2017 MET IIA PAPER 3 A.Parlikad, A. Brintrup, F. Erhun

Module 3P4: OPERATIONS MANAGEMENT
(Section A)

Module 3P5: INDUSTRIAL ENGINEERING
(Sections B)

SECTION A

1 (a) When all products use the same amount of production resources (labour and/or machines) then it is possible to determine capacity in terms of output. Examples include car assembly plants, production lines producing only one product – eg bottles of shampoo. When products use differing levels of labour and machines, then the capacity is measured in the hours available of the constraining factor – labour or machines. That factor can be identified by asking the basic question: ‘If I need to increase output, do I need more machines or more people?’

(b) Analysis of demand/load:

First change (month 2): up by 10%
Second change (month 4): up by 15%
Third change (month 6): up by 83%%

[10% marks]

Advantages and disadvantages of manufacturing options include:

- overtime: good for short periods, up to about 15- 20% extra capacity; if overtime extended for a long period of time, people tend to slow down or quality issues start to arise

- one line/two lines: if two, need twice as much capital (for equipment etc) plus space; if one, need to re-allocate work and balance the line – and to achieve a balanced/highly efficient line can take some time, plus some extra space needed too

-one/ two shifts: two shifts involves shift premiums plus extra security, lighting/heating, supervision, canteens etc; double day offers continuity between shifts, whereas day/night offers more opportunity for extra capacity through overtime (although this is not relevant here); night shift premium often large, and double-day can mean premiums on both shifts

[10% marks]

Further analysis:

We have space for expansion, and this is the cheapest option – based on shift premiums and relatively low cost or additional tools/testing equipment - is single day shift. Also good for management and control.

Current requirement for 24 assemblers, after six months requirement will be for 44 assemblers. Could have one line of 44, two of 22 or current of 24 and one of 20. If workstation assembly times are currently short – 2 minutes or less - should not consider having one line as handling time would be significant part of time, plus may be difficult to balance line with short operation times.

If we go for one large line, we need to plan carefully to balance line, physically create and test, take assemblers through learning curve, and re-check line balancing; all this takes time and could severely disrupt output to the supplier which has to be maintained at a high level throughout. A suggestion could be to add a second line of 20; all planning and set up, learning can be done while current line maintaining output.

Would need to recruit staff for a new line. There will be a learning curve for them, and some staff from the existing line will be needed for that – this will lead to a fall in output from the existing line.

Information needs thus would include: Assembly times, whether the manufacturing processes are easy to learn or there would be a learning curve effect for new workers, shift premiums.

Better students will suggest other information needs such as discussing with the customer what the demand for the next few years may also be, and reflect that in their answers.

[20% marks]

All assumptions need to be stated.

(c) (i) Since the assembly lead time is 3 days, orders released on the first day cannot satisfy net requirement prior to day 4. Thus, to avoid shortages, the current on-hand inventory (day 0) + scheduled completions must be able to satisfy all net requirements through day 3. This results in the following constraints on *x*:

$$x \geq \sum_{i=1}^{3} (\text{Gross Requirement})_i - \sum_{i=1}^{3} (\text{Planned Receipts})_i$$

Therefore, the smallest value of *x* to avoid shortages = (100+150+200)-50 = 400 bikes.

(ii) With *x* = 400 bikes, the following table provides the MRP order release times.

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Gross Requirements		100	150	200	100	300	450	500
On-hand Inventory	400	300	200	0	600	300	550	50
Scheduled Receipts			50					
Net Requirement		0	0	0	100	300	450	500
Time Phased Net Requirement		100	300	450	500			
Order Completion					700		700	
Planned Order Release		**700**		**700**				

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2 (a)

- Assumptions of stable and known, constant demand over the year. Demand is rarely constant, nor is it known a year in advance.
- Estimated holding costs. How to determine appropriate opportunity cost of holding inventory, for example? (i.e. 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 or discounts from suppliers.
- Assumes all inventory arrives in one delivery. Does not consider any supply chain implications of the batches.
- Assumes no part shortages or other disruptions in supply. 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 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. Although errors in annual demand, ordering costs or holding costs have to be estimated, 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.
- The EOQ model is 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.

(b) (i) The optimal order quantity is the EOQ;

$$\mathrm{EOQ} = \sqrt{\frac{2K\lambda}{h}} = \sqrt{\frac{2(10{,}000)(10{,}000)}{(300)(0.15)}} = 2108.19 \text{ metric tons (2 pts.)}$$

$$C(Q) = \sqrt{2K\lambda h} = \sqrt{2(10{,}000)(10{,}000)(300)(0.15)} = £94.9\text{K/year (2 pts.)}$$

(ii)

<u>The analyst is not correct in his conclusion</u>. (2 pts.)

The annual purchasing cost is relevant to our ordering decision. (2 pts.)

Under C=£300, Cλ = £300/ton x 10,000 tons/yr = £3M/year is spent to purchase soda ash.

Under C=£295, £295 x 10,000 = 2.950M/yr is spent to purchase soda ash.
Therefore, there is a £50K/yr savings in annual purchasing cost if the company orders any amount larger than or equal to 3,000 tons, rather than something below 3,000 tons. This

more than compensates for the rise of inventory and setup costs from £94.9K/year in (i) to £99.7/year. (2 pts.)

Indeed, the total annual total cost by ordering 3,000 tons at a time (including annual purchasing cost) is £99.7K/yr+£2.950M/yr=£3.047M/yr. It would be £3.095M/yr if we had ordered the amount in (i).

(iii) The supplier is offering an incremental discount with the following schedule (total unit cost):

C(Q)=300Q for Q<4000
C(Q)=1,190,000+290(Q-4000) = 30,000 + 290Q for Q≥4000 (2 pts.)

Therefore, our additional cost to order at or above 4000 metric tons is £30,000. Thus $\widehat{K} = K + 30{,}000 = 40{,}000$ (2 pts.)

$$\mathrm{EOQ}_{300} = \sqrt{\frac{2K\lambda}{h}} = \sqrt{\frac{2(10{,}000)(10{,}000)}{(300)(0.15)}} = 2108.19 \text{ metric tons}$$

$$C(\mathrm{EOQ}_{300}) = \sqrt{2K\lambda h} + c\lambda = \sqrt{2(10{,}000)(10{,}000)(300)(0.15)} + (300)(10{,}000) = £3{,}094.9\mathrm{K/year}$$

$$\mathrm{EOQ}_{290} = \sqrt{\frac{2\widehat{K}\lambda}{h}} = \sqrt{\frac{2(10{,}000+30{,}000)(10{,}000)}{(290)(0.15)}} = 4288.45 \text{ metric tons (1 pt.)}$$

Since EOQ_{290} is feasible, we do not have to check the total cost at Q=4000 (1 pt.).

To calculate Total Cost, make sure you correctly calculate the average inventory on-hand values.

$$\begin{aligned} C(\mathrm{EOQ}_{290}) &= \frac{\widehat{K}\lambda}{Q} + \frac{IC(Q)}{2} + c\lambda \\ &= \frac{(40{,}000)(10{,}000)}{(4288.45)} + \frac{(0.15)[30{,}000 + (290)(4288.45)]}{2} + (290)(10{,}000) \\ &= £3{,}088.9\mathrm{K/year} \text{ (2 pts.)} \end{aligned}$$

Therefore, it is optimal to order 4288 metric tons. (2 pts.)

Feryal Erhun

SECTION B

3 (a) Time study is a technique for measuring the times and rates of working for the elements of a specified job, and for analysing the data to establish the time necessary for carrying out the job at a defined level of performance.

Outline of Time study procedure

- Direct and continuous observation of a task using a stopwatch or other timekeeping device to record the time taken to accomplish the task
- While observing and recording the time, an appraisal of the worker's performance level is made to obtain the basic time for the task
- Allowances are then added to compute a standard time for the task

Steps taken in a time study

1. If the purpose of the time study is to establish a standard then it is **essential** that the operation has been subjected to method study first.
2. The worker to be studied must have the necessary physical and mental attributes, the necessary levels of knowledge and skill and be familiar with the operation
3. Obtain and record basic information about the part/operation, the details of the process eg equipment used, jigs, tools, speeds & feeds etc., the operator, the working environment.
4. Observe the operation and break it down into a number of elements.
5. Over a number of cycles measure the time taken for each element and for each assess the effective speed of working of the operative (rating).
6. Convert the observed times to "basic times"
7. Determine the allowances to be made on top of the basic time.
8. Determine the work content and standard time for the operation.

(b)

(i) From the data – 59.1, 62.2, 58.4
Sample Mean, $\bar{X} = 59.9$
Sample Standard deviation, $s = 2.02$
Degrees of freedom = 2
$t_{97.5}$ at 2 degrees of freedom = 4.303 (from handbook)
Thus $59.9 \pm \frac{4.303 \times 2.02}{\sqrt{3}} = [54.9, 64.9]s$

(ii) The learning curve takes the form $y = kx^m$

k is the constant representing the value of the time for the first work cycle;
y is the time taken/unit
x is the number of units completed
m is the constant related to rate of learning.

$$m = \frac{\log(0.9)}{\log 2} = -0.152$$

substituting y = 59.9 when x = 100 gives $k = 59.9/100^{-0.152} = 120.6$

Total time for the next 100 components =
$\int_{101.5}^{201.5} 120.6x^{-0.152}\,dx = 5642s$

(iii) The learning curve model will give:

Time for a batch of 500 = 7.6 hrs
Time for a batch of 5000 = 54 hrs

Without knowing the specific nature of the operation, we can only raise the issues. These are:

a) at what point does the learning curve cease to follow the same curve? Any sensible discussion about physical limits to speed of natural movements would be acceptable here.

b) what is the effect of forgetting? Especially because larger batches take longer than a shift or even a week.

[*Examiner's comments: Candidates that scored relatively poorly in (a) were those who did not discuss issues regarding standard method, tools and workers. Part (b) (i) was a simple calculation of 95% confidence limits - most candidates achieved this, some with minor arithmetic errors. Although (b) (ii) was a straightforward application of the formula (which was given in the data sheet), the responses varied widely. Many candidates did not exhibit clear understanding of the learning curve equation, and therefore could not answer correctly. The responses to (b) (iii) were reasonable, with most candidate arguing that the learning curve would not continue to be applicable for a batch of 5000 parts. Most candidates did not correctly evaluate the time taken for producing the batches if the learning curve equation was applied – many simply calculating the time taken to produce the last product within the batches.*]

4 (a) The steps involved in examining the capability of a manufacturing process to produce within customer requirements are:

1. Determine process requirements.
2. Collect baseline data on process output when process is not exhibiting "unusual" behavior;
3. Calculate process mean and standard deviation.
4. Compare specs to process mean ± 3 standard deviations.
5. If specs are outside ± 3 **σ**, process is capable

Better candidates will describe the rationale behind 3 standard deviations and also discuss the concepts of Cp and Cpk.

(b)

(i) For attribute data:

$$UCL = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = 0.196$$
$$CL = \bar{p}$$
$$LCL = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = 0$$

Note: for a *p* chart, *n* is calculated from the number of data points per sample, not the number of samples which can vary dependent on how long the process had been assessed. The lower control limit cannot be negative so is set at zero.
Samples of 20 are taken at intervals and the % defective calculated. This % is plotted on a control chart. While the process remains 'in control' subsequent plots should be randomly distributed around the 5% line.

(ii) Changes to the process will be shown by variation from this, for example, by trends, or several subsequent samples being between warning and control limits. There are various rules used to interpret the significance of such variation, better students will give several examples.

(c)

(i) Line 1:

$$C_p = \frac{USL - LSL}{6\sigma} = \frac{3.52 - 3.18}{6 * 0.07} = 0.81$$

$$Z_{UCL} = \frac{UCL - \mu}{\sigma} = 2.43$$

$$Z_{LCL} = \frac{\mu - LCL}{\sigma} = 2.43$$

$$C_{pk} = \frac{z_{min}}{3} = \frac{2.43}{3} = 0.81$$

Using the tables for normal distribution from the data book,

$$P(z < Z_{UCL}) = 0.9925$$
$$P(z > Z_{LCL}) = 0.0075$$

Percentage of parts within the specification limits = (0.9925-0.0075)*100 = 98.5%

Line 2:

$$C_p = \frac{USL - LSL}{6\sigma} = \frac{3.52 - 3.18}{6 * 0.05} = 1.13$$

$$Z_{UCL} = \frac{UCL - \mu}{\sigma} = 1.8$$

$$Z_{LCL} = \frac{\mu - LCL}{\sigma} = 5$$

$$C_{pk} = \frac{z_{min}}{3} = \frac{1.8}{3} = 0.6$$

Using the tables for normal distribution from the data book,

$$P(z < Z_{UCL}) = 0.9641$$
$$P(z > Z_{LCL}) = 0.0$$

Percentage of parts within the specification limits = (0.9641-0.0)*100 = 96.41%

(ii) Both lines are not capable. Line 2 produces parts with less variation in size, but there is an offset error. In contrast, line 1 is more centred, but has greater variation. To improve these two lines, it would be necessary to explore the similarities and differences in setup and also the machine itself. Line 1 has a more consistent setup process, whereas the offset errors in line 2 might be due to poor setup practices.

[*Examiner's comments: Part (a) was attempted well by most candidates. Some candidates went off-topic by discussing process control instead of capability. Good candidates explained how process capability can be examined and discussed how it can be measured using process capability ratio and index. Part (b) was very well attempted by most candidates. The answer to (b) (ii) varied in its quality; the best responses illustrated the p-chart with numerous examples of out-of-control behaviour. In Part (c), the* C_p *and* C_{pk} *values were calculated correctly by almost all candidates. However, most candidates failed to calculate the percentage of parts meeting specifications. The discussion that ensued reflected the candidates understanding of process capability with most answering it very well.]*

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