MANUFACTURING ENGINEERING TRIPOS PART I

Thursday, 5 May 2011 9 to 12

PAPER 3- Guidance to Form of Answers

Module 3P5: INDUSTRIAL ENGINEERING

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Paper 3 Crib

Section A

Q1.

a) The 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 is the maximum possible output rate according to the design of the equipment, and the actual capacity is the realistic estimate of the achievable output rate. The theoretical capacity of a production line is always defined by the slowest task/process in the line. When the capacity of each stage of the process is not balanced, the capacity of the line is limited by that of the bottleneck stage/equipment/process. In most cases the actual capacity is lesser than the theoretical capacity due to the following factors:
   a. Setup and switchover delays – the setup times of each machine limits the throughout of the machine. Increasing the batch sizes can improve the effect of setup, but has other negative implications. Efforts must hence be made to reduce the setup and switchover time.
   b. Defects – product quality need to be managed in order to achieve high throughput.
   c. Breakdown of equipment has a big effect on the actual production rate.
   d. In a production line, especially where assembly of components are involved, coordination of product flows will limit the actual capacity of the line.
   e. Theoretical capacity does not consider the variabilities involved in production times.
   f. Finally, supply shortages – from within and outside the factory has an influence on the actual production capacity.

b) Since the time interval between two successive arrivals is given to be 10 minutes, the mean arrival rate is 0.1 per minute, i.e., $\lambda = 0.1$ per minute. Similarly, the service rate $\mu = 0.25$ per minute.

   Now, the probability that a customer does not have to wait on arriving is the probability that the system is empty at any point of time. This is given by:

$$1 - \rho = 1 - \frac{\lambda}{\mu} = 0.6$$

   Hence, the probability that a customer has to wait is 0.4.

   The average waiting time is given by:

$$\frac{\rho}{\mu(1-\rho)} = 2.67 \text{ minutes}$$

c) The main drawbacks of a pure MRP scheduling system are:
   a. It takes no account of available machine capacity
   b. It has no feedback - having issued the plan, it assumes that this will work. This can be countered by re-calculating the schedule often to account for the current position
   c. The accuracy of the data provided, including sales forecasting data, cannot be guaranteed. Keeping accurate records of inventory - both stock and in-process is notoriously difficult.
   d. Any delay in any component prior to an assembly operation will prevent completion of assembly - so shortages always deny the master production schedule.
   e. It does not provide shop floor schedules - as information is supplied only within time buckets and without regard to capacity.

d) As customer demand is inherently unstable, companies rely on forecasting techniques to optimise its inventory and shipments. However, forecasting techniques are rarely accurate, thereby forcing companies to carry a "buffer" or safety stock to cope with uncertainties. As we move up the supply chain from the end customer to the raw material supplier, each organisation experiences a greater observed variation in demand and thus a need to keep increasing amounts of safety stock. This effect of increasing variations as we move upstream in a supply chain is known as the bullwhip effect.
   The consequences of this effect can be reduced by:
   - Information sharing – demand information at retailer (POS data) must be transmitted upstream in a timely fashion
   - Channel alignment – coordination of pricing, transportation, inventory planning, and ownership between upstream and downstream sites in a supply chain
   - Improve operational efficiency – reduction of costs and lead time
   - Smaller and more frequent batches
     - Use third-party logistics providers
     - Mixed truck loads (e.g., Tesco, Sainsburys)
   - Stabilise prices (Every Day Low Price strategy) (e.g., P&G, Kraft)
   - Eliminate gaming in shortage situations – in the face of shortage, allocate in proportion to past sales records instead of current orders (e.g., Texas Instruments, HP)
   - Building strategic partnerships and trust

e) Simple moving averages, weighted moving averages and linear regression techniques require users to continually carry a large amount of historical data. As each new piece of data is added in these methods, the oldest observation is dropped and the new forecast is calculated. However, in many situations, the most recent occurrences are more indicative of the future than those in the more distant past. If this premise is valid, then exponential smoothing maybe the most logical and easiest method to use.
   Exponential smoothing is the most used of all forecasting techniques, primarily because they are surprisingly accurate, and tests for accuracy as to

how well the model is performing are easy to compute. Only three pieces of data are needed to forecast the future: the most recent forecast, the actual demand that occurred for that forecasted period, and a smoothing constant α. A smoothing constant is used to determine the level of smoothing and speed of reaction to differences between forecasts and actual occurrences. [Better answers may also point out that upward or downward trends in data collected causes the exponential forecast to always lag behind the actual occurrence. Adding a trend adjustment (double exponential smoothing) using two smoothing constants can help improve accuracy by reducing the impact of the forecast error.]

f) Assign jobs by putting jobs with shortest processing times earlier:
   C-E-A-B-D (completion time: 4-9-15-22-31)
   For this schedule, average completion time (flow time) = 16.2
   Average lateness = (7+10+19+24)/4= 14.5 days.

Examiner's comments: Most candidates answered this question relatively well. Weaker candidates could not express a good understanding of bullwhip effect. Many candidates did not calculate the average lateness in part (f) correctly.

Q.2

a) Annual demand is D = (5 days/week)(52 weeks/year)(100 units/day) = 26000 units per year.

   The order quantity is:

$$EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2 \times 26000 \times 35}{9.40}} = 440.02$$

   Reorder point = average demand during the lead time + safety stock = 450 units.

b) Total annual cost = $PP + S\frac{D}{Q} + \frac{Q}{2}H + SS * H = 40 * 26000 + 35\frac{26000}{440} + 220 * 9.40 + 150 * 9.40 = £1{,}045{,}546.00$

c) New total annual cost = $40 * 26000 + 35\frac{26000}{380} + 190 * 9.40 + 150 * 9.40 =$ £1,045,590.00
   Additional cost = £44.55

d) 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 sensitive to deviations from estimated cost factors. Wrong estimates only move the EOQ marginally away from the optimal position. 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.

e) Under the fixed order quantity system, the orders are placed for a fixed quantity. The time interval between different orders may vary because an order is placed as and when the stock level reaches a predetermined level, called reorder level or reorder point. On the other hand, in the fixed time-period review system of inventory management, the ordering intervals are fixed but the order size may vary. Here, the stock level of an item could be found, for example, at the end of every month and a replenishment order placed to bring the stock up to a predetermined level. When demand is uniform and no variations are found in the lead-time, there is virtually no difference in the operation of the two systems. For simple situations, under the fixed order quantity system, the EOQ model is used to determine the order quantity and the re-order point.

The fixed order quantity system requires higher investment for accurate inventory stock-keeping, whereas the costs are lower for fixed time period system. However, the fixed time-period system is more susceptible to stockouts in the face of demand variations, and it sacrifices the user of a fixed (and possibly optimum) order quantity. On the other hand, the fixed order quantity system allows you to carry less inventory than fixed time period system.

f) $P = \frac{EOQ}{D} * 260 = 4\ days$

Examiner's comments: This question was answered very well by most of the candidates. Weaker candidates did not provide a reasonable discussion in parts (d) and (e).

SECTION B

3 (a)

Manufacturing strategy is a pattern of decisions, both structural and infrastructural, which determine the capability of a manufacturing system and specify how it will operate in order to meet a set of manufacturing objectives which have been derived from business objectives.

It is essential to understand the strategy so that we have a clear identification of the objectives of the production system that we are designing.

(b)

The basic procedure for method study is as follows:

SELECT the work to be studied.

RECORD all the relevant facts about the present method by direct observation

EXAMINE those facts critically and in ordered sequence

DEVELOP the most practical, economic and effective method

DEFINE the new method so that it can always be identified.

INSTALL that method as standard practice.

MAINTAIN that standard practice by regular checks

(c)

A Standard Operating Procedure (SOP) specifies how a manufacturing operation should be carried out.

It should include:

- Procedure - Description of the work elements to perform the task
- Tools – a list of the tools and gauges used at each stage in the procedure
- Layout – plan or photograph of the workplace arrangement
- Checks – checks or inspections required during the procedure
- Set-up information

The aim of Standard Operating Procedures is to ensure that tasks are always performed in the same way. This is important as it will:

- Reduce variations in operation time
- Reduce variations in quality
- Provide a basis for training new operators
- Allow variations to be easily identified
- Form a fixed basis for further improvement

(d)

During task Average *ERwrk* = 8.1(0.25) + 5.3(0.75) = 6.0 kcal/min (ER is energy rate
Recommended max mean energy expenditure over 8 hour shift = 5.0kcal/min
MER = (*TwrkERwrk* + *TrstERrst*)/(*Twrk* + *Trst*)
Rearranging: MER(*Twrk* + *Trst*) = *TwrkERwrk* + *TrstERrst*
Collecting terms: Trst(MER - *ERrst*) = *Twrk*(*ERwrk* - MER)
Hence: Trst = *Twrk*(*ERwrk* -MER)/(MER- *ERrst*)

Trst = 5(6.0 – 5.0)/(5.0 – 1.5) = 1.43min

On average the worker should rest for 17.2 minutes for each hour of work. Any sensible schedule to achieve this is acceptable. Eg alternating 15 and 20 minute breaks after each hour of work.

(e)
(i) Takt time
Takt time is defined for an operating unit as *EOT* / *Qdd*
where, *EOT* = effective daily operating time, *Qdd* = daily quantity demanded
Takt time represents the ‘drumbeat’ at which the operating unit must work, hence the work must be designed, and the necessary resources provided so that the operation cycle time is consistent with the takt time.

(ii) Poka-yoke
“Poka-yoke” – Japanese word meaning prevention of errors using low cost devices to prevent or detect them. Poka-yoke devices can prevent errors such as:
Omitting processing steps, Incorrectly locating a part in a fixture, Using the wrong tool,Neglecting to add a part in assembly

(iii) Overall Equipment Effectiveness (OEE)
OEE = (Equipment Availability)(EA) x (Equipment Efficiency Performance)(EEP) x (Equipment Quality Performance)(EQP)
Equipment Availability (EA) Measures how long equipment is not producing parts due to unplanned downtime = Actual Equipment running time / Scheduled running time

Equipment Efficiency Performance (EEP) measures actual machine output versus theoretical or standard machine output
EEP= (Standard Cycle Time) x (No. of Parts Produced)/ Actual Equipment running time

Equipment Quality Performance (EQP) measures quality in terms of % of good product
EQP = 100 (No. of good parts)/(Total No. of parts produced)

Measuring OEE and its component parts identifies weak areas of performance, and provides a basis for identifying where improvement projects might make an impact.

(iv) C_p and C_{pk}

C_p *and* C_{pk} are measures of process capability. They are used to compare the "natural variation" of a manufacturing process to the specified tolerance of the product being produced.

$$\hat{C}_p = \frac{USL - LSL}{6\hat{\sigma}}$$

$$\hat{C}_{pk} = \min\left[\frac{USL - \hat{\mu}}{3\hat{\sigma}}, \frac{\hat{\mu} - LSL}{3\hat{\sigma}}\right]$$

where σ is the standard deviation of the process, μ is the mean of the process

USL and LSL are the upper and lower specification limits of the product.

Manufacturing systems should be designed with capable processes. A C_P of 1 denotes a capable process – but to allow for drift, 1.33 is often used as the acceptable minimum. C_p does not allow for product centring, while C_{pk} does. A process operating with C_{pk} =1.33 will produce 63 defects per million operations

(f)

A cellular layout is one in which work units flow between stations, as in a production line, but each station can cope with a variety of parts which have similarities. It tries to combine efficiency of product layout with versatility of process layout. Neither objective is achieved perfectly, but it is more efficient than a process layout and more versatile than a product layout.

Compared to a functional layout, a cellular layout is likely to have:
Shorter Throughput times
Reduced inventory
Simplified planning and control at plant level
Reduction of set-up times
Improved productivity

Additionally, manufacture of a restricted range of similar components is likely to lead to
Improved quality
Improved tooling
Improved designs
Problems to be overcome when moving to a cellular layout (which might be perceived as disadvantages) include: Need for higher skill levels; lower plant utilisation; more complex control at Cell level; increased difficulty with substantial product change.

(g)

Garvin's dimensions of quality are shown in the fig below. A discussion of these would provide a good answer to the question.

Performance:	Primary operating characteristics
Features:	Secondary characteristics
Conformance:	How well specifications are met
Reliability:	Consistency of performance
Durability:	Product life
Perceived quality:	Brand image/reputation
Serviceability:	Ease of service/friendliness of server
Aesthetics:	Effect on senses

David Garvin

(h)

P chart

p	0.1	CL-p	0.1	
n	30	UCL-p	0.2643	
1-p	0.9	LCL-p	-0.0643	= 0
p*(1-p)/n	0.0030			
sigma	0.0548			

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 30 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 10% line. 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 might give examples.

Examiners Comments

Questions on the following topics were well answered:

- Method study, both traditional,(b) and modern “lean” approaches (most of e). There were a few misunderstandings of Takt time – although most understood it as ‘drumbeat’ not everyone could express it as a simple formula.

- Ergonomics (d) – most calculated the rest time accurately and had sensible suggestions for how the breaks might be arranged.

Questions on the following topics were reasonably well answered, but with some surprisingly weak answers:

- Manufacturing Strategy (a)– very few candidates grasped all the aspects – manufacturing objectives linked to business objectives, a coherent set of structural and infrastructural decisions, capability and practice (how the system will operate), although most answers had some of these elements.
- Production organization – cellular production.(f) Although most knew the principles behind cellular production, the advantages and disadvantages were less well understood.

Questions on the following topics were poorly answered by the majority of candidates:

- Standard Operating Procedures (c) This question had two parts, - discuss the concept of a Standard Operating Procedure (SOP) - and explain why a SOP is important. Most students did not adequately address both parts of the question, often not explaining all the reasons why a SOP is important.

- Product Quality (g) and SPC (h).- In spite of the guide in the question g), many students chose to answer the question without referring to Garvin’s framework. This generally led to restricted or partial views of quality, or very brief answers referring to ‘meeting customer requirements’. Question h) on SPC revealed that many students did not understand the statistics behind attribute measures and hence could not calculate the controls limits.   Some displayed only a sketchy knowledge of how an SPC chart would be used in practice. One excellent answer not only calculated the limits, but also gave examples of 8 rules for interpreting SPC data.

4 (a)

Standard times are required for:

- Production Planning
  - Capacity
  - Loading
  - Scheduling
  - Machine and operation balancing
- Costing and estimating
- Comparison of alternative methods
- Incentive and payment schemes

(b) 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.

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 (ie have done sufficient repetitions to have got beyond learning curve effects.)
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.

Summary of Standard Time
Basic Time = Observed time x Rating/Standard Rating
Work Content = Basic time + Relaxation Allowances + Allowance for Extra work
Standard Time = Work Content + Allowances for delay, unoccupied time, interference

(c)

- PMTS systems generally produce a more detailed description of the work than time study.
- In PMTS each basic motion is described along with its variables, so alternative methods can be readily compared using time as a criterion. In time study, alternative methods need to be timed to enable comparison.
- With PMTS methods can be developed and standards established before production operations start.

- PMTS are objective and consistent, they do not require the assessment of rate of working and the use of the stop watch as is required in time study. This can remove one of the impediments to good industrial relations.
- PMTS systems are not affected by learning curve effects, but on the downside cannot be used to set temporary standards in learning situations.
- However, PMTS systems are complex and very time consuming to apply. For example, MTM1 takes typically 240 minutes of analysis for 1 minute of work. Time study is generally much quicker to apply. The training of PMTS specialists is lengthy.
- PMTS systems are most suited to high volume, repetitive, short cycle time operations. For all other situations time study is likely to be more appropriate.

(*d*)

From the data mean is 126.4s and sample standard deviation is 7.02

Confidence limits are: $\bar{x} \pm \frac{t_{n-1}^{1-\alpha/2} s}{\sqrt{n}}$

t from tables is 2.776, n is 5. Hence limits: 126.4 +/- 8.72 (117.7 – 135.2)

This does not look to be a valid study. The continually reducing times suggest there may be learning occurring. It is likely that the standard time will be considerably lower than that observed.
Additionally, there is no rating information given so there is also no way of converting observed times to basic time.

Examiners Comments
. Parts a) b) and d) were answered reasonably well , whereas part c) (discussing the relative merits of Time study vs PMTS systems) was, on the whole, less well answered. The quantitative part of Part d) produced a bimodal distribution, candidates that were able to apply the statistical analysis gained full marks, whereas others scored very low marks. The qualitative comments revealed those students who had a thorough understanding, as opposed to those who had learnt the methods to apply, but had not thought more deeply, or more fully understood, the time study process. Many students spotted the learning curve, but few commented on the omission of ratings.