Module 3E10 Operations management for Engineers - Crib

1 (a) Define the theoretical capacity of a manufacturing line. Explain why the actual capacity of a manufacturing line is often different from its theoretical capacity. [20%]

ANSWER

The theoretical capacity of an operation is the maximum level of value added activity over a period of time that the process can achieve under normal operating conditions. The theoretical capacity of a manufacturing line is the maximum possible output rate according to the design of the equipment – defined by the slowest task or process in the line. Actual capacity is less than theoretical capacity die to a number of reasons:

- When capacity is not balanced the capacity is limited by the bottleneck stage/equipment/process.
- Set up delays- set up times for machines limit the throughput of the machine. Increasing batch sizes can improve this but has other implications hence need to be traded off.
- Defects – product quality need to be managed
- Breakdown of equipment
- Coordination of product flows will limit capacity in a production line
- Theoretical capacity does not consider variability involved in production times
- Supply shortages

(b) Explain and compare the three approaches to matching capacity and demand in a manufacturing line. [30%]

ANSWER

There are three options available for coping with variations in demand:

Level capacity plan: processing capacity is set at a uniform level throughout the planning period, regardless of the fluctuations in forecast demand. Common methods include:

- Capacity at uniform level throughout the planning period
- Same number of staff operate the same processes
- Finished goods transferred to inventory in anticipation of sales at later time
- Suitable for non-perishable goods

Advantages:

Stable employment patterns
High process utilisation
High productivity with low unit costs

Disadvantages:

Considerable inventory costs
Decision-making: what to produce for inventory vs immediate sale
High over/under utilisation levels for service operations

Chase demand plan: attempts to match capacity closely to the varying levels of forecast demand. Common methods include:

- Overtime and idle time
- Varying the size of the workforce (hire and fire)
- Using part-time staff
- Subcontracting
- Inventory cost vs. cost of changing capacity
- Flexibility vs. quality
- Customer satisfaction vs. Employee satisfaction

Demand management: Change demand to suit capacity. Common methods include:

- Using price as a controlling mechanism
- Increase price to reduce demand (high fashion)
- Reduce price to increase demand (food near expiry)
- Introduce counter-cyclical product

(c) A chocolate producer has two chocolate production factories and three chocolate distribution centres. Their supply and demand data is given as follows:

Factories		Distribution Centres	
Cardiff	200 tons	Norwich	100 tons
Birmingham	400 tons	London	250 tons
		Exeter	250 tons

The costs of delivery between each location are shown below:

	Norwich	London	Exeter
Cardiff	236 tons	153 tons	118 tons
Birmingham	156 tons	110 tons	167 tons

Find a transportation policy that minimises the cost of delivery from the factories to the distribution centres. [50%]

ANSWER

The initial feasible solution of the problem by North-West corner rule is as follows:

	Norwich	London	Exeter	*Supply*
Cardiff	100 (236)	100 (153)	 (118)	200
Birmingham	 (156)	150 (110)	250 (167)	400
Demand	100	250	250	

The corresponding cost is 100x236+100x153+150x110+250x167=97,150 Improvement potentials for each empty cell here are:

Cardiff-Exeter: 118-167+110-153=-92

Birmingham-Norwich: 156-236+153-110=-37

Iteration 1: We can improve the solution by shifting 100 units to Exeter

	Norwich	London	Exeter	*Supply*
Cardiff	100 (236)	 (153)	100 (118)	200
Birmingham	 (156)	250 (110)	150 (167)	400
Demand	100	250	250	

The corresponding cost is 100x236+100x118+250x110+150x167=87,950 Improvement potentials for each empty cell here are:

Cardiff-London: 153-118+167-110=92

Birmingham-Norwich: 156-236+118-167=-129

Iteration 2: We can improve the solution by shifting 100 more units to Exeter

	Norwich	London	Exeter	*Supply*
Cardiff	 (236)	 (153)	200 (118)	200
Birmingham	100 (156)	250 (110)	50 (167)	400
Demand	100	250	250	

The corresponding cost is 200x118+100x156+250x110+50x167=75,050 Improvement potentials for each empty cell here are:

Cardiff-Norwich: 236-118+167-156=129

Cardiff-London: 153-118+167-110=90

No further improvements possible, and hence this is the optimal solution.

2 You are the operations manager at Crown Packaging, a UK based producer of metal packaging for cosmetics and pharmaceuticals for a wide range of customers. Part of your job as the operations manager is to purchase sheet metal rolls for use in the production facility. Crown Packaging uses 1,500 rolls of sheet metal per year. The order cost is £75 per order. The holding cost is 1% per month of the purchase cost of £500 per roll. The facility operates for 50 weeks per year, and lead time from the supplier is 1.5 weeks.

(a) (i) How many rolls of sheet metal should you order at one time? What is the reorder point? [20%]

ANSWER

EoQ= $\sqrt{\frac{2DS}{H}} = \sqrt{\frac{2*1500*75}{0.01*500*12}} = 61.23$

Round down to nearest whole integer = 61 rolls is the EOQ

Reorder point = Annual Demand / Time unit * lead time = 1500/50 = 30 rolls per week * 1.5 week lead time

= 45 rolls is the reorder point (assuming linear usage)

(ii) What would be the change in total annual cost if Crown Packaging had storage space for only 50 rolls, and thus was forced to use an order quantity of 50? [15%]

ANSWER

Current EOQ Policy:

$$\text{Total Annual Cost} = PP + S\frac{D}{Q} + \frac{Q}{2}\text{H} = 1500 * 500 + 75\frac{1500}{61} + \frac{61}{2}60$$

$$= 750{,}000 + 1844.26 + 1830$$

$$= £753{,}674.26$$

Restricted Order Quantity:

$$\text{Total Annual Cost} = PP + S\frac{D}{Q} + \frac{Q}{2}\text{H} = 1500 * 500 + 75\frac{1500}{50} + \frac{50}{2}60$$

$$= 750{,}000 + 2250 + 1500$$

$$= £753{,}750$$

Change in annual cost: = 753,750 - 753,674.26 = £75.74

(b) Discuss the assumptions of the EOQ model. [25%]

ANSWER

The EOQ model has been criticised due to its 'unrealistic' assumptions.

- Assumptions of relatively stable and known demand. The EOQ model is based on the assumption of constant demand over the year, which is hardly the case in reality. Demand is rarely constant, nor is it known a year in advance.
- Holding costs are estimates. How to determine appropriate opportunity cost of holding inventory, for example? (ie, the bank rate or return on capital?). This results in the model tendering 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).
- Assumes only one part purchased, independent of all others. Does not consider interactions/synergies between parts sharing the same transportation equipment
- Assumes all inventory arrives in one delivery. Does not consider any supply chain implications of the batches (synchronisation with suppliers).
- Assumes no part shortages. This assumption may not be correct, particularly for purchasing commodities or industries of restricted supply.
- The cost factors for placing an order 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.

- However, despite the 'unrealistic' assumptions the EOQ model is robust to errors in estimation of its parameters – a key advantage. Errors in annual demand, ordering costs or holding costs have to be estimated, with risk of inaccuracy. However, because of the square root in the model, it mathematically mitigates this risk resulting in the model being less sensitive to deviations from estimated cost factors. Wrong estimates only move the EOQ marginally away from the optimal position. Results from part f might be included as evidence of this robustness.
- The EOQ model is also adaptable. For example, where demand or lead time is not constant, application of the perpetual inventory model with reorder point can help minimise the costs of variability. The model can also be adapted for quantity discounts, or situations of product interdependence. These modifications help overcome departures from EOQ's underlying assumptions.

(c) Describe fixed-order quantity and fixed-time period ordering systems, and provide an example of each. What are the key differences between fixed-order quantity and fixed-time period ordering systems. [20%]

ANSWER

In a fixed-order quantity system (Q-system) the order quantity remains constant, but the time between orders varies, depending on the demand for items. Orders are thus event triggered when inventory decreases to a predetermined reorder point. E.g. buying eggs when 2 left.

In a fixed period system (P-system) the time period between orders remains constant, but the order quantity varies. Orders are thus "time triggered". Inventory is only reviewed at the end of the period, with only the amount necessary to bring total inventory up to a pre-specified target level is ordered. E.g. refilling petrol tank, refilling vending machine, buying newspaper

Major differences include:

- The fixed time period model typically requires holding more inventory on average, since it must protect against stockout during the review period and lead time from reordering. The fixed-order quantity model has no review period
- The fixed-order quantity model is preferred for more expensive items because average inventory is lower
- The fixed-time period model is preferred when several different items are purchased from the same vendor, and there are potential savings from ordering all these items at the same time (economies of scale)
- The fixed-order quantity model is more appropriate for important items such as critical repair parts because there is closer monitoring and therefore quicker response to a potential stockout
- The fixed-period system has no physical count of inventory items after an item is withdrawn. By contrast, the fixed-order quantity model requires more time and resources to maintain because every addition or withdrawal is recorded (a perpetual inventory system). Note that advances in information technologies (point of sale

computers, bar coding, RFID) have greatly reduced the cost and facilitated the use of the fixed-order quantity model.

(d) A well-known pet food producer has approached you to inquire about supplying them with pet food cans. As the operations manager of Crown Packaging, you are thinking about tasking one of your suppliers, Metals Inc., with the production of pet food cans instead of producing them yourself. Discuss the advantages and disadvantages of doing so. What is your recommendation as the operations manager? [20%]

ANSWER

Advantages of outsourcing include:

- Focus on core competences
- Harness lower labour cost at supplier
- Access to technology
- Stable and predictable financial planning in fee-for-transaction services
- Less investment risk

Disadvantages would include:

- Loss of control over process
- Limited ability to improve processes
- Risk of opportunistic behaviour of supplier
- Loss of human capital and tacit knowledge

Crown Packaging does not have previous experience in pet food packaging. Hence they may choose to learn from this experience and use it to expand into the food business, or they can focus on core competences and outsource the business. They would need to consider the potential volume of this new market opportunity, whether they can use existing resources, and how the new production would fit in with existing operations.

3 Manufacturing Requirements Planning (MRP) provides a means for scheduling the ordering of raw materials and parts.

(a) (i) What are the main inputs to an MRP system? [10%]

ANSWER

MRP takes these main inputs: 1. *Master Production Schedule*: the volume and timing of end products to be made. Derived from known order and forecasted demand. 2. *Bill of materials*: details of materials, components and sub-assemblies required to make each product. 3. *Inventory record*: the inventory currently being held. 4. Lead times - prediction of how long it will take to complete each task 5. Lot sizing rules - to determine the size of batch to be ordered.

(ii) How is a Bill of Materials used in MRP calculations? [10%]

ANSWER

The knowledge of the structure of the MPS and BOM allows an explosion of requirements for each component and raw material item. The BOM enables a structure for the MRP calculation to be put into place.

(b) (i) Why is MRP called "push scheduling" and JIT is called "pull scheduling"? [15%]

ANSWER

In MRP orders are planned and issued centrally. Upon completion the order is moved forward until next process is issued an order to start processing it. MRP uses backward scheduling i.e. starting jobs at the last possible moment to stop them being late. The push analogy refers to the order being pushed through the system only taking place when instructed.

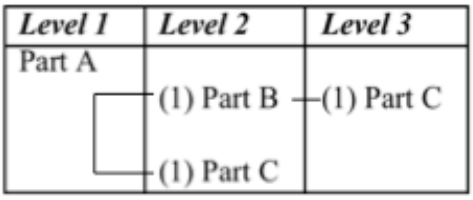
In JIT processes are triggered by a replenishment signal. Upon withdrawal of material from inventory the preceding process is authorised to start processing. The system uses forward scheduling, starting jobs as soon as they arrive. The pull analogy refers to material being pulled through the system with production taking place as soon as material arrives.

(ii) Compare the purpose of inventory in an MRP system with that of a JIT system.[15%]

ANSWER

In an MRP system the purpose of inventory is to place buffers between process operations. The idea is to protect each operation from fluctuations in upstream processes, errors in forecasts and delays caused by routings and disruptions and thereby reduce the unplanned idle time. In a JIT system the purpose of inventory is the WIP fulfil Kanban requests and to minimise the amount of inventory required, given there is predictable demand.

(c) Part of the Bill of Materials for a skateboard includes the following structure:



- Part A has a lead time of 2 weeks and a Minimum Order Quantity of 50.

- Part B has a lead time of 1 week and Economic Order Quantity of 65.

- Part C has a lead time of 2 weeks and a fixed order period of 3 weeks i.e. there is always 3 weeks between orders.

The gross requirements for Part A over the following 10 weeks are:

Weeks	1	2	3	4	5	6	7	8	9	10
Number of parts	40		30	60		20	80		70	30

In week 1, there are scheduled receipts of 50 of Part A, 65 of Part B and 165 of Part C.

Construct the MRP records for all three parts over the ten week planning horizon. [50%]

ANSWER

A typical MRP calculation for the system outlined is given below. Students might have different approaches but solution outcome would be the same.

Part A	*Weeks*	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	Gross Reqs	40		30	60		20	80		70	30
	Scheduled Receipts	50									
	Projected Balance	10	10	30	20	20	0				20
	Planned order release	50	50			80		70	50		

Part B	*Weeks*	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	Gross Reqs	50	50			80		70	50		
	Scheduled Receipts	65									
	Projected Balance	15	30	30	30	15	15	10	25		
	Planned order release	65			65		65	65			

Part C	*Weeks*	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	Gross Reqs	115	50		65	80	65	135	50		
	Scheduled Receipts	165									
	Projected Balance	50	0	0	145	65	0	50	0		
	Planned order release		210			185					

END OF PAPER

Examiner's Comment

Question 1

1a) Most students were able to give a basic definition of the theoretical capacity of a manufacturing line. However, very few stated explicitly that actual capacity would be less than theoretical capacity although most acknowledged a difference did exist. Comments regarding the factors which could impact the capacity of a manufacturing line (e.g. breakdown, supply shortages, bottlenecks) were of a good standard and students who used examples to underpin their explanations scored highly.

1b) The three approaches to matching capacity and demand answers varied. Students were generally able to identify level capacity plan, chase capacity plan, and demand management and those that provided a definition, explanation and drew on examples (e.g. fashion for demand management) in their answers scored highly. However, there was some confusion in this answer with students incorrectly mislabelling approaches and some students misunderstood the question instead listing or explaining process improvement approaches e.g. TQM, TOC.

1c) In most cases students correctly identified and applied the North West Corner method using tables of their working processes to show their method. However, mistakes were common in tables 2 and 3 and this had a knock on impact for the final delivery solution and total cost calculations (however, marks were awarded for 2 correct method even if the final answer was incorrect). Many students did not complete the iteration workings and the corresponding cost improvement calculations. A few students applied a different method e.g. mathematical simplex method and marks were warded for the correct solution and cost improvement calculations where appropriate.

Question 2

2ai) Most students were able to correctly calculate the EOQ and re-order point, however, there were some instances of small rounding errors and often students forgot to add the units (e.g. rolls of sheet metal).

2aii) Whilst most were able to clearly state the total cost formula students struggled to provide a full and correct answer for this question. This was due to three main reasons (1) incorrectly calculated EOQ in (2ai) which then caused comparison errors between current EOQ policy and restricted order quantity (marks were awarded for correct method even if the final answer was incorrect), (2) errors in the holding costs calculations (e.g. 0.001 instead of 0.01), or (3) the students correctly calculated the new restricted total order quantity cost but forgot to provide the final change in annual cost calculation e.g. £75.74

2b) Most students were able to confidently discuss at least 3 disadvantages of the EOQ model assumptions with the most popular including; constant demand, holding costs are estimates, that all inventory arrives in one delivery, and that it assumes only one product is purchased independent of all others from the supplier. Some students provided extra commentary on the advantages of using the EOQ model e.g. that it is a useful model providing robust estimates or that it is a good starting point for operation's managers, which scored higher.

2c) Students demonstrated a good understanding of the basic differences between fixed-order quantity systems and fixed time period systems supporting their answers with appropriate operations examples and detailed diagrams. Some students needed to provide further clarification in their answers. For example, students needed to state more explicitly that "quantity remains constant but time between orders varies" (Qsystem) whilst "time period between orders remains constant but the order quantity varies" (P-system). Finally, in order to gain full points, additional explanation of the major points of difference e.g holding more inventory to protect against stock outs (Psystem) and that the Q-system is preferred for more expensive items due to lower average inventory costs needed to be clearly stated.

2d) The majority of students answered this question very well. Most students were able to highlight the key benefits and risks of outsourcing drawing on company and operations examples to support their discussion. Those students that offered a detailed discussion of the implications scored higher whereas others simply listed bullet points with little or no

Question 3

3ai) Most students were able to describe the 3 main inputs into a MRP system e.g. (1) master production schedule, (2) Bill of materials, (3) inventory record and explain each individually. Some students forgot to add a description/explanation of the input thus scored lower. Students commonly missed mentioning (4) lead times and (5) lot sizing rules.

3aii) Most students managed to give a full explanation of how a bill of materials is used in MRP calculations. Many used an example of a product e.g a chair and it's component parts and sub-assemblies to support their answer. Some students also provided a structure of a component diagram to support their explanation. 3bi) Generally, students explained the differences between push and a pull scheduling well grasping the basic difference of backward v. forward scheduling and centrally issued v. triggered by a replenishment signal and drawing on examples in their answers. Students that supported their answers with clear diagrams highlighting the differences also scored highly.

3bii) Some students struggled to focus their answer on the question and instead repeated a version of the answer given in (3bi) rather than focusing on a comparing the purpose of inventory in a MRP and a JIT system. The majority of students identified that in a MRP system the purpose of inventory is to buffer operations and to protect each operation from upstream fluctuations providing examples of fluctuations (e.g. delays), however, very few students mentioned inventory reducing idle time for MRP. Most students were able to explain that in a JIT system the purpose of inventory is the WIP to fulfil kanban requests and also that the aim is to keep inventory to a minimum.

3c) In most cases students correctly constructed the MRP records for all three parts over the ten week planning horizon and applied the MRP calculations for the system using