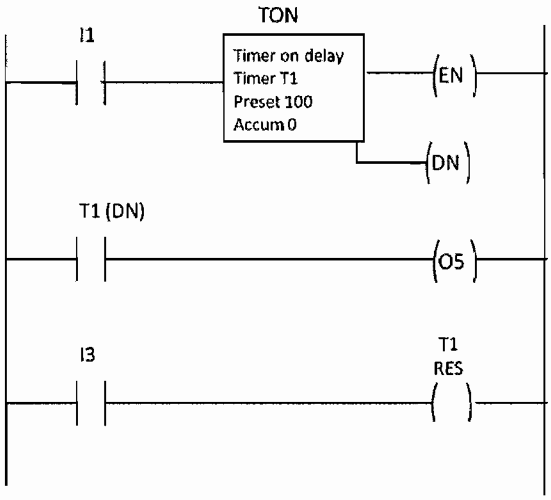
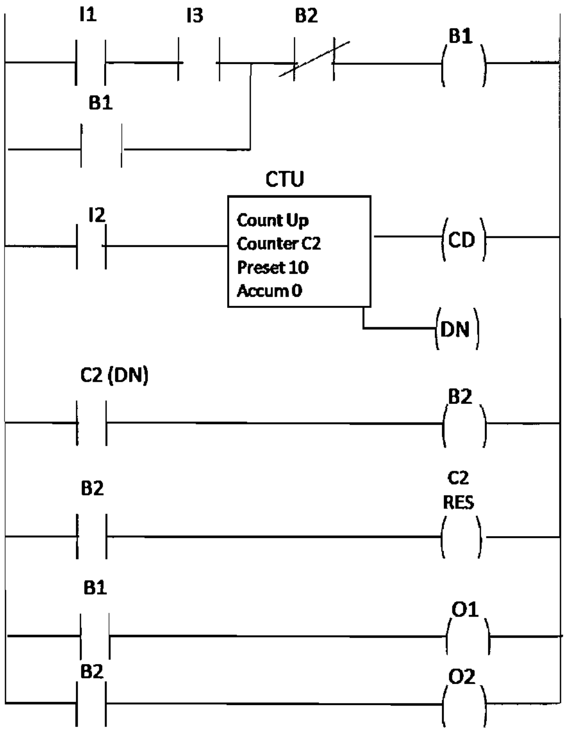
MANUFACTURING ENGINEERING TRIPOS PART I
Paper P2 – SAMPLE SOLUTIONS
ORGANISATION AND CONTROL OF MANUFACTURING SYSTEMS

SECTION A

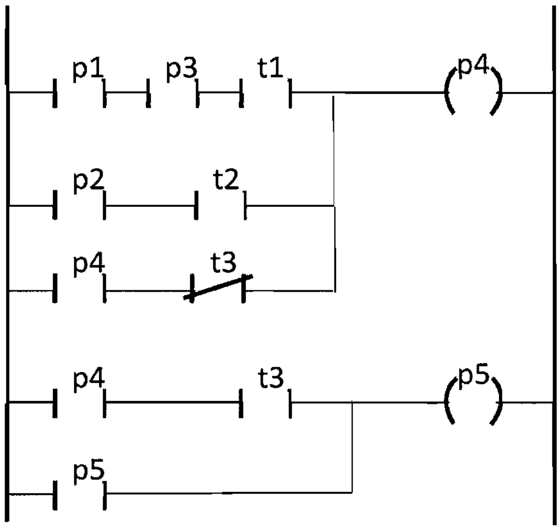
1 (a) Timer-On (respectively Timer-Off) functions are set by the associated rung conditions becoming true (resp. false). They remain set until the accumulated time reaches a preset value. EN indicates that the timer is enabled.



(b)


I1
I3
B2
B1
B1
CTU
I2
Count Up
Counter C2
Preset 10
Accum 0
CD
DN
C2 (DN)
B2
B2
C2
RES
B1
O1
B2
O2

(c)


p1
p3
t1
p4
p2
t2
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t3
p4
t3
p5
p5

Version 4

2 (a)

ADVANTAGES	*LIMITATIONS*
• *flexibility of operation*	• *additional cost of machines*
• *ability to produce complex shapes*	• *additional effort for one-off jobs*
• *easy to make machine adjustments*	• *increased maintenance requirements*
• *reduced operator experience requirement*	• *complexity associated with diagnosing faults*
• *reduced set up and fixturing time*	• *need for more highly trained personnel for managing and maintaining the machinery*
• *reduced number of set ups*	
• *rapid preparation of programmes*	
• *reduced tooling costs*	

(b) *Three categories of position disruption are:*

- *Static loads*
  - *Caused due to masses of the work-piece and machine components, forces due to the cutting process, etc.*
- *Dynamic disturbances*
  - *Caused due to vibrations caused by external or internal processes*
- *Thermal variations*
  - *Caused due to temperature variations within the machine tool, as well as in the surroundings.*

For a number of reasons, 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*

(c)
(i)

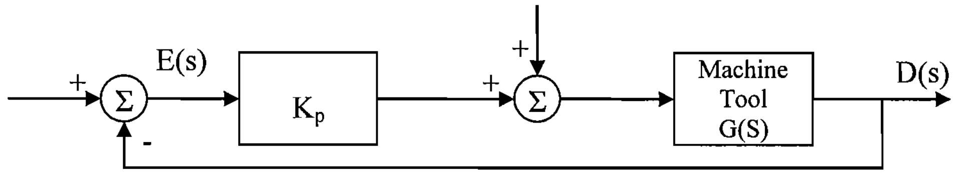


Fig. 1

The transfer function from reference input to tracking error is given by

$$E(s) = \frac{1}{1 + GK_p}$$

Setting $s = 0$ *for steady state analysis, quickly yields*

$$E(s) = \frac{10}{10 + 0.9K_p}$$

Setting $E(s) = 0.01$, *we have* $K_p = 1100$.

(ii) Good students would be able to remember the implications of different types of controllers. The high value of the proportional controller indicates that the machine is prone to oscillations. A tighter control regime such as integral control would give better tracking performance. However, implementing purely integral control would slow down the machine tool. PID control might be a better solution.

Comment: This question was poorly done by many, especially part (c). Most of the students did not remember the transfer function for steady state error nor could they derive it.

SECTION B

3 ***A good answer should include the following points:***

a.)

- *The EBQ model considers two types of cost: holding cost and ordering cost. The basic assumption of the EBQ 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 EBQ model marks the minimum of the total cost curve, which is the sum of the holding cost and ordering cost.*

- *Mathematically, the cost curves are:*

  Holding cost = $\frac{1}{2} Q * C_H$

  Ordering cost = $(D / Q) * C_O$

  With D = annual demand, and Q = batch size, C_S *= setup cost,* 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 $EBQ = sqrt(2*D * C_S / C_H)$

- *Annual demand is 6000 units. EBQ = sqrt [2 * 6,000 * 5,000 / (4,000 * 0.1 + 500)] = 258.2 , i.e. 258 units.*

b.)

There are a range of problems associated with the EBQ model. A good answer is expected to include (at least) the following points:

- *The EBQ model is based on the assumption of constant demand over the year, which is hardly the case in reality. Therefore, any change in demand will shift the optimal position away from the calculated EBQ. Furthermore, recalculating the EBQ in every period to correct the problem would be require high computational effort, thus nullify the EBQ's main advantage of simplicity.*

- *The EBQ model does not consider the rate of production. This calculation is very simplistic and might lead to stock-outs or the need to hold additional safety stock to buffer, and hence incur additional cost.*

- *The cost factors for placing an order or keeping an item in stock for one period are very hard to determine exactly. Estimating the cost of administrative processes is in particular very hard to quantify, as often fractions of a person's work time need to be estimated. Therefore, the cost data the model is based on often draws on inaccurate assumptions.*

- *Further points could include that items are looked at individually, i.e. no synergy of joint ordering / delivery between parts is explored).*

The main advantages of the EBQ model are:

- *The simplicity of the model is the key advantage. Only based on few key parameters, the EBQ model can give the scheduler or planner a very good guideline how large* *production batches should be. In particular for B- and C–items this brings a significant simplification of the planning process.*

- *The robustness of the model is a second advantage. As outlined above, several key parameters such as the ordering and holding cost in the formula have to be estimated, which induces a serious risk of inaccuracy. However, the model mathematically mitigates this risk by drawing the square root. Thus, the model is less sensitive to deviations in the estimated cost factors, and wrong estimates only move the calculated EBQ away from the optimal position.*

c.)

- *For A-parts, the relative impact of the individual part requires a need-driven ordering policy, as holding these items in stock would be very costly. A-parts should only be ordered when actually needed. For example, JIT or MRP-based ordering systems might be used that will order parts only when needed, and not "just in case".*
- *For B-parts, there is no clear policy recommendations, as these could be either ordered individually (like the A-parts), or automatically, like the C-parts. Here, a decision should be made on a part-by-part basis which method to adopt.*
- *For C-parts, the ordering cost will be considerably greater than the stockholding costs. These tend to be low-value, high-volume items ("nuts and bolts"). Therefore, an automatic review policy is most appropriate, such as a reorder point with periodic review, i.e. a (R,s,S) or (R,Q) policy, or a policy based on a re-order point (s,S) or (s,Q) policy.*

d.)

- *The two-bin system is a scheduling system that controls two connected operations. It takes its name from the fact that there are two bins of parts that circulate between these two operations. As the downstream operation starts working on bin #1, it will do so until bin #1 is empty. At this point, bin #1 will return to the feeder operation, where it serves as the authorization to make more parts. While the feeder operation replenishes bin #1, the downstream operation works on the material in bin #2. As bin #1 is replenished, it will return to the downstream operation. This system is based on the assumption that the rate of replenishment at the feeder operation is greater than*
- *The main advantages of the system are: (1) the maximum amount of inventory in the system is fixed, as it cannot be greater than "two bins" at any point in time, and (2), the system is paced by customer demand, or consumption, at the downstream end. Thus, there cannot be any overproduction.*

Comment: This question was again attempted by slightly less than half the class possibly due to the descriptive nature of the question. However, the attempts were generally good. A common error: most got confused between "A" parts and "C" parts in the ABC analysis.

4 *A good answer should include the following points:*

a)

A good answer should include the following points:

- *There is a minimum inventory in a manufacturing system needed to run the operations without stock-outs. According to Little's Law, this inventory is a function of lead-time and throughput rate.*
- *In general, this cycle stock found in a manufacturing system is half the batch size used (Q/2). The larger the batch, i.e. the less frequent a part is ordered or made, the more inventory is needed.*
- *In addition to the cycle stock, there is also safety stock, which is used to buffer uncertainties. These uncertainties can arise from suppliers (supply uncertainty), from the market (demand uncertainty, or volatile demand which requires a buffer of finished goods), and from within the production process (machine break-downs, quality problems and the like).*
- *Extra inventory can also be used to smooth or level production, in particular in markets with volatile demand, where the notion is that the extra cost of inventory is offset by the saving through stable production levels.*
- *Further points that could be mentioned are the exploitation of economies of scale and price fluctuations in raw material markets.*

b)

- *According to Little's Law, the minimum WIP inventory is a function of the throughput rate and the production lead-time. The formula is N = Lambda * T, with N = minimum required inventory, Lambda = Throughput in units per time, and T = production lead time.*
- *Calculation: 2 shifts of 7.5 hours give 15 working hours/day. With a production rate of 14,400 / month (= 720/day, or 48/hour, or 0.8/minute), and a production lead time of 490 minutes, the minimum inventory is this N = 0.8 units/minute * 490 minutes = 392 units.*
- *Thus, the inventory level could be reduced by n=[(490-392)/490]*100=18.3%.*

c)

- *Exponential smoothing forecasts in principle can be made responsive by using a large smoothing constant Alpha. However, even for large values of Alpha, which would make the forecast very responsive to trends, the forecast would not "lock on" to such exponential trends.*
- *One approach to improving the demand forecast might be to use triple (or quadratic, or Type III) exponential smoothing, as neither simple nor double (or linear, or Type II) exponential smoothing models are able to "lock on" to exponential growth trends.*

- *Another approach might be to extract general patterns from past years as to how demand climbs in the months leading up the summer, and use that information to predict demand. Obvious methods here would be Fourier analysis, or time series modelling.*

d)

- *The main factors to consider are:*
    - *Household disposable income, as this drives the purchases on non-essential goods*
    - *Interest rates, as this determines to what degree available income has to be used to cover mortgage payments*
    - *Consumer confidence indices, as this determines whether or not customers are likely to spend disposable income, or not.*
- *Other indicators that might be considered are:*
    - *Demographic profile of the UK population, to understand the size of the market, by age.*
    - *Oil price, as this might drive the substitution from cars to bikes*

Comment: This was a popular question and was generally very well attempted. The average would have been much higher if not for an extremely poor performance by one student. Part (c) was used as the differentiator since the quality of responses varied.

SECTION C

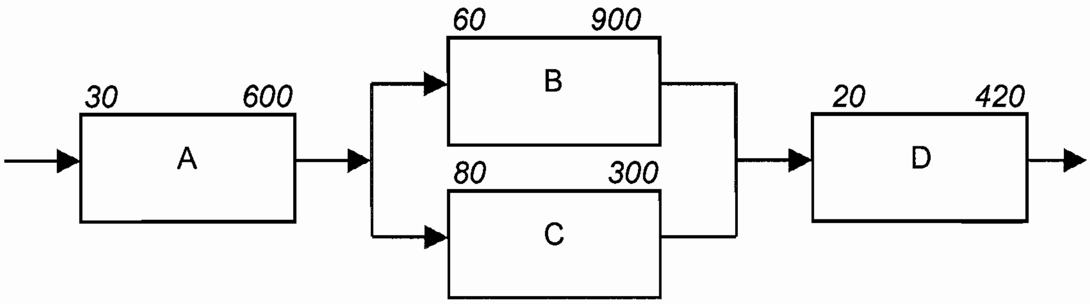
5 *(a)*

The main difficulties which inhibit perfect utilisation of a manufacturing system - ie which restrict the actual capacity - are:

- *Bottlenecks - and more generally imbalances in task times*
- *Setup/Switchover delays*
- *Defects, errors and breakdowns*
- *Co-ordination conflicts (of equipment and labour) - waiting for all the inputs required before being ready to start. This is particularly related to product mix and uncertainty of demand*
- *Variability in process times causing a build up of inventory*
- *Supply shortages or quality problems*

(b)

(i)



(ii)

	A (one batch of each product)	*B*	*C*	*D (one batch of each product)*
No. products to process for one batch of each product	*20*	*10*	*10*	*20*
Setup time	*1200*	*900*	*300*	*840*
Run time	*600*	*600*	*800*	*400*
Time for one batch of 10 of each product	***1800 (Bottleneck)***	*1500*	*1100*	*1240*
Average time for one pair or products	*180*			
Capacity in "no of pairs (one of each product) per hour"	*20*			

No. products to process for one batch of each product	*2000*	*1000*	*1000*	*2000*
Setup time	*1200*	*900*	*300*	*840*
Run time	*6000*	*6000*	*8000*	*4000*
Time for one batch of 100 of each product	*7120*	*6900*	***8300 (Bottleneck)***	*4840*
Average time for one pair or products			*83*	
Capacity in "no of pairs (one of each product) per hour"			*43.3*	

(iii) The bottleneck has shifted due to the high setup time of process C. With smaller batch sizes, the processing time plays a bigger role in determining capacity. However, as batch sizes get larger, capacity increases – however, the setup times become more important. Moreover, increasing the batch size would result in loss of flexibility, and add to inventory costs.

(c) There are three options available for coping with demand variations:

- *Ignore the fluctuations and keep activity levels constant (level capacity plan) – however, there is a cost associated with keeping inventory, and also the risk of the forecast being inaccurate.*
- *Adjust capacity to reflect the fluctuations in demand (chase demand plan) – this would involve significant investment in machinery, labour etc – again might be risky.*
- *Attempt to change demand to fit capacity availability (demand management) – exploring export opportunities especially to countries in the southern hemisphere (Australia, NZ, etc.) where cricket is popular.*

In reality, most manufacturers use a combination of the above plans. Good students will be not just repeat what is said in the lectures, but be able to significantly elaborate on these plans and apply it to the given problem.

Comment: The quality of responses was low. Many students struggled with the calculation of the capacity of the production line and identification of bottleneck.

6 (a)

Characteristics of MRP

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

Most of the implementations follow MRP for overall control and JIT for internal control. Good students will significantly elaborate on these points.

(b)

(i)

Widget

Week	0	1	2	3	4	5	6
Gross Requirements		100		100	150		100
Projected Available Balance	100	0	0	25	0	0	25
Scheduled Receipts		0	0	0	0	0	0
Planned Order Releases			125	125		125	0

Sub-assembly B

Week	0	1	2	3	4	5	6
Gross Requirements		0	125	125	0	125	0
Projected Available Balance	50	50	0	175	175	50	50
Scheduled Receipts		0	75	0	0	0	0
Planned Order Releases		300					

Component A

Week	0	1	2	3	4	5	6
Gross Requirements		300	250	250	0	250	0
Projected Available Balance	500	200	450	200	200	0	0
Scheduled Receipts		0	500	0	0	0	0
Planned Order Releases					50		

Component C

Week	*0*	*1*	*2*	*3*	*4*	*5*	*6*
Gross Requirements		*600*	*0*	*0*	*0*	*0*	*0*
Projected Available Balance	*1000*	*400*	*400*	*400*	*400*	*400*	*400*
Scheduled Receipts		*0*	*0*	*0*	*0*	*0*	*0*
Planned Order Releases							

(ii) The company is far from JIT at present – push scheduling and high levels of inventory. However, demand seems to be lumpy, with some spikes. JIT can be recommended only if there is sufficient capacity to meet such demand. Nevertheless, the principles of JIT – aiming at low stock levels, and reducing setup times are basic tenets of good practice even if other scheduling is required.

SECTION D

(7)

(a)

$$Weeks\ of\ supply = \frac{\sum Inventory\ level * Unit\ price}{Sales\ per\ week}$$

$$Inventory\ turns = \frac{Annual\ Sales}{\sum Inventory\ level * Unit\ price}$$

		Inventory level	Unit Price (£)	Total Cost
Raw material	R1	2000	£ 0.50	£ 1,000.00
	R2	1400	£ 4.00	£ 5,600.00
	R3	800	£ 7.00	£ 5,600.00
	R4	600	£ 12.00	£ 7,200.00
	R5	400	£ 16.00	£ 6,400.00
	R6	200	£ 20.00	£ 4,000.00
Work in Progress	W1	90	£ 70.00	£ 6,300.00
	W2	80	£ 140.00	£ 11,200.00
	W3	160	£ 180.00	£ 28,800.00
Finished Goods	F1	70	£ 1,200.00	£ 84,000.00
	F2	140	£ 1,600.00	£ 224,000.00
Total supply				£ 384,100.00
Weeks of supply				**8**
Inventory turns				**6.25**

(b) Within the enterprise, the trade-offs are:

Functional objectives	*Impact on Inventory*	*Impact on Customer Service*	*Impact on Total Costs*
High customer Service	⇧	⬆	⇧
Low transportation costs	⇧	⇩	⬇
Low warehousing costs	⬇	⇩	⬇
Reduced inventories	⬇	⇩	⬇
Fast deliveries	⇧	⬆	⇧
Reduced labour costs	⇧	⇩	⬇
Desired results	⬇	⬆	⬇

Across the supply chain:
Raw material supplier wants:

- Stable volume requirements
- Limited variability of mix of orders
- Flexible delivery times
- Large demand volumes

Manufacturing wants:

- Known demand pattern
- Limited changeovers, long production runs
- Limited variability of demand

Materials, warehousing and logistics want:

- Minimum transport costs
- Minimum inventory
- Rapid replenishment

Retailer wants:

- Short order lead times
- Efficient and accurate deliveries

Customer wants:

- Complete availability
- High variety
- Low prices

Good candidates should be able to apply these ideas to produce a coherent discussion of the statement.

c) Again, we will not have discussed this in this specific form, but concepts from the course such as the causes of the bullwhip effect may be relevant i.e.

- Long cycle times (information/delivery lags) – *so takes time before upstream demand changes feed through to downstream suppliers*
- Decisions made locally (by one business) not globally (by the whole chain) – *upstream companies immediately cut orders when demand starts to fall (rather than hold inventory or work with suppliers to promote sales)*
- Conservative decision making
  - managers are generally risk averse – *reluctance to cut production in hope of rapid recovery from recession*
  - risks are usually not symmetric - stockout hurts more than excess – *don't want to risk losing orders with key customers due to stockouts*
- Poor forecasting of demand – *producing to outdated forecast (and not adjusting quickly enough)*
- Inflated orders – *probably works in reverse in recession ie excessively deflated orders*
  - due to wrong incentives – *geared to increased production*
  - due to fear of shortage – *due to fear of excess inventory*
- Order batching – *may mean that production not affected until existing orders complete, then no new orders*

(8) a) Standards are discussed at various points in the course (VMI, business process eg RosettaNet.

PapiNet), but not directly in terms of their importance in B2B transactions. These should be evident from the lectures, though:

- common language => reduced communication problems
- common processes => better integration
- modularity => flexible to company requirements
- may be non-proprietary => avoid ties to particular supplier/customer
- network effects => increased participation should enable reduced costs

b) advantages of internet-based transactions

- flexibility
- open standards
- low entry cost
- low operating cost (25% of EDI)

c) EDI continues to dominate because

- installed base – reluctance to abandon investment and experience
- used by large manufacturers (account for large proportion of B2B transactions)
  - gives them more control
- perceived security risks of internet

d) internet-based transactions likely to be favoured for

- short-term surplus/shortage
- one-off purchases/sales
- standardised products/services
- high search costs e.g. complex specification, rarely-purchased products

Types of marketplace

- MRO hubs Ariba, WW Grainger
- Exchanges PaperExchange.com ThePlasticsExchange.com
- Yield managers Employease, Rapt
- Catalogue hubs SciQuest, Vertmarkets