Version FE/TM/2

MET 2
MANUFACTURING ENGINEERING TRIPOS PART IIA

Thursday 4th May 2022   9.00 to 11:10

CRIB

SECTION A

Question 1:

(a) There are two fundamental approaches to scheduling production operations, pull and push scheduling.

(i) Discuss the key differences between pull and push scheduling. [10%]

A "pull" system uses the customer demand signal to trigger replenishment. It is an autonomous system that purely works by replenishing goods that have been consumed by the preceding process. The demand signal is the only trigger for production, not forecasts or centrally planned work orders. The demand signal is conveyed by a "kanban", which could be an empty bin, a card or electronic signal.

In a "push" system, production is planned centrally using a Master Production Schedule (MPS), which generally comprises of a combination of actual customer orders and forecasts. Based on the MPS and standard routing and lead-time data, work orders are centrally issued that "push" the material forward towards the customer end.

Thus, the key differences are twofold: (1) what triggers the replenishment, and (2) what information the "schedule" is based on.

(ii) What is the role of inventory in a pull-scheduled production system? [10%]

In a "pull" system, inventory buffers are needed to convey the pull signal from a downstream process to an upstream process. Essentially the process needs some small buffers "to pull from", in order to convey the replenishment signal upstream. A kanban supermarket is a typical example of inventory in a pull system.

(iii) What is the role of inventory in a push-scheduled production system? [10%]

In a "push" system, production is scheduled according to a Master Production Schedule (MPS). The MPS generally is a combination of actual orders and forecast orders, thus the main function of inventory in a push system is to buffer against any forecast errors.

Also, as production orders are based on fixed lead-times, WIP inventory between processes exists as actual lead-times will vary from those set in the planning system.

(b)

(i) What are the main inputs to a Material Requirements Planning (MRP) system? How is a Bill of Materials (BOM) used in MRP calculations? [20%]

What are the main inputs to an MRP system? (10%)

- Master Production Schedule - a complete list of the volume and due dates of all expected product sales
- Inventory Record File - a record of current stocks
- Bill of Material File - design information relating products to components - usually expressed in hierarchical form
- Lead times - prediction of how long it will take to complete each task
- Lot sizing rules - to determine the size of batch to be ordered

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

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

(ii) Discuss the limitations of MRP? How do extensions to MRP address these limitations? [10%]

Discuss the limitations of MRP? (5%)

Here are some limitation of MRP:

- MRP produces excess inventory, which masks quality problems and limits the opportunity to improve, leads to lower responsiveness, and higher lead times.
- MRP is a black-box. Data maintenance priority is low.
- There is no feedback mechanism
- It pushes production, and so distorts demand.
- Lead time is an input to MRP, so there is no incentive to improve lead time.

Any other reasonable limitations are OK.

How do extensions to MRP address these limitations? (5%)

- Manufacturing Resource Planning (MRP-II) system
- Enterprise Resource Planning (ERP) system

(c) The product structure for an end item is described below. The number in parentheses indicates the lead time (in weeks) for making or purchasing each item.

End Item: Composed of 2 units of A, 2 units of B and 3 units of C.

Item A (1 week): Composed of 2 units of B and 1 unit of D.

Item C (2 weeks): Composed of 1 unit of B and 2 units of D.

Item B has a lead time of 2 weeks and item D has a lead time of 4 weeks.

What is the lead time for making the end item from scratch (i.e., order-to-delivery lead time)? [10%]

The product structure diagram is presented in Figure 1.

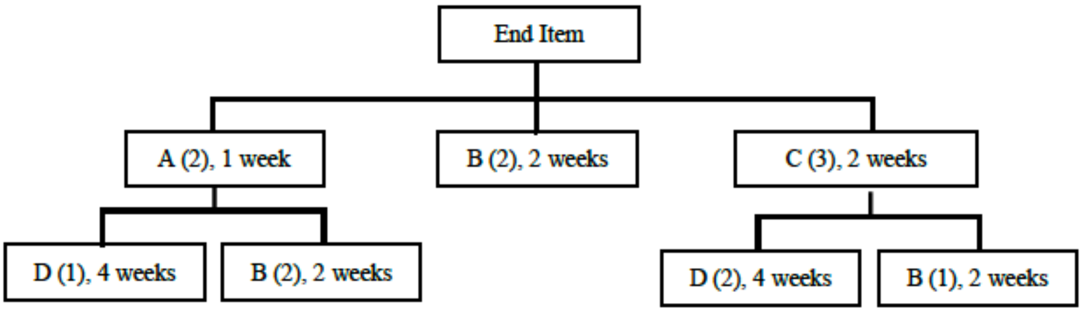


Fig. 1

Based on this diagram, the lead time is 6 weeks

(d) Three refineries with maximum daily capacities of 6, 5, and 8 million gallons of oil supply three distribution centres (DCs) with daily demands of 4, 8, and 7 million gallons. Oil is transported to the three DCs through a network of pipes. The transportation cost is 1 pence per 100 gallons per mile. The mileage table below shows that refinery I is not connected to DC3.

Table 1: Mileage table

	DC1	DC2	DC3	Capacity (in million gallons)
Refinery I	120	180	-	6
Refinery II	300	100	80	5
Refinery III	200	250	120	8
Demand (million gallons)	4	8	7	19

(i) State the basic principles of the North West Corner approach for allocating supply to demand. What are the limitations of the approach? [10%]

Basic Principles (8%):

- Create a matrix of sources and destinations
- Set initial allocation from NW corner
  - Fulfil as much of demand from first destination from the first source as possible
  - If supply from first source > demand from first destination, allocate excess to second destination
  - If supply from first source < demand from first destination, fulfil demand from second source (and so on ...)

Limitations (2%):

- Not necessarily optimal (but "good enough")
- May not be evident why they work

(ii) Find an initial North West corner allocation for the configuration in Table 1 and calculate the total distribution cost associated with that allocation. [10%]

An initial North West corner allocation (8%)

Problem:

The cost of delivery of a unit of production from the supplier to the consumer is located in the lower right corner of the cell.

Supplier	Consumer B_1	B_2	B_3	Supply
A_1	120	180	0	6
A_2	300	100	80	5
A_3	200	250	120	8
Customer needs	4	8	7	

It is necessary to find a transport plan in which the total cost of delivery will be the lowest.

Solution:

This is a necessary condition for solving the problem:

the total supply of suppliers should be equal to the total needs of consumers.

Upon checking it.

The total supply of suppliers: 6 + 5 + 8 = 19 units.

The total needs of consumers: 4 + 8 + 7 = 19 units.

The total supply of suppliers equals the total needs of consumers.

This is a necessary condition for solving the problem:

number of used routes = number of suppliers + number of consumers - 1.

Therefore, if we have a situation where it is necessary to exclude a column and a row at the same time, we will exclude one thing.

We will start filling the table from the upper left corner and gradually move to the lower right corner.

From the North-West to South-East.

Supplier	Consumer			Supply
	B_1	B_2	B_3	
A_1	? 120	180	0	6
A_2	300	100	80	5
A_3	200	250	120	8
Customer needs	4	8	7	

4 = min { 4, 6 }

Supplier	Consumer			Supply
	B 1	B 2	B 3	
A 1	**4** 120	**?** 180	0	~~6~~ 2
A 2	300	100	80	5
A 3	200	250	120	8
Customer needs	~~4~~ No	8	7	

2 = min { 8, 2 }

Supplier	Consumer			Supply
	B 1	B 2	B 3	
A 1	**4** 120	**2** 180	0	~~6~~ ~~2~~ No
A 2	300	**?** 100	80	5
A 3	200	250	120	8
Customer needs	~~4~~ No	~~8~~ 6	7	

5 = min { 6, 5 }

Supplier	Consumer			Supply
	B 1	B 2	B 3	
A 1	**4** 120	**2** 180	0	~~6~~ ~~2~~ No
A 2	300	**5** 100	80	~~5~~ No
A 3	200	**?** 250	120	8
Customer needs	~~4~~ No	~~8~~ ~~6~~ 1	7	

1 = min { 1, 8 }

Supplier	Consumer			Supply
	B 1	B 2	B 3	
A 1	**4** 120	**2** 180	0	~~6~~ ~~2~~ No
A 2	300	**5** 100	80	~~5~~ No
A 3	200	**1** 250	**?** 120	~~8~~ 7
Customer needs	~~4~~ No	~~8~~ ~~6~~ ~~1~~ No	7	

7 = min { 7, 7 }

Supplier	Consumer			Supply
	B_1	B_2	B_3	
A_1	**4** 120	**2** 180	0	~~6~~ ~~2~~ No
A_2	300	**5** 100	80	~~5~~ No
A_3	200	**1** 250	**7** 120	~~8~~ ~~7~~ No
Customer needs	~~4~~ No	~~8~~ ~~6~~ ~~1~~ No	~~7~~ No	

The total distribution cost associated with the above allocation (2%)

The total cost of delivery for the initial solution

= 4*120 + 2*180 + 5*100 + 1*250 + 7*120 = 2,430 or in other converted units

(iii) Is the solution in part (ii) optimal? If yes, explain why. If no, find an improved solution. [10%]

This solution is optimal as all the feasible empty cells would have positive opportunity costs.

Supplier	Consumer			Supply
	B_1	B_2	B_3	
A_1	4 120	2 180	0	6
A_2	300	5 100	80	5
A_3	200	1 250	7 120	8
Customer needs	4	8	7	

Question 2:

(a) D= 1000*12 = 12000 per year, C_S = $ 3500, and C_H = 15*0.25 = £3.75 per box per year.

EOQ = SQRT[2*D*C_S/C_H] = SQRT[2*12,000*3500/3.75] = 4732 boxes per order.

That is, the store has to place 12,000/4732 = 2.5 orders /year or every 4.7 months.

(b)

TC(Q) = Q/2*C_H + D/Q*C_S + 15 * D
= 4732/2*3.75 + 12,000/4732*2500 + 15 * 12,000 = 8874+8874+180,000 =197,748.

(c)

EOQ formulation comes with many modelling assumptions:

- Demand is constant and steady and continues indefinitely. ==> Demand is most likely seasonal.
- The entire order arrives at the same time. ==> There might be supply uncertainties; e.g., workforce problems, raw material unavailability, etc., hence it might now always be possible to get such a big order every single time.
- No supply uncertainties or yield problems. ==> There might be supply uncertainties; e.g., workforce problems, raw material unavailability, etc.
- Replenishment lead-time is known and constant. ==> Due to supply uncertainties, lead-time may be variable.
- Holding cost per item per period is constant. ==> The holding cost is very low; so probably this assumption is not a big issue. However, candies are perishable items, therefore, there will be additional inventory related costs one needs to consider.
- Cost of ordering/setup is constant. ==> As the cost function is quite flat around the optima, this should not be a big issue.
- Item is independent of others; benefits from joint reviews are ignored. ==>It might be possible to combine the order with other candies.

(d)

Pros of outsourcing:

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

Cons of outsourcing:

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

They should consider:

- Cost per unit, including quantity discounts
- Any administrative costs
- Lead time on orders (both mean and variance)
- Order restrictions, e.g., minimum order quantity
- Information sharing, collaboration, communication
- Quality

Yummy Treats may consider selecting a supplier in the UK. A good answer will also discuss the advantages of onshoring and offshoring.

SECTION B

3 (a)

(i)
From the data – 59.1, 62.2, 58.4
Sample Mean, 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: datasheet)
Thus 59.9 ± [4.303x2.02]/ √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

Basic answers will provide the correct numerical answers to the question.
Stronger answers even without knowing the specific nature of the operation, stronger answers will discuss the issues: 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 expected.
Best answers will provide the above and discuss the effect of forgetting is. Especially because larger batches take longer than a shift or even a week.

(b)

The basic principles are consideration for the use of the human body, design of the workplace and design of tools and equipment. The good practices can be chosen from the list below:

- Use of the Human Body
  - Both hands should start and stop work at the same time
  - Motions of the arms should be symmetrical and in opposite direction
  - Hand and body motions should be minimized.
  - Momentum should be employed to help the worker
  - Continuous curved movements are better than straight line movements
  - Ballistic or free-swinging movements are easier than controlled movements
  - Rhythm is essential to smooth performance of repetitive operations.
  - The work should be arranged to provide easy and natural rhythm where possible
  - Work should be arranged so that eye movements are confined to a comfortable area, without the need for frequent changes of focus.

- Arrangement of the workplace
  - Definite and fixed stations should be provided for all tools and materials.
  - Gravity feed, bins and containers should be used to deliver the materials as close to the point of use as possible.
  - Materials and tools should be arranged to permit the best sequence of motion and placed in the reachable area.
  - Drop deliveries or ejectors should be used wherever possible so the operator does not have to use his hands or feed to dispose of finished work.
  - Provision should be made for adequate lighting and the colour of the workplace should contrast with the work.
  - A chair of suitable height should be provided and the workplace should be arranged to allow alternate sitting and standing.

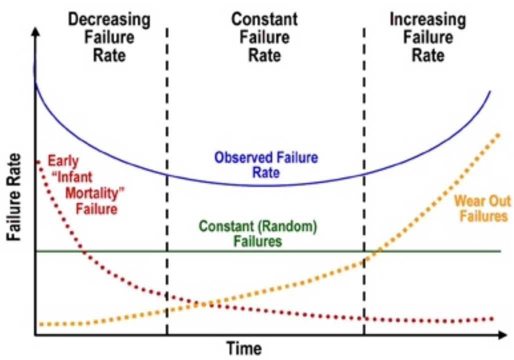
- Design of tools and Equipment
  - The hands should be relieved of holding work where this can be done by a jig fixture or foot operated device.
  - Two or more tools should be combined where possible. Where each finger performs some specific movements such as, typewriting the load should be distributed in accordance with the inherent capacities of the fingers.
  - Handles should be designed so that as much of the hand as possible comes into contact with the handle.

- Levers, crossbars and hand-wheels should be placed so that the operator can use them with the least possible change in body position and to maximize mechanical advantage.

Basic answers will describe the basic principles are consideration for the use of the human body, design of the workplace and design of tools and equipment.
Stronger answers will discuss the complementarity of the human body, design of the work place and design of tools and equipment and provide complementary examples for each group.
Best answers will provide more descriptive examples drawing from manufacturers Domino Printing, JLR, Daimler-Chrysler, Lisi Aerospace, etc.

4.

a. Over many years, and across a wide variety of mechanical and electronic components and systems, people have calculated empirical population failure rates as units age over time and repeatedly obtained a graph such as shown above. Because of the shape of this failure rate curve, it has become widely known as the "Bathtub" curve.



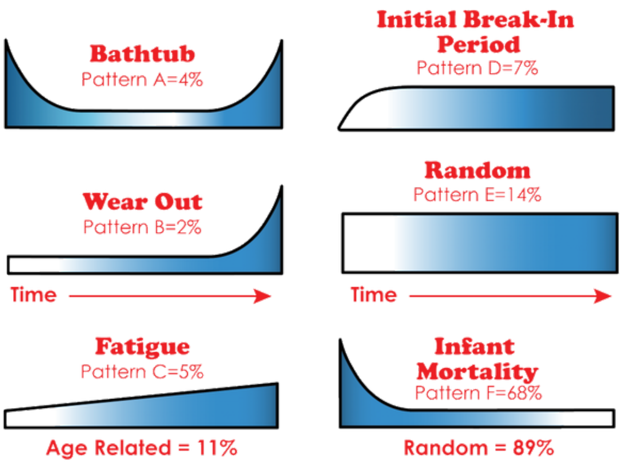
The initial region that begins at time zero when a customer first begins to use the product is characterized by a high but rapidly decreasing failure rate. The high failure rate during this "burn-in" period accounts for parts with slight manufacturing defects not found during manufacture's testing. This region is known as the Early Failure Period (also referred to as Infant Mortality Period, from the actuarial origins of the first bathtub curve plots). This decreasing failure rate typically lasts several weeks to a few months.

Next, the failure rate levels off and remains roughly constant for (hopefully) the majority of the useful life of the product. This long period of a level failure rate is known as the Intrinsic Failure Period (also called the Stable

Failure Period) and the constant failure rate level is called the Intrinsic Failure Rate. Note that most systems spend most of their lifetimes operating in this flat portion of the bathtub curve.

Finally, if units from the population remain in use long enough, the failure rate begins to increase as materials wear out and degradation failures occur at an ever increasing rate. This is the Wearout Failure Period.

[NOTE: A good response will provide a basic description of the bathtub curve along with a clear figure. Excellent responses will discuss the following points: (i) the bathtub curve arises due to different failure modes across the lifecycle; (ii) the different stages of the bathtub curve are associated with different strategies for improving reliability, e.g., burn-in, better design and maintenance; (iii) the failure rate curves are not typically bathtub-shaped for most equipment, and there are a variety of different types of failure-rate curves as shown in the figure below:]



b.

(i) The failure probability function given is a Weibull distribution. Hence we can use the Dobson's table (from the 3P5 handbook) to calculate the approximate age-based replacement policy.

The ratio of corrective to preventive replacement costs =

$$C_f / C_p = \frac{320000}{20000} = 16$$

From the Dobson's table for $\beta = 3$ and the above ratio, the value for m is 0.323.

The optimal age based preventive replacement interval is therefore given by $m \cdot \eta = 0.323 \times 3500 = 1130.5$ days.

(ii) Assuming continuous operation, the reliability of each tank at the end of three years $R(t = 1095\ days)$ is given by

$$R(t) = e^{-(t/\eta)^{\beta}} = e^{-(1095/3500)^3} = 0.9698$$

The reliability of the system is given by $(n = 7;\ k = 5)$:

$$R_s = \sum_{x=k}^{n} \binom{n}{x} R^x (1-R)^{n-x} = \sum_{x=5}^{7} \binom{7}{x} R^x (1-R)^{7-x}$$

$$= \binom{7}{5} R^5 (1-R)^2 + \binom{7}{6} R^6 (1-R) + \binom{7}{7} R^7 (1-R)^0$$

$$= 21 \times 0.9698^5 \times 0.0302^2 + 7 \times 0.9698^6 \times 0.0302 + 0.9698^7$$

$$= .0164 + 0.1758 + 0.8068 = 0.999$$

(iii) In warm/cold standby redundancy, the components are connected in parallel but do not start operating simultaneously from the beginning of the operation of the system.
Warm standby: When the failure rate of the standby component is less in quiescent mode than in active mode,
Cold standby: When the failure rate of the standby component is zero in quiescent mode (i.e. the component cannot fail when in standby)
The function of the changeover device or switch is to sense the failure of normally operating component and in case of a failure, to bring a standby component into the normal operating mode.
The following issues will need to be considered while calculating system reliability when the tanks are operated on warm/cold standby:

- Need to consider the failure rate of the redundant tanks while in passive mode and active mode separately.
- Calculating system reliability involves estimating the conditional failure probabilities of the redundant tanks given the failure of the active tanks.
- Need to consider the reliability of the switch (i.e., the probability that the switch may not be functioning when necessary)

- May also need to consider any switching/startup time required for cold standby tanks to be brought online

[Note: Good answers will describe warm/cold standby contrasting it with hot standby. Better answers will discuss the issues to be considered while modelling warm/cold standby systems. Excellent answers might involve an attempt to provide the mathematical formulation.]

Basic answers will describe warm/cold standby contrasting it with hot standby.
Stronger answers will discuss the issues to be considered while modelling warm/cold standby systems.
Best answers might involve an attempt to provide the mathematical formulation.