2019 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)

$$\lambda_{yearly} = \lambda_{daily} * 365 = 5 * 365 = 1825$$

$i = .3$

$c_a = 2$

$$h_a = i * c_a = .6$$

$K_a = 55$

$$EOQ_a = \sqrt{\frac{2 * K_a * \lambda_{yearly}}{h_a}} = \mathbf{578}$$

(b)

OQ systems work on the basis that there will be steady demand. Demand for parts may change:

- when there are modifications to products, and when component parts are changed
- when new products are introduced or others are removed
- when the general level of demand for products change (recession, boom, newer/ alternative products produced)

When demand increases there will be regular shortages if the re-order point and the batch size are not reviewed; this situation is very visible due to shortages. On the other hand, when demand falls the batch size and the re-order point need to be reviewed, otherwise stocks may be higher than necessary; this is not as visible – and when demand falls excess inventory can cripple or even bankrupt a business.

EOQ has rigid assumptions:

1. Demand is constant and steady, and continues indefinitely
2. EOQ assumes whole replenishment lot arrives at same time
3. Replenishment lead-time is known
4. Order size is not constrained by supplier, no min/max restrictions
5. Holding cost per item per period is a constant
6. Cost of ordering/setup is a constant
7. Item is independent of others; benefits from joint reviews are ignored
8. Doesn't encourage us to decrease fixed ordering/setup costs

EOQ also suffers from a potential lack of accuracy in calculating costs:

- How much does a set-up or placing an order cost?
- Holding costs: often calculated at interest level (cost of capital)

(c)

$\psi_{daily} = 400$

$c_b = 1.95$

$$h_b = i * c_b * \left(1 - \frac{\lambda_{daily}}{\psi_{daily}}\right) = .577$$

$K_b = 80$

$$EOQ_b = \sqrt{\frac{2 * K_b * \lambda_{yearly}}{h_b}} = \mathbf{711} \leq 800 = 2 * 400$$

(d)

$c_c = c_a = 2; \; h_c = i * c_c = .6$

$$K_c * \frac{\lambda_{daily}}{EOQ_c} + h_c \frac{EOQ_c}{2} + c_c * \lambda_{yearly} \leq 3969$$

$$K_c * \frac{\lambda_{daily}}{\sqrt{\frac{2*K_c*\lambda_{yearly}}{h_c}}} + h_c \frac{\sqrt{\frac{2*K_c*\lambda_{yearly}}{h_c}}}{2} + c_c * \lambda_{yearly} \leq 3969$$

$$\leftrightarrow \qquad \sqrt{K_c} * \sqrt{\frac{h_c*\lambda_{yearly}}{2}} + \sqrt{K_c} * \sqrt{\frac{h_c*\lambda_{yearly}}{2}} + c_c * \lambda_{yearly} \leq 3969$$

$$\leftrightarrow \qquad K_c \leq \frac{(3969 - c_c*\lambda_{yearly})^2}{2*h_c*\lambda_{yearly}} = \mathbf{46.47}$$

2 (a)

Utilisation = 78/100=0.78
Efficiency = 78/(100-15) = 0.92

Utilisation is measured by Actual output / Design capacity, whereas Efficiency is Actual output / Effective capacity. Both are measures of productive efficiency. Per unit production costs will decrease as utilisation increases, hence firms aim to be as close to 100% utilization as possible. However, 100% utilisation is risky as even small demand and supply fluctuations may cause disruptions in the system; for example, an increase in demand or a yield problem can lead backorders or lost sales. Achieving the theoretical utilisation of 100% is nearly impossible due to everyday issues in operations and demand fluctuations.

(b)

Supply side:

- Level output, ignoring demand fluctuations. This may result in under-utilisation of capacity when output cannot be stored, and inventory build up where it can. On the plus side, the manufacturer will have stable employment patterns, and better relations with suppliers because of steady ordering.
- Chase demand by fluctuating output, through a combination of overtime, and hiring temporary workforce. While this gives the manufacturer flexibility and a reputation for reliably addressing demand, temporary workforce has a learning curve and may create quality issues.
- Chase demand with outsourcing.

Demand side:

- Demand management, by advertising and promotion, moving demand to alternative or countercyclical products (e.g., Dell during Taiwan earthquake).

(c)

- Capacity is a soft, malleable constraint: it isn't a hard constraint
    - Typically, manufacturing capacity increases strongly beyond the number that we call capacity. (E.g.: capacity is 300 per day ➔ one shift or two shifts, annual capacity 250 days or 365 days)

- Capacity is like "black art"; it depends on everything
    - Hard to define precisely:
        - Service capacity (where there is not much automation can run beyond theoretical limit in the short run -- working "110%"), expediting
        - Everything: downtime, mix, inventory, …
        - Time & scale: typically consider years in which case year-to-year inventory build up is small and ok to ignore; this is not the case for capacity adjustments on small time scale (seasons, months, days).

- Capacity frictions: leadtimes, lumpiness, fixed costs: lag time between the investment decision and availability of the new resource):
    - Mercedes-Benz already decided in the late 1990s to plan for R-class and to expand Alabama plant capacity, but the first GST vehicle just came on the market in Sep 2005, or 6 years later!
    - Lumpy: machines > integer problem vs. continuous
- Capacity requires large and irreversible investment

    - Irreversible = can't recoup investment fully. New > used; cost to lay off (Eurosclerosis – employment problem of usually slow-moving, rigid labor markets of Europe).
- Capacity decisions can be political
    - Big capacity decisions literally deal with politicians to get incentives to keep jobs power wars within the organization (competition for the new Amazon HQs)
    - Unions: threat to close/move plants (Siemens threatened to move capacity to Hungary in June 2004 in case unions did not make concessions to reduce the labor cost); contest to get new product/plant (Harley)
- Measuring and valuing capacity shortfall is not obvious
    - *How would you measure excess demand = capacity shortfall?*
        - Corporate clients you would know; retail: waiting list or estimate by when you ran out.
        - *What is impact?*
            - backlogs: perhaps customer wait
            - Substitution: spill-overs to other products
            - lost sale: for Lexus RS330. Denny Clements, GM of Lexus, said his company could easily sell more than 300,000 vehicles in 2003 (smashing his sales record of 234,000) if it had enough cars and trucks to meet the demand. They sold 10,000 in Aug 2003 but could easily sell more.
- Capacity investment involves long-run planning under uncertainty

(d) (i)

There are 4 rows and 3 columns so a nondegenerate solution will use 4 + 3 - 1 = 6 cells. As we know the solution is degenerate, it should use less than that.

	L	**M**	**N**	**Supply**
P	3 **15**	5 **7**	6	**22**
Q	4	3 **10**	7	**a = 10**
R	6	4	8 **11**	**11**

S	8	2	5 **9**	**b = 9**
Demand	**15**	**17**	**20**	

(ii)

See table above; cost = 3 * 15 + 5 * 7 + 3 * 10 + 8 * 11 + 5 * 9 = 243

(iii)

Δ(cost) = -5+6-8+4 = -3

	L	**M**	**N**	**Supply**
P	3 **15**	(-) 5 **7**	(+) 6	**22**
Q	4	3 **10**	7	**a = 10**
R	6	(+) 4 **+ε**	(-) 8 **11−ε**	**11**
S	8	2	5 **9**	**b = 9**
Demand	**15**	**17**	**20**	

See table below; new cost = 3 * 15 + 6 * 7 + 3 * 10 + 4 * 7 + 8 * 4 + 5 * 9 = 222

	L	**M**	**N**	**Supply**
P	3 **15**	5	6 **7**	**22**
Q	4	3 **10**	7	**a = 10**
R	6	4 **7**	8 **4**	**11**
S	8	2	5 **9**	**b = 9**
Demand	**15**	**17**	**20**	

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SECTION B

3 (a)

(i) The characteristics of work situations for which work sampling is most suited are (1) there is enough time available to perform the study because of the substantial period of time required to complete a work sampling study, (2) observing multiple subjects are feasible, (3) long cycle times of the jobs covered, and (4) the work is not highly repetitive; instead, the jobs usually consist of various tasks rather than a single repetitive task.

(ii) Disadvantages and limitations are the following: (1) For setting time standards, work sampling is not as accurate as other work measurement techniques, such as DTS and PMTS. (2) Work sampling is usually not practical for studying a single subject. (3) If the subjects in a work sampling study are separated geographically by significant distances, the observer may spend too much time walking between them. In addition, it may allow workers at the beginning of the observer's tour to alert workers at the end of the tour that the observer is coming, with the possible risk that they would adjust their activities and bias the results of the study. (4) Work sampling provides less detailed information about the work elements of a task than direct time study or predetermined time systems. (5) Since work sampling is usually performed on multiple subjects, it tends to average their activities; thus, differences in each individual's activities may be missed by the study. (6) Because work sampling is based on statistical theory, workers and their supervisors may not understand the technique as readily as they understand direct time study. (7) A work sampling study does not normally include detailed documentation of the methods used by the workers. (8) As in so many fields of study, the behaviour of the subject may be influenced by the act of observing him or her. If this occurs in work sampling, the results of the study can become biased, perhaps leading to incorrect conclusions and inappropriate recommendations

(b)

(i) Proportion of time on the phone

$$\hat{p}_1 = 164/500 = 0.328$$

Hours on the phone for 4 account executives =
4 (5 days) (7 hr/day) (0.328) = 45.92 hr

(ii) For 97% confidence interval, $z_{\alpha/2} = 2.17$

$$\hat{\sigma}_p = \sqrt{\frac{0.328(0.672)}{500}} = 0.021$$

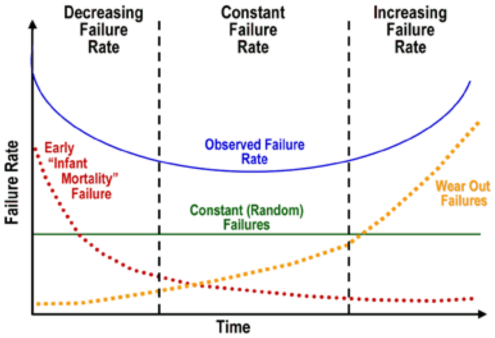
$\hat{p}_1 - z_{\alpha/2}\hat{\sigma}_p$ = 0.328– 2.17(0.021) = 0.328 – 0.0456 = 0.2824
$\hat{p}_1 + z_{\alpha/2}\hat{\sigma}_p$= 0.328+ 2.17(0.021) = 0.328 + 0.0456 = 0.3736

(iii) Consider how much time is spent in category 2 by account executives.
$\hat{p}_2$= 150/500 = 0.30
Total hours of 4 account executives in category 2 = 4(7)(0.30) = 8.4 hr/day

The newly hired clerk would spend 7 hr/day performing filing and sorting for the account executives.
Commissions per week = £525,000(0.04) = £21,000/wk
Sales commissions per hour = 21,000/45.92 = £457.32/hr
Increase in commissions for 7 hours = 7(457.32) = £3,201.24
Increase in commissions per week = 5(£3,201.24) = £16,006/wk
the net weekly increase = 16,006 – 800 = £15,206.
With the clerk costing only £800/wk, it is worth recruiting the clerk.

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.



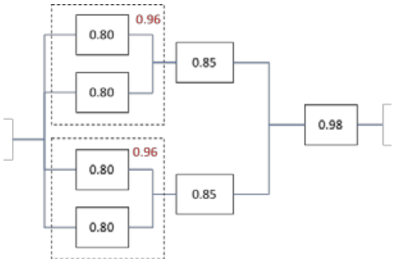
The initial region that begins at time zero when a customer first begins to use the product is characterized by a high but rapidly decreasing failure rate. The high failure rate during this “burn-in” period accounts for parts with slight manufacturing defects not found during manufacture’s testing. This 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.

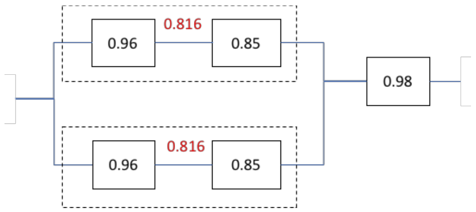
Finally, if units from the population remain in use long enough, the failure rate begins to increase as materials wear out and degradation failures occur at an ever increasing rate. This is the **Wearout Failure Period**.

(b) (i) The reliability of the device can be calculated by step-wise simplification of the reliability block diagram, as follows:

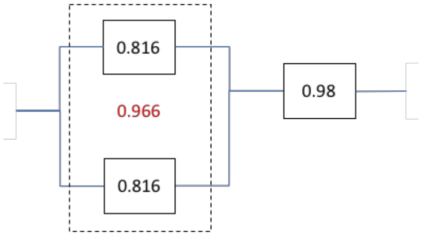
Iteration 1:



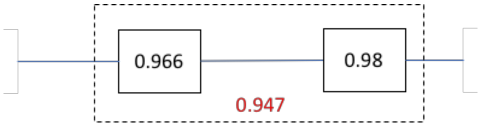
Iteration 2:



Iteration 3:



Iteration 4:



The reliability of the device is 0.947.

(ii) Maximum increase in reliability can be achieved by making the independently least reliable component redundant. Since this is a complex system, we examine the last iteration of the above calculation, which shows that the sub-system on the left if the least reliable. Within that sub-system, by examining iteration 2, we can see that components b_1 and b_2 are the least reliable. Hence adding redundancy to either of these components will result in the maximum increase in reliability of the device.

(c)

(i)

$$\lambda(t) = \frac{m}{\theta}\left(\frac{t}{\theta}\right)^{m-1}$$

Therefore, the reliability of the device is given by:

$$R(t) = exp\left[-\left(\frac{T}{\theta}\right)^{m}\right]$$

$$-\left(\frac{T}{\theta}\right)^{m} = \ln[R(t)]$$

$$\therefore T = \theta\{\ln[1/R(t)]\}^{1/m} = 2\ years$$

(ii) The reliability with burn-in time T_0 is given by:

$$R(t|T_0) = \frac{\exp\left[-\left(\frac{t+T_0}{\theta}\right)^m\right]}{\exp\left[-\left(\frac{T_0}{\theta}\right)^m\right]}$$

Setting $t = T$, the design life, we solve for T, and $R(t|T_0) = 0.90$,

$$T = \theta\left\{ln\left[\frac{1}{R(t)}\right] + \left(\frac{T_0}{\theta}\right)^m\right\}^{1/m} - T_0 = 2.81\ years$$

(iii)

The burn-in time can be optimised by examining the trade-off between the cost of burn-in and the risk of product failure within a period of interest (e.g., warranty period).

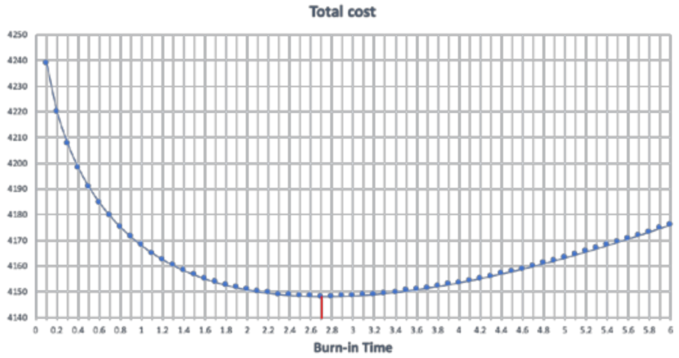
C_b= cost per unit time for burn-in test
C_f= cost per failure during burn-in
C_o= cost per failure when operational $\gg C_f$
t_b= length of burn-in testing
t = operational life of the system (e.g., warranty period)
n = number of units for burn-in
Expected cost incl. burn-in =

$$E[TC] = nC_bt_b + C_fn[1 - R(t_b)] + C_on[1 - R(t|t_b)]$$

Expected cost per unit incl. burn-in

$$E[C] = C_bt_b + C_f[1 - R(t_b)] + C_o[1 - R(t|t_b)]$$

The optimal burn-in period can be identified by calculating t_b that minimises $E[C]$.
A typical cost curve is shown below:



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