1 (a) Consider the following modification of the EOQ problem. Company A&F orders 2 items from their supplier. Let D_i be the annual demand, K_i the fixed ordering cost, and h_i inventory holding cost per unit per time for item $i = 1,2$. For management, it is easier and more convenient to order both items at the same time.

(i) Write the total cost function for Company A&F. [20%]

ANSWER:

$$TC(T) = \frac{K_1}{T} + \frac{h_1}{2} D_1 T + \frac{K_2}{T} + \frac{h_2}{2} D_2 T = \frac{K_1 + K_2}{T} + \frac{h_1 * D_1 + h_2 * D_2}{2} T.$$

(ii) Find the optimal order quantity and discuss how different it can be from the EOQ quantity. [20%]

ANSWER:

$$\frac{dTC(T)}{dT} = -\frac{K_1 + K_2}{T^2} + \frac{h_1 * D_1 + h_2 * D_2}{2} = 0 \Rightarrow T = \sqrt{\frac{2 * (K_1 + K_2)}{h_1 * D_1 + h_2 * D_2}},$$

Therefore,

$$Q_i^* = D_i * T = \sqrt{\frac{2 * D_i^2 * (K_1 + K_2)}{h_1 * D_1 + h_2 * D_2}}.$$

Assume that $h_i = h$, $K_i = K$ and $D_i = D$. In that case the order quantity with common ordering interval would be the same as individual EOQs. However, if the items are very different from each other, than there can be a big change in the ordering pattern.

(b) EOQ comes with very rigid assumptions. Discuss how one can update the inventory policy when we relax some of the assumptions:

(i) Demand is stochastic [20%]

ANSWER: If uncertainty of demand is low, EOQ may still work effectively. Otherwise, one can hold safety stock. If uncertainty is very high, then looking into better forecasting may also be a good approach.

(ii) Backorders are allowed [20%]

ANSWER: One needs to update the total cost function with the backorder cost. If the backorder cost is not too high compared to holding cost, reordering when there are backorders will be an option. In the extreme case, if it is very expensive to hold inventory compared to having backorders, one can even consider a MTO inventory policy. As the backorder cost increases, however, this option will no longer be attractive. In the extreme case when the backorder costs are very high, the solution will ignore having backorders.

(iii) Costs are not known for sure [20%]

ANSWER: If uncertainty of costs are low, EOQ formulation is usually good with tolerating that uncertainty. If the uncertainty is high, one can perform sensitivity analysis.

Version AB/v1

2

(a) A hard-drive repair facility is organised such that each incoming hard-drive undergoes an initial registration process. Each fault is then diagnosed by a technician, and sent either for a software upgrade, or a complete refurbishment. Currently, 50 hard-drives per hour arrive at the facility, 10% of which are sent for refurbishment. On average, 30 drives are waiting to be registered and 40 are registered and waiting to be seen by the repair technician. The registration process takes, on average, 2 minutes per hard drive. Among drives which receive software upgrades, average time spent with a repair technician is 5 minutes. Among those sent for refurbishment, the refurbishment average time is 30 minutes.

(i) On average, how long does a hard-drive stay in the repair facility?

(ii) On average, how many drives are being examined by technicians?

(iii) On average, how many drives are in the repair facility?

ANSWER:

The facility can be divided into 4 processes:

Queue for registration, registration, queue for repair technicians, seeing the repair technicians

Arrival rate R for all processes is 50 /hr = 5/6 /min

We can derive the following for each process using Little's Law (WIP=R*LT):

	Q for Registration	Registration	Q for repair	Repair
WIP	30	2 x 5/6 = 10 / 6 =1.6	40	7.5 x 5/6 = 6.25
R	5/6	5/6	5/6	5/6
LT	30x5/6=36 min	2 min	40 x 5/6 = 48 min	(30x10%) + (5x90%) = 7.5 min

(i) Total LT = 36+2+48+7.5 = 93.5 min (15 marks)

(ii) WIP at Repair process= 6.25 (10 marks)

(iii) Total WIP = 30+1.6 +60+6.25=77.9 hard-drives (15 marks)

(b) Discuss the advantages and disadvantages of using an MRP system.

A basic answer will include the fact that MRP allows for systematic planning, what-if scenario analysis, better control of operations, can be extended to connect different levels of the enterprise. Better answers will mention that it allows tracking of performance measures and deviations, reduces number of planners/expediters. Additional points will include that an MRP system can be used to collect and analyze data about inventory and sales, which will allow one to better predict and understand customer trends, develop a better procurement strategy, identify stock that has become obsolete, and increase inventory turns.

Students will then mention problems of MRP that we discussed: assumption of infinite capacity, having no feedback mechanism, that it pushes production – and may distort demand patterns.

Better answers will demonstrate wider understanding of the issues: that lead times are inputs to an MRP system so no incentive to trim them, that MRP fixes business processes in general, inflexibility to accommodate the “rush job”, creates a black-box attitude, data maintenance becomes low priority etc.

(c) Is JIT applicable to services? If not, why not? If so, how? Give examples where appropriate.

A basic answer will deem JIT as applicable because a pull system that initiates processes as a reaction to present demand can be applied to the context of service businesses (rather than initiating processes in anticipation of future demand). Students will get marks for good examples. For instance, in a fast food restaurant a pull system may be triggered when the customer orders a hamburger, the service operator takes one hamburger from the rack. The hamburger maker keeps an eye on the rack and makes new burgers when the number decreases below a set number. The manager orders more ground beef when the maker’s inventory gets too low. In a push scenario hamburgers would be made by estimating sales during a week, purchasing in advance and pushing materials to where they are expected to be needed.

Better answers will discuss also when a jit situation may better be hybridised with MRP (service shop), or not be applicable (mass service) when the service business demand is predictably large (e.g. when the fast food outlet is serving near a popular football match, or a port authority is anticipating additional paperwork after changes to import law). Students may additionally discuss the role of the following in these choices: degree of customisation required, product/process focus, customer contact time, equipment/people focus, discretion etc.

3

(a) A worker operates a machine in an environment with a background noise of 83dBA. The machine produces an additional noise, also of 83dBA.

(i) What is the maximum length of time the worker could operate the machine to ensure the daily personal noise exposure level does not exceed 85dBA? **[20%]**

(ii) Describe three approaches that could be taken to allow the worker to operate the machine for a full eight-hour shift. **[30%]**

ANSWER:

(i)
The answer is:
SPL average= 10 log10{1/To Σ Ti(100.1SPLi)}
Ti is the time at SPLi and To is 8 hours

Subs values, antilog and rearrange
8*108.5 = 2T 108.3
T = 4*108.5-8.3 = 6.34 hours

Answer: The maximum length of time the worker could operate the machine to ensure the daily personal noise exposure level does not exceed 85dBA **is 6.34 hours**

(ii)
The fundamental concepts that must be included in this answer are: Discuss the three approaches: noise reduction, barriers to noise and hearing protection.

1. **A basic answer should cover (50%-60% - 15-18 marks**). Students should be able to state and describe the three approaches. They are: noise reduction, barriers to noise and hearing protection
   - reduce noise at source – identify and address vibrations, add damping etc.
   - provide barrier to noise – between the noise source and the operator, eg machine enclosure
   - Supply personal hearing protection
2. **A better answer should cover (61%- 70% - 18.3-21 marks**). The above plus illustrate with examples and detail the three approaches. Ie.:
   - To reduce noise at source: identify and address vibrations, add damping, etc.
   - To provide barrier to noise between the noise source and the operator: machine enclosure, dispersion of noisy machines

- To Supply personal hearing protection: earplugs, earmuffs, etc

3. **A 'best' answer should cover (71%- 100% - 21.3-30 marks).** The student should be able to compare and contrast the importance of each approach (again comparing and contrasting).

(b) A production machine is scheduled to run for 10 shifts per week. Each shift lasts for 7.5 hours. The standard cycle time for producing a component on this machine is 5 minutes. Calculate the OEE for this machine for a given week, considering the following information:

- Due to a breakdown, the machine was not operational for 3 hours,
- The machine operator was not available on one of the ten scheduled shifts,
- The scrap rate was, on average, 2%,
- Whilst running, the machine was producing 10 components an hour.

[20%]

ANSWER:

OEE = Availability* EEP*Quality (expressed as %)
Availability =75-3-7.5/75 = 86%
EEP = 10*5/60 =83.3%
Quality = 98%
OEE = (.86*.833*.98)*100%
OEE = **70.2%**

(c) A direct time study was performed for a task. The regular cycle included four elements, *a*, *b*, c and *d*. Elements *e* and *f* are irregular elements performed every six and four cycles respectively. The performance rating for each element is shown in the following table.

Work element	***a***	***b***	***c***	***d***	***e***	***f***
Observed time (min)	0.50	0.25	0.58	0.72	0.85	1.01
Performance rating	80%	100%	95%	100%	100%	95%

(i) Calculate the basic time and the standard time for the cycle using an allowance factor of 17%. **[20%]**

(ii) It is planned that element *e* of this task will be replaced by element *g*. The observed time of the element g is estimated to be 0.32 min and the performance rating will be 96%. Calculate the basic time and the standard time for the cycle using the same allowance factor of 17%. **[20%]**

ANSWER:

(i)
Basic time: $T_b = T_{obs} \text{ x } PR$

T_b = 0.50(0.80) + 0.25(1.0) + 0.58(0.95) + 0.72(1.0) + 0.85(1.0)/6 + 1.01(0.95)/4

$\boldsymbol{T_b}$ **= 2.30 min**

Standard time: T_{std} = Basic Time + Allowances

$T_{std} = 2.30(1 + 0.17)$

$\boldsymbol{T_{std} = 2.69}$ **min**

(ii)

Basic time: $T_b = T_{obs} \times PR$

$T_b = 0.50(0.80) + 0.25(1.0) + 0.58(0.95) + 0.72(1.0) + 1.01(0.95)/4 + 0.32(0.96)$

$\boldsymbol{T_b = 2.468}$ **min for the 2022 production**

Standard time: T_{std} = Basic Time + Allowances

$T_{std} = 2.468(1 + 0.17)$

$\boldsymbol{T_{std} = 2.887}$ **min for the 2022 production**

4

(a) A workshop is lit by 50 lights, positioned at a height of 5 metres. Calculate how many lamps can be removed, while maintaining the same level of illuminance, if lamps are repositioned at a 3 meters height?

[20%]

ANSWER:

(a)

Illuminance decreases with distance from the light source:

$E = I/d^2$

Where E = illuminance, l = luminous intensity and d = distance.

Therefore, if one light has a luminous intensity of l

Currently E = 50l/25

if the height is reduced to 3 metres, then E = xl/9

Therefore x = 9 x 50/25 = 18

(b) You have just taken over as the cell leader for a poorly performing production cell. Scrap levels are high, mainly due to careless mistakes by operators. Efficiency is low, due to high product variation, high work-in-progress and poor raw materials control. The factory manager has instructed you to carry out a *5S* implementation and to develop a six-month improvement plan based on the principles of the *Toyota Production System*.

(i) Explain and illustrate with examples the set of activities that are involved in your 5S implementation for your cell. **[40%]**

(ii) Describe in detail, the three initiatives that would underpin your six-month Toyota Production System improvement plan. **[40%]**

ANSWER:

(i) Explain and illustrate with examples the set of activities that are involved in your 5S implementation for your cell. **[40%]**

The fundamental concepts that must be included in this answer are:

5S Task Structure

Sort:
1. Dispose of Obsolete Items
2. Red Tag
3. Initial 5S Audit &
4. Take Pictures
5. Organise Sort
6. Materials
7. Plan Project
8. Form Team
9. Team Training
10. Define Area & scope

Set in Order:
1. Install Visual Indicators
2. Implement Inventory
3. Control Procedures
4. Erect Improvement &
5. Production Control Board
6. Erect Sign Boards
7. Erect Shadow Boards
8. Agree all Locations
9. Labelling & Marking
10. Organise Straighten
11. Materials (i.e. Tool Boards)

Sweep:
1. Health and Safety Briefing
2. Agree Color
3. Codes & Mark Floor
4. Clean Area &
5. Yellow Tag
6. Organise Cleaning
7. Materials

Standarise:
1. Produce Maintenance Checklist

2. Re - Audit & Take Pictures
3. Produce SOP's
4. Produce skills matrices
5. Produce Operator
6. Checklists
7. Presentation to
8. Management

Sustain:
1. Review Project
2. Presentation to Other groups
3. Finalize Auditing Process

1. **A basic answer should cover (50%-60% - 20-24 marks**). Students should be able to explain the 5S Task Structure. The answer should describe each 'S' and all their correspondent activities. This would entitle to clearly describe their correspondent activities for each 'S Task' – Sort, Set in order, Sweep, Standardise and Sustain.

2. **A better answer should cover (61%- 70% - 24.4-28 marks**). The above plus:
    - Illustrate with clear examples the application of each of the five 'S Tasks'.

3. **A 'best' answer should cover (71%- 100% - 28.4-40 marks).** The student should be able to compare and contrast implications for implementation for each '5S'.

(ii) Describe in detail, the three initiatives that would underpin your six-month Toyota Production System improvement plan. **[40%]**

The fundamental concepts that should be included this answer are:

It is expected the improvement plan to address (with some degree of variation):
1) Quality issues
2) Improved efficiencies
3) Continuous improvement

1) Quality issues
Reduced Quality issues are due to carelessness.
The first step should be to introduce Poka-Yoke. Simply training and exhorting is unlikely to be sufficient, although this needs to be done in parallel. "*Poka-yoke*"is Japanese word meaning prevention of errors using low-cost devices to prevent or detect them
Common mistakes in manufacturing, that can be addressed by poka-yoke:
- o Omitting processing steps
- o Incorrectly locating a part in a fixture

- Using the wrong tool
- Neglecting to add a part in assembly

Different approaches to poka-yoke. The initiative should look at the major areas where errors occur and then implement an appropriate prevention or detection method.

- Contact method - identifies product defects, or operational mistakes by testing the product's physical attributes eg. shape, size, colour.
- The fixed-value (or constant number) method - alerts the operator if a certain number of movements are not made.
- The motion-step (or sequence) method - determines whether the prescribed steps of the process have been followed.
- Warning Poka-yoke - operator is alerted when a mistake is about to be made,
- Control Poka-yoke - the poka-yoke device actually prevents the mistake from being made.

2) Improve efficiencies

Efficiencies are stated to be due to short runs. The key activity here would be a set-up time reduction program such as SMED (Single Minute Exchange of Dies).

- Set-up time reductions has 3 phases
- Identify and separate external and internal set up activities
- Convert internal to external set-up where possible
- Reduce time for internal set up

External set-up

- Can be accomplished while previous job is still running
- Strategy: Design the setup tooling and plan the changeover procedure to permit as much of the setup as possible to consist of external elements
- • Examples:
    - Obtain tooling for next job
    - Pre - Assemble tools for next job
    - Pre-load parts to fixtures
    - Reprogram machine for next job
    - Collect all paperwork

Internal set-up

- Use work study to minimize the sum of the internal work element times
- Use multiple workers rather than one
- Improve tooling eg use quick-acting fasteners rather than bolts and nuts, use U-shaped washers instead of O-shaped washers
- Eliminate adjustments in the setup

3.Continuous improvement.

"*Kaizen*" – Japanese word meaning continuous improvement of production operations.

Usually implemented by worker teams, sometimes called "*quality circles*"

- – Encourages worker sense of responsibility
- – Allows workers to gain recognition among colleagues
- – Improves worker's technical skills

This is less formulaic than the previous two initiatives – its about changing mindsets as much as about applying technique.

1. **A basic answer should cover (50%-60% - 20-24 marks)**. Students should be able to explain the logic/rationale behind the selection of the three initiatives that would form the basis of the student's improvement plan. Then, the answer should comprehensively describe each of the selected three initiatives. In prioritizing, it is expected that the students should cover at least two of the following three – (1) Quality issues, (2) Efficiencies and (3) Continuous Improvement.

2. **A better answer should cover (61%- 70% - 24.4-28 marks)**. The above plus one or both of the following:

    - Draft a detailed implementation plan (example) for at least one production line/cell using the three selected initiatives.
    - Using the three priorities selected, give different examples of the change – the 'before scenario' and the 'after 5S scenario' by describing the implication for operations.

3. **A 'best' answer should cover (71%- 100% - 28.4-40 marks).** The student should be able to compare and contrast the selected initiatives (the selected ones) in term of implementation e.g. feasibility, order of priority and sequence, etc. It is expected that the student talks about their changes.

END OF PAPER