outsource or subcontract production during peak periods.*

6. *To answer (a) and (b) it is best to find a general formula for capacity and utilisation. Assuming both processes start a batch production with a switchover, the time for process B must always be longer (the total operating time is the same, but the switchover time is greater) so the cycle time for a batch of N is:*

T = 200+30N+300+50N = 600 + 80N

During this cycle, N of product X (or product Y) are produced, so the capacity (output rate) per hour is

*C = 3600*N/(600+80N)*

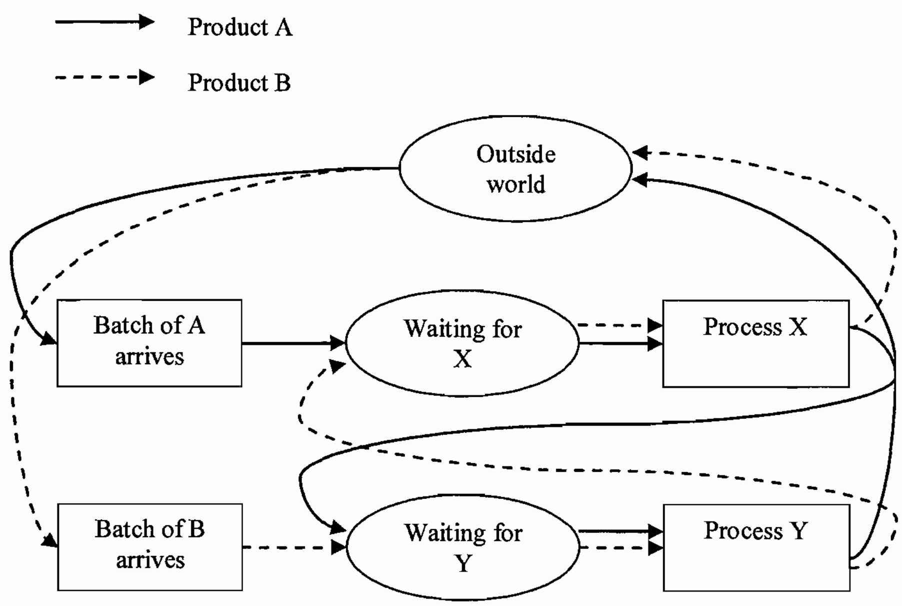
During this time, process A is operating for 80N and process B for 80N, so the utilisation is

*U = 100%*160N/(2*(600+80N))*

(a) From the above, when N = 1, U = 12%, C = 5.3 per hour.

(b) When N=5, U=40%, C=18 per hour; when N=20, U=73%, C=33 per hour.

(c) Activity cycle diagram assumes both processes can draw directly on the unlimited supply of waiting work in the "outside world" queue, and that work returns to the outside world immediately after it is completed.



(d) The event list will be

0	*A switches over to X, B switches over to Y*
200	*A starts processing X*
220	*A finishes processing X, switches over to Y*
300	*B starts processing Y*
330	*B finishes processing Y, switches over to X*
420	*A switchover complete, starts processing Y*
480	*A finishes processing Y, starts switchover to X*
630	*B starts processing X*
680	*B finishes processing X, starts switchover to Y*
680	*A starts processing X*
700	*A finishes processing X, starts switchover to Y*

(e) Broadly, the manager should choose as large a batch size as possible, to avoid the loss of productivity associated with the switchover times. The batch size will be limited by available space for storage between the two processes, supply constraints, order patterns, or the risk that excess production will incur. In future it would be sensible to aim to reduce the switchover on both processes, and attempt to balance the line – ideally by buying new equipment to allow the two products to be made independently.

SECTION D

7.

(a) *see spreadsheet next page*

Euclidean distance $d_{AB} = \sqrt{(x_A - x_B)^2 + (y_A - y_B)^2}$

load distance = $d_j * l_j$

b) *Transportation network e.g. access to motorway i.e. effective distance*
Local infrastructure and incentives e.g. suitable sites, utilities, workforce
Social factors e.g. preferences of senior management

the categories will be mentioned in lectures, but good students were able to give examples (beyond those listed above)

c) *International location factors*

- *choice of country*
  - *financial*
    - *duties and tariffs*
    - *taxes*
  - *regulations*
    - *employment*
    - *environmental*
    - *construction*
  - *risk*
    - *political stability*
    - *economic stability*
    - *social stability*
  - *labour force*
    - *costs*
    - *education/skill level*
  - *local culture*
    - *ethics*
    - *language*
  - *infrastructure*
    - *transportation*
    - *utilities*
- *within country similar to b), but geared to local resources (which are likely to be much more unevenly distributed than in UK).*
  - *access to ports*
  - *location relative to transportation network*
  - *location relative to supplies*

Load/distance or Centre of Gravity probably not applicable, more likely to use some sort of Multi-attribute Utility Theory for deciding between different possible locations.

(a) spreadsheet

	X	Y	Load
CustomerA	10	50	60
CustomerB	40	20	40
CustomerC	50	10	50
Location1	20	30	
Location2	30	50	
Location3	40	20	

Load distance

	distance	dist sqrd	sqrt	load distance	
Xa-X1	10	100			
Ya-Y1	-20	400	22.36	1341.64	
Xb-X1	-20	400			
Yb-Y1	10	100	22.36	894.43	
Xc-X1	-30	900			
Yc-Y1	20	400	36.06	1802.78	
				4038.84	
Xa-X2	20	400			
Ya-Y2	0	0	20	1200	
Xb-X2	-10	100			
Yb-Y2	30	900	31.62	1264.91	
Xc-X2	-20	400			
Yc-Y2	40	1600	44.72	2236.07	
				4700.98	
Xa-X3	30	900			
Ya-Y3	-30	900	42.43	2545.58	
Xb-X3	0	0			
Yb-Y3	0	0	0	0	
Xc-X3	-10	100			
Yc-Y3	10	100	14.14	707.11	
				3252.69	So Location3 is the best choice

Centre of Gravity

	A	B	C	sum l	
X	600	1600	2500	150	31.33
Y	3000	800	500		28.67

8.

a)

- *Risk pooling occurs where demand is aggregated across several locations (so higher than average demand in one location may be offset by lower demand in another).*
- *Allows reduced safety stock and inventory levels*
- *best where high coefficient of variation in demand (so greatest reduction in safety stock possible)*
- *less benefit where demand at different locations is positively correlated*

b)

- *direct shipping does not benefit from risk pooling and will increase transportation costs, but may reduce holding costs.*
- *Warehousing enables risk pooling and reduced inbound transport costs, but incurs holding costs*
- *Cross docking reduces inbound transport costs and has low holding costs, but does not benefit from risk pooling*
- *transshipment enables risk pooling, but does not reduce transport or holding costs*

- *direct shipping appropriate where items are large and/or bulky or transport speed is a priority (eg perishable goods, speciality goods)*
- *warehousing is appropriate where production is remote, where risk pooling is beneficial, where rapid, JIT delivery is required e.g.*
- *Cross-docking is appropriate where a company is supplying high volume amd variety of products frpm multiple suppliers to multiple locations*
- *transhipment is appropriate to provide flexibility for customers from a single supplier with multiple locations*

c)

- *Quick response (clothing manufacturers and retailers)*
    - *Suppliers receive Point of Sale (POS) data to improve forecasting and scheduling*
    - *very loose form of partnership involving little commitment by retailer, but allowing suppliers to improve delivery performance*
- *Continuous/rapid replenishment (Tesco, Die Tech, Campbell Soup)*
    - *Suppliers receive POS data to prepare shipments at previously agreed intervals to maintain specific inventory levels*
    - *retailer retains control of orders, but supplier gets commitment to certain level of business*
- *Advanced continuous replenishment (Kmart)*
    - *Seeks continuous improvement in performance eg reduced inventory*
    - *gives more control to supplier in order to get potential improvement*
- *Vendor Managed Inventory (VMI) P&G and Walmart, Paperpak*
    - *Supplier decides on inventory levels for customer (within bounds) and manages inventory at customer site*
    - *Aim is to eliminate customer oversight of orders => reduce their costs*
    - *supplier ownership of inventory also reduces costs*

Main difference is about control, but students may also mention new skills needed by supplier (forecasting, forecasting and inventory control, retail management respectively)
Quick response – retailer retains control, supplier just gets access to POS data
CR & ACR – either party own inventory (ACR supplier has inventive to improve)
VMI – supplier owns inventory and control delivery

d) CPFR

- *Key difference is systematic collaboration*
    - *Use of a combination of non-proprietary vehicles including the Internet to share information*
    - *Focus on integration of business processes between retailer and manufacturer*
- *Retailer and manufacturer share a broader set of information dynamically*
- *Coordinated collaboration from planning and forecasting through entire execution.*

Challenges

- *Organizational readiness*
    - *move from adversarial/independent relationship to collaboration*
- *Process confirmation*
    - *need to agree and implement common (or compatible) processes*
- *Integration of supply chain collaboration tools with backend applications*
    - *not always straightforward*
- *Change management*
    - *involves a big organisational change*

e)

Possible reasons

- *establish preferred relationship with customer (=> exclude competitors)*
    - *reduced contract costs*
    - *justify dedicated assets*
    - *opportunities for mutual learning*
- *reduced variability (smooth demand)*
- *greater visibility => potential for greater efficiency*
    - *optimise whole supply chain*
- *other*
    - *because other companies are doing it*
    - *because consultants/vendors sell them "solutions"*
- *risks (increase with the relative power of the retailer)*
    - *loss of control*
    - *loss of flexibility*
    - *greater variability*
    - *coordination and communication problems*
    - *lack of commitment*
    - *opportunism*