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Module 3P4: OPERATIONS MANAGEMENT
(Section A)

Module 3P5: INDUSTRIAL ENGINEERING
(Sections B)

SECTION A

1. (a) (i)

This question must be answered using the load-distance method. First, the distance between each candidate location and each DC must be calculated using the Euclidean method of measuring distance:

$$d_{AB} = \sqrt{(x_A - x_B)^2 + \sqrt{(y_A - y_B)^2}}$$

The next step is to calculate the weighted (demand*distance) for each candidate location.

The table below shows the results of the calculation.

	A	B	C	D	Load-distance
1	161.2	412.3	434.2	184.4	125061.8
2	333.0	323.9	226.7	170.0	99790.5
3	206.2	180.3	200.0	269.3	77546.3

It can be seen from the above calculation that location 3 is the best option.

(ii) The COG/LD methods may not be optimal, but is a good place to start. In practice, it will also depend on:

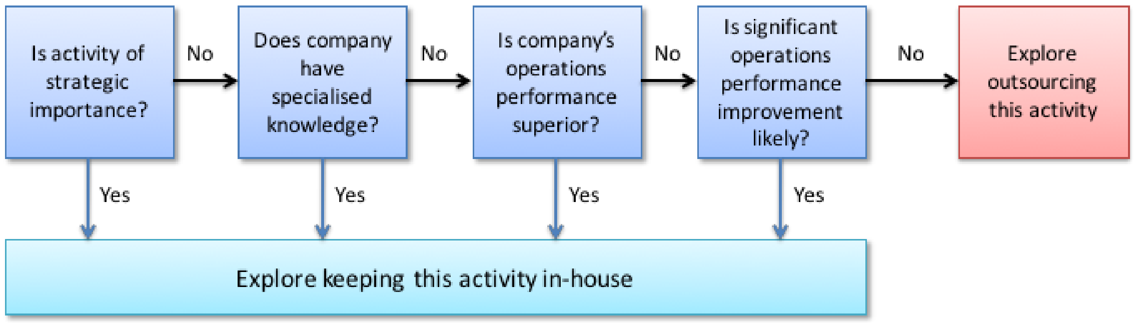
- Transportation network (effective distance)
- Local infrastructure and incentives (as discussed before)
- Social factors (as discussed before)
- Preferences of senior management
- Market
- Supplier base / alternative suppliers

(b) This problem must be solved using the North-West corner method. There are two complications in this question: (i) The total demand and spare capacity are not equal. This can be addressed by creating a "dummy DC" with zero cost that will absorb the excess capacity. (ii) The problem given here is of profit maximisation – in the examples shown in lectures and supervisions, the problems were of cost minimisation. Hence, during each iteration, the reallocation that provides the maximum increase in profit must be chosen.

The solution to this question is: F1-C: 125 units; F2-A: 45 units; F2-B: 105 units; F3-A: 30 units; F3-C: 10 units; F3-D: 60 units. This allocation gives a total profit of £126,100.

(c)

The inhouse vs. outsource decision may be taken using the logic given in the figure below.



Candidates must consider the particular case given here when answering the question. For example, the fact that this is a new and innovative technology will weigh heavily on the CEO's mind, in addition to concerns about IP protection in China and the availability of spare capacity in the company's own factories.

Ajith Parlikad

2 (a) 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. Therefore, **the fixed-order quantity model is preferred for more expensive items** because average inventory is lower.

The fixed-order quantity model has no review period. Therefore, **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 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 time period model 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). Therefore, **the fixed-order quantity model should be preferred only when such a monitoring is feasible**. 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.

(b) At optimal solution, the firm's annual inventory holding cost should be equal to their annual setup cost. Since the current annual holding cost is $500 and annual setup cost is $700, we should increase *Q* further to increase the annual holding cost and decrease the annual setup cost. Therefore, the optimal order quantity should be larger than 1,000 units.

(c)

(i)

$$EOQ_i = \sqrt{2K_i\lambda_i/h_i}$$
$$TC_i^* = h\,\frac{EOQ_i}{2} + K_i\frac{\lambda_i}{EOQ_i} = \sqrt{2K_i\lambda_i h_i}$$

(ii)

Due to the economy of scale in setup costs, 3G-Mobile will incur a setup cost of $\alpha(K_A + K_B)$ for setup at the same time. Since the cycle length is *T*, the setup cost per unit time will be $\alpha(K_A + K_B)/T$. *During each order cycle*, 3G-Mobile will order $T * \lambda_A$ units of A and $T * \lambda_B$ units of B. The average inventory holding cost for these units will be $\frac{T}{2}(h_A\lambda_A + h_B\lambda_B)$. Therefore, the total cost (annual setup cost + annual holding cost) in terms of the cycle T, i.e., time elapsed between subsequent runs, can be expressed as:

$$TC(T) = \frac{\alpha(K_A + K_B)}{T} + \frac{T}{2}(h_A\lambda_A + h_B\lambda_B)$$

(iii)

Using the first-order optimality conditions, we can calculate the optimal T^*. Take the derivative *TC(T)* with respect to *T*, which should be equal to 0 at optimality:

$$-\frac{\alpha(K_A + K_B)}{T^2} + \frac{1}{2}(h_A\lambda_A + h_B\lambda_B) = 0.$$

From the equation above, we can calculate the optimal T^* as:

$$T^* = \sqrt{2\alpha(K_A + K_B)/(h_A\lambda_A + h_B\lambda_B)}\,.$$

Insert optimal T^* into the cost function to find the expression for the optimal total annual cost in terms of the given parameters $(\lambda_i, K_i, h_i, \alpha)$:

$$TC^* = \sqrt{2\alpha(K_A + K_B)(h_A\lambda_A + h_B\lambda_B)}.$$

(iv)

We can now express this condition for α in terms of the given parameters (λ_i, K_i, h_i) using total cost expressions from parts (i) and (iii):

$TC^* \leq TC_A^* + TC_B^*$

➔ $\sqrt{2\alpha(K_A + K_B)(h_A\lambda_A + h_B\lambda_B)} \leq \sqrt{2K_A\lambda_A h_A} + \sqrt{2K_B\lambda_B h_B}$

➔ $\alpha \leq \left(\sqrt{K_A\lambda_A h_A} + \sqrt{K_B\lambda_B h_B}\right)^2/((K_A + K_B)(h_A\lambda_A + h_B\lambda_B))$

Feryal Erhun

SECTION B

4 (a)

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

(b) During task Average *ERwrk* = 9/3+ 4*2/3= 5.66 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 = 6(5.66 – 5.0)/(5.0 – 1.5) = 2.28
On average the worker should rest for 11 minutes for each hour of work. Any sensibleschedule to achieve this is acceptable. Eg a 20 minute breaks every 2 hours

(c)
(i) *SMED*

SMED stands for Single Minute Exchange of Dies. It is a set of techniques for Set-up time reduction. The starting point is the recognition that the work elements in setup are of two types:

- Internal elements – can only be done while the production machine is stopped

- External elements – do not require the machine to be stopped

The basic concept behind set up time reduction is then:
Stage 1 – Identify and separate internal and external set–up
Stage 2 – Convert internal set-up to external set-up where ever possible.
Stage 3 – Streamline and reduce the time required for the set-up operations

(ii) *Poka-yoke*

"Poka-yoke" – Japanese word meaning prevention of errors using low cost devices toprevent or detect them. Poka-yoke devices can prevent errors such as: Omitting processing steps, Incorrectly locating a part in a fixture, Using the wrongtool,Neglecting to add a part in assembly
Implementing Poka –Yoke devices is a major step in improving quality at source in manufacturing operations

(iii) *5-S*

5-S is a technique for Workplace Organization. It is the first step in any improvement activity
– Removes Unnecessary Obsolescence & Clutter, Clears needed floor space
– Prepares environment for effective study.
– Uncovers Waste in Process or Flow – Removes 'Can't see the wood for trees'
– Establishes "Action-Oriented" Pace –by involving workers ina very visible process.

There are 5 stages characterised by 5 Japanese words

Japanese word	English equivalent
Seiri	Sort
Seiton	Set in order, simplify access
Seiso	Shine, sweep, scrub
Seiketsu	Standardize
Shitsuke	Self-discipline, sustain

(iv) *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)
Measuring OEE and its constituent parts is a way of tracking machine performance and identifying problems in the effective use of manufacturing equipment as a first step towards making improvements.

(d) From the normal approximation to the binomial distribution

$$c = \left(z_{\alpha/2}\right)\sqrt{\frac{\hat{p}\left(1-\hat{p}\right)}{n}} \qquad n = \frac{\left(z_{\alpha/2}\right)^2 \hat{p}\left(1-\hat{p}\right)}{c^2}$$

hence,
p=0.75, c=0.05*0.75 z= 1.645 (for 90% conf) hence n= 361

(e) **P chart**

$$\bar{p} = 0.15$$
$$n = 25$$
$$1 - \bar{p} = 0.85$$
$$\bar{p} * {(1-\bar{p})}/{n} = 0.0051$$
$$\sigma = \sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = 0.071$$
$$UCL = \bar{p} + 3\sigma = 0.294$$
$$CL = \bar{p} = 0.15$$
$$LCL = \max(0, \bar{p} - 3\sigma) = \max(0, -0.064) = 0$$

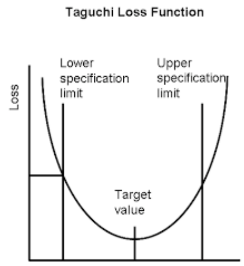
Notes:

1) 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.

2) The lower control limit cannot be negative so is set at zero.

Samples of 25 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 15% 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.

(f) Taguchi’s Loss to Society idea is that, when there are quality problems within the firm, society also suffers. There is no trade-off and the impact of poor quality is much broader than within the firm.

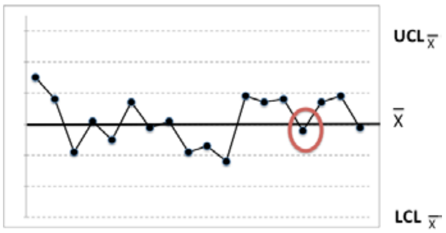


Juran's Cost of Quality model, on the other hand, balances prevention and appraisal costs against internal and external failure costs and finds an optimal conformance level based on that balance.

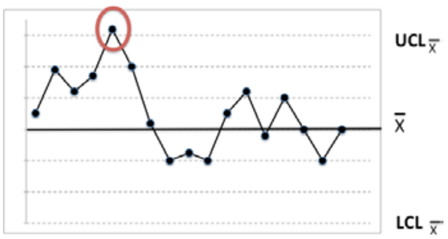
(g)

(I) In control

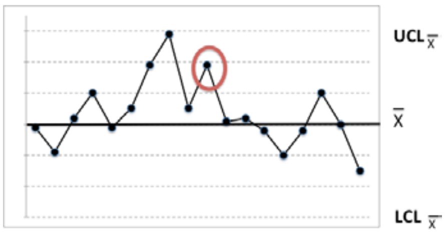
(II) Special cause variation: 14-in-a-row alternating



(III) Special cause variation: Point outside of limit



(IV) Special cause variation: 5-in-a-row one side of CL



4 (a) The time study is of a small sample, thus the student *t*-distribution should be used when calculating confidence intervals. The formula for the 95% confidence limits is:

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

Mean = 83.0 Std Dev 2.01 n=5
For 4 degrees of freedom and α = 0.05 from the tables of student t distribution t = 2.776
95% confidence interval is 83.0 +/- 2.776 (2.01)/√5 = 83.0+/- 2.5
The 95% confidence interval is 80.5 to 85.5

(b) Basic time = 83*110/100 = 91.3 but with 95% confidence limits of 88.55 to 94.05

Std Time = 83*1.1*1.17= 106.8s but with 95% confidence limits of 103.6 to 110

Basic time is the time that a worker working at standard performance would take to perform the task, while working.

Note:Standard Performance (standard rate of working) is defined as the rate of output which qualified workers will naturally achieve, without over exertion, averaged over the working shift, provided that they know and adhere to the specified method and provided that they are motivated to apply themselves to their work.

{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}

Standard Time adds on to basic time all allowances to cover fatigue, personal need breaks and many other small elements that are essential to the job, but may not appear in the basic time.

Its importance is that Output = Hours worked/Standard time, and this is used for all planning.

(c) (i) Current TAKT time for product = 75*60/5000 = 0.9 mins or 54 secs.

There are 2 machines producing so the standard time must be 108 or less. The best estimate of standard time is 106.8 s so this looks just doable. However, from the data we have there is a chance that the standard time could average more than this. We can roughly evaluate this chance from the probability that the standard time is greater than

108, by looking at p(t>1.2/2.5) for 4 degrees of freedom. From t tables this is slightly over 30%. So THIS IS NOT A ROBUST SITUATION even for the current output.

(ii) Anticipated TAKT time = 75*60/6000=0.75mins, or 45 secs.

Note if students merely look at the observed cycle times , ignoring rating and allowances, they might conclude that both outputs can be robustly covered by the existing capacity.

(d) The noise regulations require that the average sound pressure level (SPL) over 8 hours is less than 85 dBA, and that there is no exposure to noise exceeding 87 dbA when attenuated by hearing protection.

SPL average= 10 log10{1/To ∑Ti($10^{0.1SPLi}$)} Ti is the time at SPLi and To is 8 hours
The background noise of 70dbA is insignificant compared with the machine noise and we can ignore it. With 2 machines operating together, we can calculate the maximum time of exposure (T) as follows
Subs values, antilog and rearrange
$8*10^{8.5} = 2T\ 10^{8.2}$
$T = 4*10^{8.5-8.2}$ = 7.98 hours, which is longer than the shift length and is therefore OK.
With 3 machines this becomes $8*10^{8.5} = 3T\ 10^{8.2}$ and T= 5.32 hours. Thus simply buying a 3rd machine would only increase total output by a factor of 15.96/15 = 6% assuming that no other changes are made and operators work legally.

e) One option would be to use several operators, and redeploy them through the shift to ensure they never work in this environment for longer than 5 hours. However, this might not be practical and would also require monitoring their other activities. A better alternative would be to address the noise issue. Several options here:

1) reduce noise at source – identify and address vibrations, add damping etc.

2) provide barrier to noise – between the noise source and the operator, eg machine enclosures

3) supply personal hearing protection

Option 3 is clearly the most expedient in the short term