ENGINEERING TRIPOS PART IIA: 3E10 Operations Management for Engineers

1 (a) Explain why firms use forecasts. Illustrate with one brief example.

[20%: 10% explanation, 10% example]

A good answer should include:

- *Forecasts help by making decisions about resourcing the organisation for the future. Expanding or decreasing capacity mostly requires preparation and cannot be done instantaneously*
- *For example, the process of hiring new employees or acquiring new machinery often takes time, and firms should instigate these processes before the new employee or machine becomes necessary*

(b) A distinction is often made between qualitative and quantitative approaches to forecasting. Briefly explain the difference, and for each approach give one example of a method used, and one problem associated with the approach.

[20%: 5% per method, 5% per problem]

A good answer should include:

Qualitative approaches involve collecting and appraising judgments, opinions, best guesses, past trends, and predictions from experts. Quantitative approaches involve analysing patterns of data on past behaviour.

- *Examples of methods used by qualitative approaches are market surveys, Delphi study, scenario planning, and the panel approach.*
- *Problems associated with qualitative forecasts are bias and ignorance.*
- *Examples of methods used by quantitative forecasts are time series analysis (e.g. decomposition and Fourier analysis), causal modeling, moving average, and exponential smoothing.*
- *Problems associated with quantitative forecasts are that they miss unusual events and short term issues, and are almost exclusively based on historical data.*
- *Quantitative approaches can further be divided into extrinsic and intrinsic.*

(c) The table below gives the demand for a product for nine periods. Use the 4-period moving average to calculate forecasted demand from time 1 up until time 5. Use exponential smoothing (ES) with $\alpha = 0.2$ to forecast demand from time 2 until time 5. For exponential smoothing use X_t of time 0 as the forecast of time 1 to calculate your forecast from time 2 onwards.

Time	Demand
-3	201
-2	197
-1	190
0	208
1	201
2	185
3	182
4	220
5	200

[40%: 15% MAV, 25% ES]

Answer:

Time	Demand	4-period MAV	ES with α = 0.2	Without rounding
-3	201			
-2	197			
-1	190			
0	208			
1	201	199	208	208
2	185	199	207	206.6
3	182	196	203	202.28
4	220	194	199	198.224
5	200	197	203	202.5792

(d) Compare the use of a large value of α with the use of a small value of α in simple exponential smoothing.

[20%]

A good answer should include:

- *A large value of* α *results in a forecast that is very responsive to changes in demand because* X_t *(real demand for the period in which the forecast for the next period is made) is given most weight. I.e., a large value of* α *implies that a considerable amount of weight is being placed on current observations of demand. Consequently, the forecast will adjust quickly to changes in the demand pattern.*
- *A small value of* α *results in a forecast that is less responsive to changes in demand while* S_{t-1} *(the forecast for the preceding period, based on actual demand patterns) is given most weight. I.e. a small value of* α *implies that little weight is placed on current observations of demand while a considerable amount of weight is given to the history of forecasted demand. Consequently, the forecast is stable but not very responsive.*

Note: students do not need to include X_t *and* S_{t-1} *in their answers and will be given full credit if they can explain the difference in words.*

2 A manufacturer has fifty hours to complete the processing of ten jobs, A-J, all of which have to go through two consecutive processes. The first is printing and the second is binding. The technology is such that two jobs cannot be processed together. Each job requires the same machine for the first operation (printing), of which there is only one, and the same machine for the second operation (binding) of which there is also only one. If necessary, entire jobs (printing plus binding) can be subcontracted, the cost of which is the same for all jobs. The times needed for the two processes are given in the table below:

Job	A	B	C	D	E	F	G	H	I	J
Printing	6	13	11	10	5	9	11	12	5	7
Binding	2	7	8	1	4	10	13	14	3	5

(a) If the deadline of fifty hours is to be met and the manufacturer wants to minimise the total cost of subcontracting jobs, provide the optimal schedule and indicate which jobs have to be subcontracted. State which approach you use.

[35%]

A good answer should include:
Moore's Algorithm
The final optimal schedule: FJEIAD
Subcontracted jobs: H, B, G and C (in any order).

This question is worked out as follows:

The deadline for the first operation can be calculated by subtracting processing time on the second machine from the overall deadline of fifty hours.

Job	A	B	C	D	E	F	G	H	I	J
Due	48	43	42	49	46	40	37	36	47	45

EDD (regardless of deadlines): H, G, F, C, B, J, E, I, A, D

Moore's algorithm can now be applied.
Start with a schedule based on earliest due dates (EDD):

Job	H	G	F	C
Processing time m/c 1	12	11	9	11
Completion time m/c 1 printing	12	23	32	**43**
Due date for m/c 2	36	37	40	42

Job C is late: drop the longest job allocated (H) and start again

Job	G	F	C	B
Processing time m/c 1	11	9	11	13
Completion time m/c 1 printing	11	20	31	**44**
Due date for m/c 2	37	40	42	43

Job B is late: drop the longest job allocated (B) and start again

Job	G	F	C	J	E	I
Processing time m/c 1	11	9	11	7	5	5
Completion time m/c 1 printing	11	20	31	38	43	**48**
Due date for m/c 2	37	40	42	45	46	47

Job I is late: drop the longest job (G [or C]) and start again

Job	F	C	J	E	I	A	D
Processing time m/c 1	9	11	7	5	5	6	10
Completion time m/c 1 printing	9	20	27	32	37	43	**53**
Due date for m/c 2	40	42	45	46	47	48	49

Job D is late: drop the longest job (C [or G]) and start again

Job	F	J	E	I	A	D
Processing time m/c 1	9	7	5	5	6	10
Completion time m/c 1 printing	9	16	21	26	32	42
Due date for m/c 2	*40*	*45*	*46*	*47*	*48*	*49*
Processing time m/c 2	10	5	4	3	2	1
Completion on m/c 2 *(must meet deadline!)*	19	24	28	31	34	43 **OK**

The new schedule is FJEIAD and finishes on 43
We subcontract H, B, G and C (in any order).

Note that another approach is applying Johnson's rule for a two-machine workshop (as worked out in b) and taking out the longest jobs "by the eye". This gives exactly the same schedule.

(b) Due to an unforeseen event the supplier to which the manufacturer used to subcontract jobs has gone bankrupt and no other suppliers are available. Fortunately, at the same time, an increase in the popularity of the manufacturer's products means that its customers are willing to wait longer than the previous fifty hours. Nevertheless, the manufacturer still attempts to bring its products to the market as quickly as possible. Does the schedule above change now that the manufacturer has decided to produce everything in house? If the schedule changes, give the new schedule and its completion time. State which approach you use.

[35%]

A good answer should include:
Johnson's Rule
The new schedule is FGHCBJEIAD
It completes at time 90
This question is worked out as follows:
Whereas previously we had to minimise the number of late jobs, we now minimise makespan.

Job	A	B	C	D	E	F	G	H	I	J
Printing	6	13	11	10	5	9	11	12	5	7
Binding	2	7	8	1	4	10	13	14	3	5

Job D (1) on m/c 2 → end
Job A (2) on m/c 2 → end
Job I (3) on m/c 2 → end
Job E (4) on m/c 2 → end
Job J (5) on m/c 2 → end
Job B (7) on m/c 2 → end
Job C (8) on m/c 2 → end
Job F (9) on m/c 1 → start
Job G (11) on m/c 1 → start
Job H (12) on m/c 1 → start

This yields schedule FGHCBJEIAD

Job	F	G	H	C	B	J	E	I	A	D
Printing	9	11	12	11	13	7	5	5	6	10
Processing time	9	20	32	43	56	63	68	73	79	89
Binding	10	13	14	8	7	5	4	3	2	1
Processing time	19	33	47	55	63	68	72	76	81	**90**

(c) Discuss three important considerations for firms when they decide to subcontract jobs.

[30%]

A good answer should include:

- *Whether the outsourced job (process/product/service) is a core capability of the firm, or essential to a core capability of the firm [no full credits if not included]*
- *The QCD performance of the supplier*

Other considerations are:

- *Flexibility of the supplier*
- *Innovative potential of supplier*
- *Location of supplier*
- *The impact of the supplier on the value chain of the firm*
- *The impact of the supplier brand on your brand (ethical code, sustainability)*
- *History of relation with supplier (trust)*

3 Toyota Production System (TPS), also known as Lean Manufacturing, and Six Sigma are two much studied process improvement approaches in manufacturing and service.

(a) Compare Lean production with traditional mass production with regards to scheduling, orders and processes.

[30%: 5% per item]

A good answer should include:

- *Scheduling:*
  Push (traditional/mass): backward scheduling, the last process sees the new order first (from the customer's point of view)
  Pull (Toyota/Lean): forward scheduling, the first process sees the new order first (from customer's point of view)
- *Orders:*
  Push: orders are centrally planned and issued by the firm
  Pull: actual customer orders dictate the system
- *Processes:*
  Push: manufacturing processes are centrally planned by the firm; orders are moved forward and then wait (stored in inventory) until the next process is issued with the order to start processing it
  Pull: manufacturing processes are triggered by a replenishment signal; only when material is withdrawn from inventory is the preceding process authorised to start processing (Just in Time production)

NB. The answer should include the terms "push" and "pull"

(b) (i) Give two definitions of waste as it is used in Lean Manufacturing.

[12%: 6% per definition]

A good answer should include:

- *Anything which does not add value to a product or service in any office or manufacturing activity*
- *Everything the customer is not prepared to pay for*

(ii) Which wastes are identified in TPS? Briefly describe each waste.

[28%: 2% per waste, 2% per explanation]

A good answer should include:

- *Transportation: unnecessarily moving around of materials around the plant, double handling of WIP (work in process/progress), caused by an inefficient layout of the workplace*
- *Inventory: known as "dead material" in TPS because it hides problems and distorts signals. Only by tackling the cause of inventory cannot it actually be reduced*
- *Motion: simplification of work can reduce motion of operations that does not add value*
- *Waiting: machine and labour efficiency are negatively affected by waiting (idle time). A hidden source of waiting is operators producing WIP that is not needed at the time*
- *Overproduction: producing more than is directly needed (results in unwanted WIP, inventory)*
- *Over-processing (inappropriate processing): processing of poor components or products, processing of over-engineered components or products (quality specifications not demanded by the customer)*
- *Defects: defect components or products that have to be scrapped waste materials, machine and labour time.*

(c) (i) Which of these wastes identified in TPS is the focus of Six Sigma?

[5%]

A good answer should include:
Defects

(ii) What is the cause of this waste according to Six Sigma?

[5%]

A good answer should include:
Defects are caused by variability in processes

(iii) How does Six Sigma tackle this cause?

[10%]

A good answer should include:
Variability is tackled by statistical process control, e.g. DMAIC

(iv) What role does the customer play in the Six Sigma approach?

[10%]

A good answer should include:

- *The customer (ideally) decides the upper and lower specification limits that specify the width of the six sigma curve*

4 (a) Discuss three reasons for firms to hold inventory, and three reasons why firms should not hold inventory.

[30%: 5% per reason]

A good answer should include:
The need for / function of inventory:

- *There is a minimum of inventory needed as WIP in every system, dependent on processing time and rate of throughput, see Little's Law*
- *It can provide a buffer against uncertainty arising from irregularities in production, supply, or demand (market/customer)*
- *It can be used as buffer to smooth production*
- *It can be used to achieve economies of scale in production*
- *It can be used to take advantage of price fluctuations for raw materials*
- *It can be used to take advantage of bulk order discounts from suppliers*

Problems with Inventory:

- *It masks problems and inhibits improvement opportunities (see Rock-Boat Analogy) by covering the problems and reducing the need to tackle them*
- *It leads to quality defects through corrosion, decay, and multiple handling*
- *It leads to cost of storage (warehouse, labour, energy), cost of capital tied up in stock (opportunity cost of capital), and obsolescence cost*

(b) Inventory placed in the supply chain is known as a "decoupling point". What is the main consequence for the processes in the supply chain of having such a decoupling point? Give one advantage and one disadvantage of using decoupling points.

[30%: 10% explanation, 10% advantage, 10% disadvantage]

A good answer should include:

- *The main consequence of placing inventory in the supply chain as a decoupling point is that it creates independence between processes*
- *The advantage of independence between operations (areas, processes) is that it can maximise the local utilisation and efficiency of the equipment and staff. Each batch of work-in-progress inventory joins a queue awaiting its turn in the schedule for the next processing stage. This allows each operation to be set to the optimum*

processing speed (cycle time). I.e., de-coupling inventory creates the opportunity for independent scheduling.

- *A disadvantage of independence is that local optimisation creates "island of excellence" that not necessarily contribute to the overall flow in the value chain.*
- *Another disadvantage is that Finished Goods Inventory (FGI) can decouple the value chain from customer demand. I.e. the downstream value chain (dealers, retailers) will want to sell what they have in stock, rather than supply what the customer actually wants.*

(c) Explain the role of inventory in the Theory of Constraints.

[20%]

A good answer should include:

- *TOC focuses on throughput and eliminating bottlenecks in order to increase flow (efficiency). A bottleneck should always be working at its maximum capacity and inventory is therefore placed in front of the bottleneck resource(s) to make sure it is never idle ("never runs dry"). While one way in which TOC identifies bottlenecks is by looking for unnecessary inventory, TOC does not prescribe what to do with such inventory; it only focuses on eliminating the bottleneck.*

(d) Give two examples of how holding raw materials inventory differs from holding finished goods inventory.

[20%]

A good answer should include:

- *The main difference is that raw materials can still be configured and therefore used to make other products, while finished goods mostly cannot be reconfigured (and therefore have to be "pushed" to the customer, e.g. by incentives like price discounts)*

Additional points:

- *Another difference is that raw materials are mostly easier and cheaper to store because they take less space and depreciate less due to handling and waiting than finished goods*

- *Finished goods inventory can distort customer demand signals because customer are encouraged to buy from existing inventory rather than making their actual demand known [see also question b]. Raw materials inventory mostly does not distort customer demand*