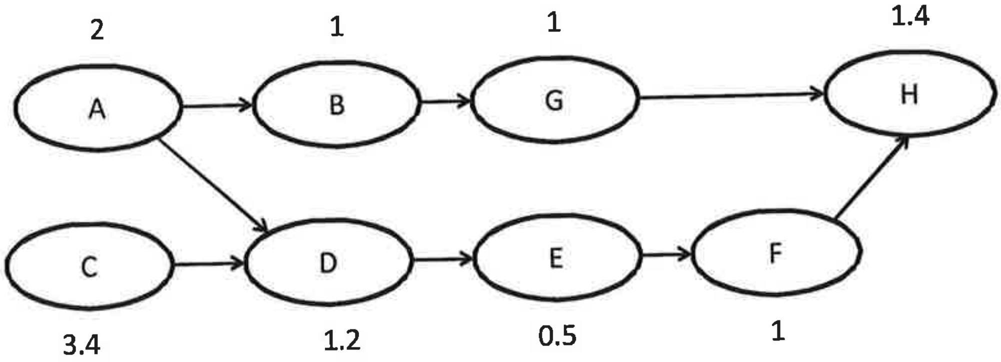
2012 Part IIA 3E10 Operations Management for Engineers Dr W Kerley

Question 1:

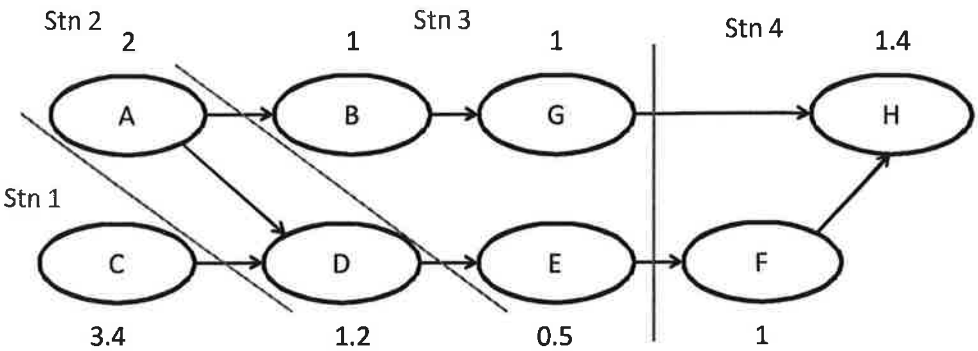
1(a) The precedence diagram, annotated with the task durations, is as follows:



1(b)(i) The maximum number of fans will be produced per hour when the tasks are grouped into a number of stations giving the lowest possible cycle time. Task C has the longest task duration (= 3.4 minutes) and therefore determines the lowest cycle time for any possible configuration. Therefore the maximum number of fans produced per hour is 60/3.4 = 17.6 fans/ hour

1(b)(ii) The total work content is the sum of all the task times i.e. 2+1+1=3.4+1.2+0.5+1+1+1 = 11.5 minutes.
The theoretical minimum number of workstations is the total work content divided by the target cycle time = 11.5/3.4 = 3.4 i.e. 4 workstations.

By inspection it is possible (in practice as well as in theory) to group the tasks into four workstations (numbered in sequence), as shown below. NB There are other possible solutions for the groupings, although task C is always by itself.



1(b)(iii) The labour efficiency = work content/labour input expressed as a percentage
= (11.5/ (4*3.4))*100% = 84.6%

1(b)(iv) Station 4 (Tasks F and H) has the lowest work content i.e. 2.4 minutes compared with 3.4, 3.2 and 2.5 for the other 3 workstations. The idle time for Station 4 is 3.4 – 2.4 = 1 minute

1(b)(v) Using Little's Law (I = RT)
The production rate (R) = 1/3.4 fans/minute
The lead time (T) = 3*3.4 + 2.4 = 12.6 minutes

So average inventory (I) = 12.6/3.4 = 3.7 fans

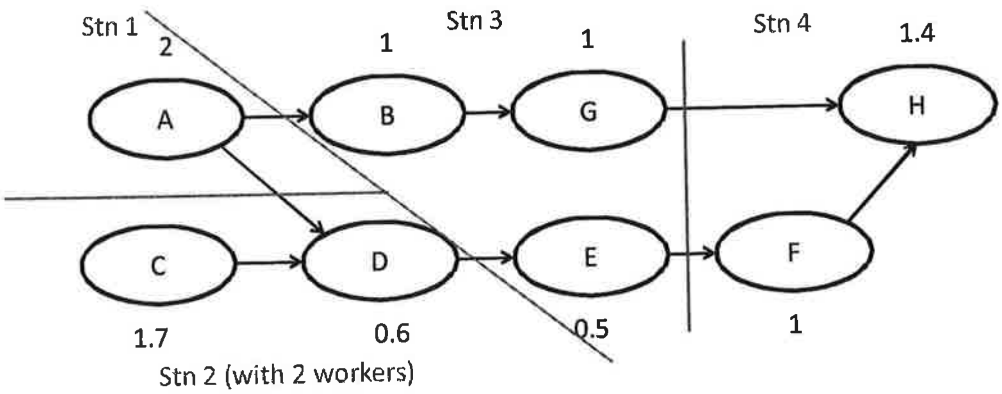
1(c)(i) According to the Theory of Constraints the following 5 steps should be followed:

1. Identify the constraint (in this case the bottleneck workstation)
2. Decide how to exploit the constraint (e.g. add the extra worker)
3. Subordinate all other processes to above decision (make sure that the bottleneck is always running at 100% capacity e.g. by adding a buffer in front of it)
4. Elevate the constraint (e.g. reorganise the workstations)
5. If, as a result of these steps, the constraint has moved, return to Step 1.

1(c)(ii) The bottleneck workstation is Task C/Station 1.
Adding the extra worker to that workstation will decrease the duration of Task C to 1.7 minutes. This will move the bottleneck to Station 2 which has a total duration of 3.2 minutes

BUT can we do better?
Given that there are 4 workstations the lowest possible cycle time for the whole process with two workers on Task C is (11.5-1.7)/4 = 2.45 minutes
Perhaps we can reduce the processing time at Station 2 by reallocating tasks?

By inspection the first two workstations can be reorganised as follows (showing new task durations and sequence). Note that the order of the stations has changed so that Task A is performed first, and then C with D.



Let's check that's the best we can do:

- Lowest possible cycle time for this configuration is (2+1+1.7+0.6+1+1+1+1.4)/4 = 2.3 minutes.
- The new bottleneck is Station 3 with a cycle time of 2.5 minutes
- Taking Task E from Station 3 and adding it to Station 2 would make Station 2's cycle time = (3.4+1.2+0.5)/2 = 2.55 minutes (which is greater)

NB 1. It is not possible to combine task A with B, E and G and allocate two workers to the new workstation because this would break one of the precedence relationships i.e. A before D and D before E.
NB 2. The solution given is unique.

1(c)(iii) The general principle is to place the buffer in front of the bottleneck station, in this case Station 3. A buffer would protect this station from variation in process times in the upstream stations (1 and 2) which might starve it of materials. Ideally the bottleneck always runs at 100% capacity as time lost at the bottleneck cannot be recovered later in the process.

However, given that the processing times for Station 1 (2 mins) and Station 2 (2.3 mins) are somewhat less than Station 3 (2.5 mins) a buffer may not be required. It depends on whether the cost of extra inventory is outweighed by the risk of starving Station 3.

1(c)(iv) Using Little's Law again $I = (3*2.5 + 2.4)/2.5 = 3.96$ fans

1(c)(v) Labour efficiency = $11.5/(5*2.5) = 92\%$

1(d) Maximum (i.e. 100%) labour efficiency could be achieved if EITHER

- A single person performed all the assembly tasks by themselves OR
- Workers could move between assembly lines.

These are unlikely to happen in practice for the following reasons:

- *Benefits of specialisation:* The less variety of tasks a worker has to perform the more productive they are likely to be
- *Workspace design (ergonomics):* It may be difficult to lay out the assembly lines in such a way that the worker(s) can perform all the tasks without excessive movement leading to productivity loss (travel time, fatigue etc.)
- EITHER *Capital intensity:* Having one worker per assembly line will increase the number of assembly lines needed. This is likely to require a larger factory and more tooling.
- OR *Control:* Having workers moving around makes it difficult to keep track of who has worked on what and therefore to monitor their performance (i.e. quality of work, productivity etc.)

Question 2:

2(a)(i) Start of week 1: Order to cover demand for n weeks

N	units	cost (£)	cost/unit (£)
1	400	30	0.075
2	1000	30 + 600(0.02) = 42	0.042
3	1400	42 + 2*400(0.02) = 58	0.04143
4	1600	58 + 3*200(0.02) = 70	0.04375

So order beer for 3 weeks i.e. 1400 bottle, order cost £30 and storage cost £28

Start of week 4: Order to cover demand for n weeks

N	units	cost (£)	cost/unit (£)
1	200	30	0.15
2	600	30 + 400(0.02) = 38	0.06333
3	800	38 + 2*200(0.02) = 46	0.0575
4	1000	46 + 3*200(0.02) = 58	0.058

So order beer for 3 weeks i.e. 800 bottles, order cost £30 and storage cost £16

Start of week 7: Order to cover demand for n weeks

N	units	cost (£)	cost/unit (£)
1	200	30	0.15
2	800	30 + 600(0.02) = 42	0.06333

So order beer for remaining 2 weeks i.e. 800 bottles, order cost £30 and storage cost £12

In summary, order:

1400 bottles in week 1
800 bottles in week 4
800 bottles in week 7

2(a)(ii) Total storage cost = 28 + 16 + 12 = £56

2(b) POQ uses the EOQ formula to calculate the economic batch size. This is then divided by the periodic demand to give a fixed order frequency.

EOQ = √(2DCo/Ch)

Working in weeks

D = total demand for the term/ 8 weeks = 3 000/ 8 = 375 bottles/ week
Co = £30
Ch = £0.02/ bottle

EOQ = 1061 bottles/ order

(i) The Economic Time Cycle = EOQ/ D = 2.83 i.e. 3 weeks (as working in whole weeks)

(ii) The orders will be:
 1400 bottles in week 1
 800 bottles in week 4
 800 bottles in week 7

(iii) This is exactly the same as for the LUC method, so the cost to the bar will be exactly the same.

2(c) The purpose of Pareto analysis is to give priority to the things that have the most effect on organisational performance. For inventory management Pareto analysis is used to create the ABC classification of SKUs (see Fig.1 below)

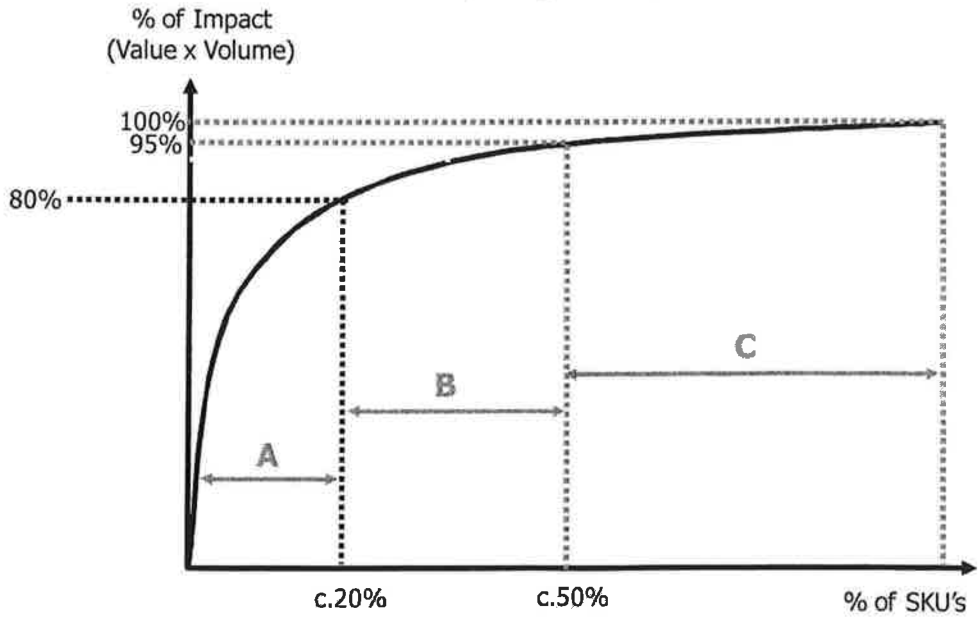


Fig 1. Pareto analysis of SKUs based on Usage Value

SKU's are ranked by usage value (Value x Volume).

- The Value is determined by the cost of the item
- The Volumes need to be forecast using either qualitative methods (e.g. surveys, panels, Delphi study and/or scenario planning) or quantitative methods (using extrinsic or intrinsic) data

Class A: 20% of the SKUs , expected to represent 80% of the usage value
Class B: the next 30%, expected to represent 15% of the usage value
Class C: the remainder. About 50% of the SKUs but only 5% of the usage value

The classification of an SKU may be modified by

- Consequence of stock out
- Uncertainty of supply
- High obsolescence or deterioration risk

For Class A

- Constantly monitor the usage and ordering of these items closely
- Minimise stock level and aim for flow
- Ideally only order what's needed when it's needed (i.e. a variable order quantity and timing policy). In a "push" system calculate individual order quantities and timings using the MRP. In a "pull" system incorporate into the JIT Kanban system

For Class B

- Rather than constant monitoring, review ordering policy from time to time
- Could determine order timing and quantity using any of the methods covered in lectures, although common is to use EOQ and a continuous review approach i.e. order the EOQ when the quantity in stock falls to the re-order level (i.e. fixed order quantities and variable timing)
- A fixed period approach (such as POQ) is also possible. Using a variable order and variable timing heuristic (such as LUC) is less likely.

For Class C

- Review the ordering policy only occasionally
- Fixed order quantities (like Class B)
- Automate replenishment based on reorder levels e.g. using a simple system like two-bin or three-bin reordering

In a two-bin system: Bin 1 = items being used; Bin 2 = reorder level and safety stock

In a three-bin system; Bin 2 = reorder level; Bin 3 = safety inventory

In both cases, place order when Bin 1 is empty. The three-bin system shows clearly if demand is exceeding expectations (in which case Bin 2 will be emptied and stock drawn from Bin 3)

Question 3:

3(a) Push Scheduling

(a)(i) MRP takes three inputs to generate three outputs.

The 3 inputs are:

1. *Master Production Schedule:* the volume and timing of the end products to be made. Derived from both known order and forecast demand.
2. *Bill of Materials:* Details of the materials, components and sub-assemblies required to make each product.
3. *Inventory Master File:* The inventory currently held

The 3 outputs are:

1. *Work Orders:* instructions of when, how and with what to produce the end product demanded
2. *Purchase Orders:* Orders to a supplier to provide materials.
3. *Rescheduling Notices (Exception Reports):* These *recommend* cancelling, increasing, delaying or speeding up existing work and/or purchase orders

(a)(ii) In a push system, such as MRP:

- Orders are planned and issued centrally
- Upon completion the order is moved forward until the next process is issued with the order to start processing it
- Uses backward scheduling i.e. starting jobs at the last possible moment to stop them being late
- The analogy is of the order being pushed through the system with work only taking place when instructed

(a)(iii) The purpose of inventory with a push system is to place buffers between process operations. The idea is to protect (decouple) each operation from factors such as fluctuations in the upstream processes, errors in forecasts and delays caused by routings and thereby reduce unplanned idle time (maintaining process efficiency).

3(b) Pull Scheduling

(b)(i) In a pull system, such as JIT:

- Processes are triggered by a replenishment signal
- Upon withdrawal of material from inventory the preceding process is authorised to start processing and only then
- Uses forward scheduling i.e. starting jobs as soon as they arrive
- The analogy is of material being pulled through the system with production taking place as soon as the material arrives

(b)(ii) Kanban cards are used to withdraw inventory and signal the need for production, if there is insufficient inventory on hand. In JIT a Two-Kanban System is used (see Fig 2 below)

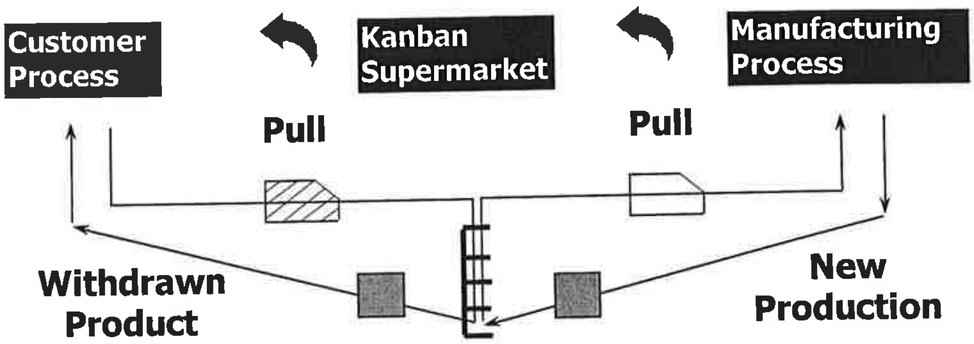


Fig 2. Two Kanban System

A *withdrawal kanban card* is used request inventory from the kanban supermarket to satisfy a customer order
If there is insufficient inventory in the kanban supermarket then a *production kanban card* is used to request inventory from manufacturing. This goes to the last stage in the production process first.
If the last stage cannot satisfy the order then it tries to produce the materials needed. If it is lacking the necessary inventory to do this then it passes the card to preceding stage and waits for the card and requested inventory to return.
The production kanban card is passed down the production line until it either reaches a stage which has the required inventory or reaches the first stage in the line. If the first stage does not have the inventory then an order will be placed with a supplier.

Materials and associated kanban card then flow back down the production line until the inventory is placed in the kanban supermarket.

(b)(iii) In a JIT system the purpose of inventory is the WIP needed to fulfil kanban requests.

3(c) A push system would be preferred to a pull system when:
(i) Order frequency is low. Pull systems work better when the same things are being produced over and over again
(ii) Production lead time (P) is long compared with customer lead time (D). If P:D ratio is greater than one then production will need to be planned and buffers will be needed to decouple demand from production.
(iii) Fluctuations in demand are high. Pull systems tend to be fragile to large fluctuations in demand.
(iv) Product complexity is high. Pull systems work better for simple bills of materials with simple routings
(v) Product variability is high. Pull systems work better for "runners" and "repeaters" (i.e. larger volumes) and not "strangers"
(vi) Process variability is high e.g. Pull systems work better for batch and continuous processes; push for one-off projects and job shops

Question 4:

4(a)(i) Slack's 5 performance objectives are:

- *Quality:* Consistent conformance of the output (product or service) to customers' expectations
- *Speed:* The elapsed time between customer request and delivery
- *Dependability:* Delivering, or making available, products and services when they were requested by the customer
- *Flexibility:* The degree to which an operation's process can change what it does, how it is doing it, or when it is doing it
- *Cost:* How much the product or service costs the organisation to produce or provide it (NB strictly this is not its price to the customer)

An example is required for each one.

4(a)(ii) Ferdow and de Meyer (1990) propose that improvement is a cumulative process that has to be addressed in stages, like building a sandcone. The base of this sandcone is *quality*. Once there is a minimum level of quality then it should be possible to increase *dependability*, which will require further increases in quality. Then *speed* can be increased while continuing to increase quality and dependability. Then *flexibility*, building on quality, dependability and speed. Finally lower *costs* should derive from the process changes required to improve the other four performance objectives.

4(b) Radical improvement

- Step change
- Short-term execution
- One-off activity e.g. Kaikaku or Kaizen-Blitzen
- Specific (often narrow) focus

Continuous improvement

- May be known as Kaizen
- Gradual/ incremental improvements
- Long-term activity
- Organisation wide or beyond to supplier and distribution

4(c)(i) The DMAIC cycle is key method behind Six Sigma process improvement projects. The methodology is primarily of use when improving existing processes.

- *Define* - focuses on selecting the underlying metric that will reflect project success. In this case, warranty claims.
- *Measure* - document the current process, validate how it is measured, and assess baseline performance. Tools might include SPC trend charts, basic Pareto charts, process flowcharts, and process capability measurement.
- *Analyse* - Isolate the *top causes* behind the metric we are tackling. Tools might include Pareto chart, fishbone diagram, 5-Whys, regression analysis, histograms, scatter diagrams, tree diagrams.
- *Improve* – focus on understanding the top causes identified in the Analyse phase. Work out how to control or eliminate the causes of variation. This process redesign can be achieved through, for example, design of experiments (DOE), poka yoke (mistake proofing) and new standard work.
- *Control* – sustain the changes that have been made in the improve phase. Ideally, changes would require no monitoring (irreversible product or process design changes), otherwise SPC techniques, visual controls, production boards, etc, could be applied.

4(c)(ii) As described by Spear and Bowen (1999), *Decoding the DNA of the Toyota Production System,* in the TPS each operation is designed and improved following the scientific method.

Relies on the following rules:

1. All work shall be highly specified as to content, sequence, timing, and outcome.
2. Every customer supplier connection must be direct, **and** there must be an unambiguous yes-or-no way to send requests and receive responses.
3. The pathway for every product and service must be simple and direct.
4. Any improvement must be made in accordance with the scientific method, under the guidance of a teacher, at the lowest possible level in the organization.

Every execution of an operation is an "experiment" that the operation is correctly designed. If the experiment fails then the hypotheses behind the design must be incorrect and the operation should be redesigned, thereby leading to improvement.

END OF PAPER