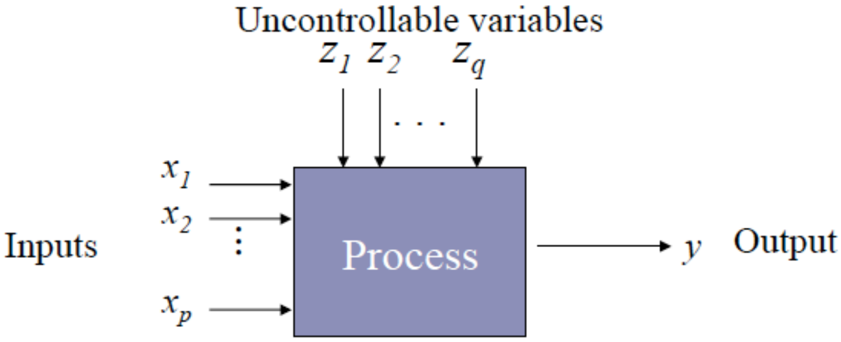
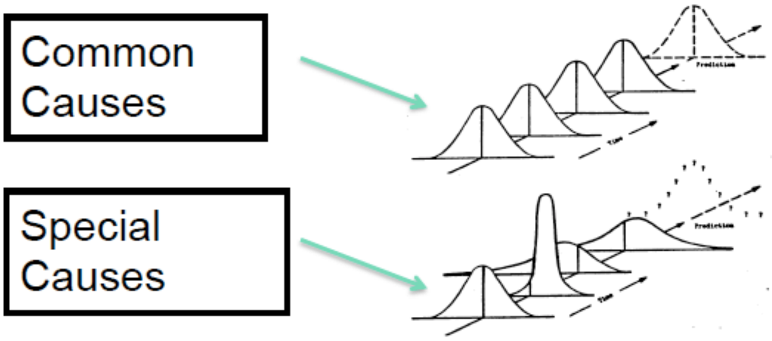
MET 2 Manufacturing Engineering Tripos Part IIA 2018

Paper 2 Module 3P2

a) SPC is used to detect and eliminate the sources of variation in the process that could not be attributed to the routine operation of the process.



There are two main types of variation. Chance variation that is inherent in process, and stable over time, and Assignable, or Uncontrolled variation, which is unstable over time - the result of specific events outside the system. Chance variation is cited as Common Cause variation, and assignable variation is cited as Special Cause variation.



- A process that is operating with only chance causes of variation present is said to be in statistical control.
- A process that is operating in the presence of assignable causes is said to be out of control.
- The eventual goal of SPC is the elimination of variability in the process.

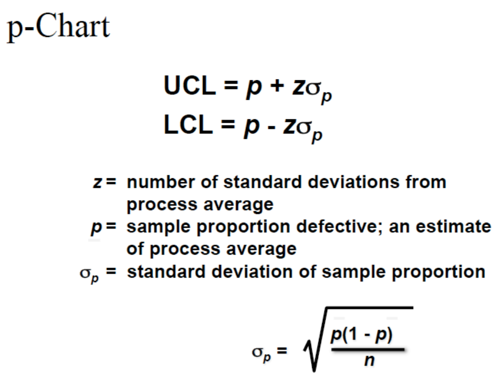
There are two types of charts employed

- Those that measure Attributes: p-chart (uses portion defective in a sample) and c-chart (uses number of defects in an item. These are product characteristics that can be evaluated with a discrete response, good – bad; yes - no
- Those that measure Variables: range (R-chart) and mean (x bar – chart). These are for variables that have continuous dimensions, Weight, speed, length,strength, etc.

Note to examiner:

Better answers will provide more details of chart constructions:

P-Chart:



p-Chart

$$UCL = p + z\sigma_p$$

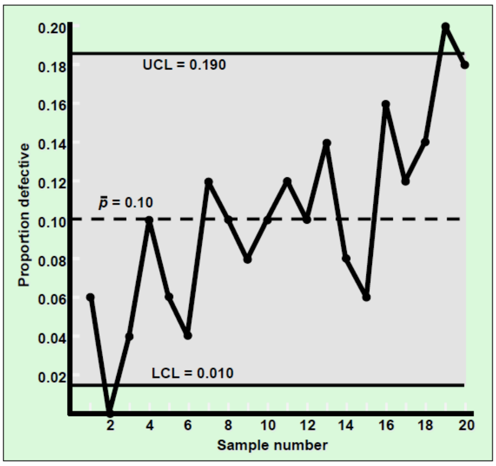
$$LCL = p - z\sigma_p$$

z = number of standard deviations from process average

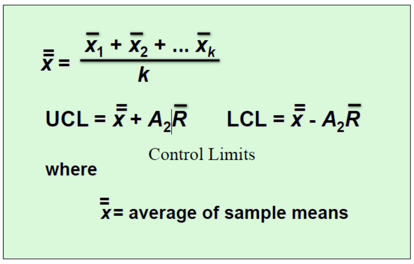
p = sample proportion defective; an estimate of process average

σ_p = standard deviation of sample proportion

$$\sigma_p = \sqrt{\frac{p(1-p)}{n}}$$



X-bar Chart



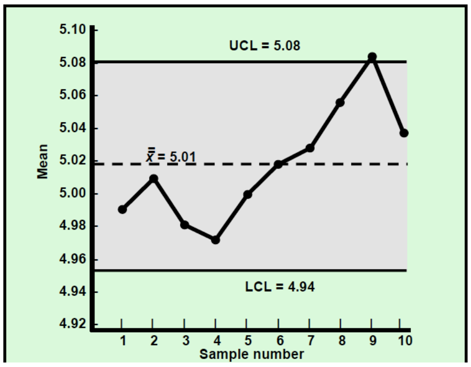
$$\bar{\bar{x}} = \frac{\bar{x}_1 + \bar{x}_2 + \ldots \bar{x}_k}{k}$$

$$UCL = \bar{\bar{x}} + A_2\bar{R} \qquad LCL = \bar{\bar{x}} - A_2\bar{R}$$

Control Limits

where

$\bar{\bar{x}}$ = average of sample means



b) This problem can be easily solved. Since SPC methods are most frequently applied to characteristics of a product, we can extend SPC to the job-shop environment by focussing on the processing characteristic in each unit of product.

Consider the drilling operation. Operators drill hoes of various sizes in each part passing through a machining centre. Some parts require one hole, and others several holes of various sizes. It is impossible to construct control charts on hole diameter. The correct approach is to focus on the characteristic interest in the process. In this case the ‘correct diameter’, and therefore the desire is to reduce the variation in hole diameter. This could be achieved by charting the deviation in hole diameter across the many holes produced on the machine. A control chart for this could be used such as a conventional X-bar of R chart.

c)

i) The appropriate pair of control charts are the Range Chart and X-bar Chart, with the R chart determining the spread of the data (dispersion), the X-bar chart determining the shift of the central tendency.

X-bar Chart:

The Upper control limit is given as: $UCL = \bar{\bar{X}} + A_2\bar{R}$

and the Lower control limit is given as: $LCL = \overline{\overline{X}} - A_2\overline{R}$

Where $\overline{\overline{X}}$ is the average of sample means

$$\overline{\overline{X}} = \frac{\overline{X}_1 + \overline{X}_2 \ldots \overline{X}_k}{k}$$

and A_2 is the control limit calculation constant for a subgroup of 5 ($A_2 = 0.577$).

From the data we have,

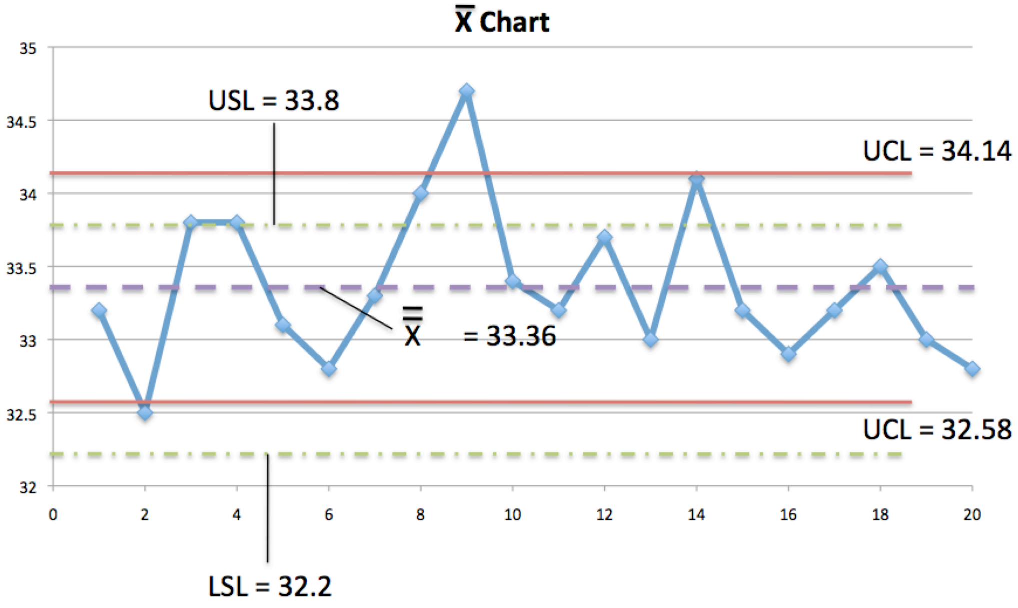
The R-bar value is calculated as: 1.35

The X-double bar is calculated as: 33.36

Therefore:

UCL= 34.14 and LCL = 32.58

The Annotated X-bar Control Chart is shown below, with the locations of the Upper Specification Limits (USL) and Lower Specifications Limits (LSL).



R-Chart

The Upper control limit is given as: $UCL = D_4\overline{R}$

and the Lower control limit is given as: $LCL = D_3\overline{R}$

Where $\overline{R}$ is the average of sample Ranges

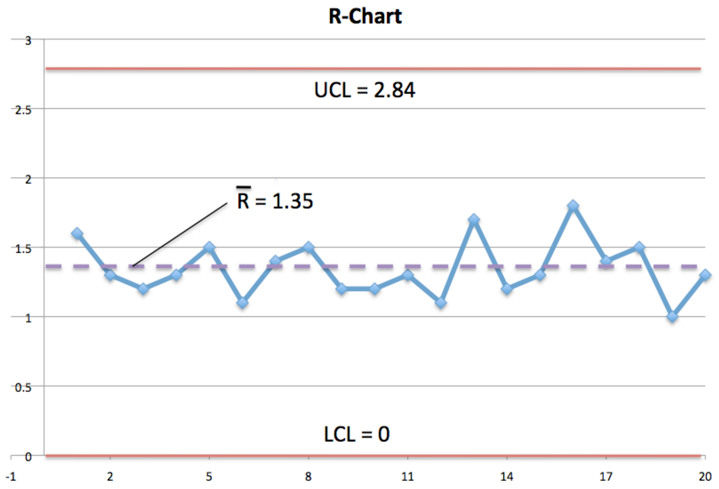
$$\overline{R} = \frac{R_1 + R_2 \ldots R_k}{k} = 1.35$$

and D_3 and D_4 are the control limit calculation constants for a subgroup of 5 ($D_3 = 0$, $D_4 = 2.115$).

Therefore:

UCL= 2.84 and LCL = 0

The Annotated Range Control Chart is shown below



ii) Observations from the charts.

The Process average and process variability (Range) must be in control to deliver a successful process operation. It is possible for samples to have very narrow ranges, but their averages go beyond control limits. It is also possible for sample averages to be in control, but ranges might be very large. We have the first situation in this case.

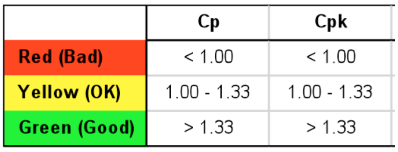
1. The most striking observation is the position of the process average, which is 0.36mm above the mid-point of the specification range (33mm). This is of significant concern.
2. The X-bar chart shows considerable shift of sampling mean, oscillating widely through the production of subgroups 1-10, and exceeding the UCL by a considerable margin for sub-group 9.
3. The sampling mean starts to settle beyond sub-group 10, with an oscillating, although reducing trend beyond sample 10.
4. The central tendency of the process starts to settle around the mid-point of the specification range after sub-group 15.
5. The R-chart shows a low level of dispersion in that we have a relatively narrow range of diameter across all sample groups.

iii) Process capability can be determined by looking at the control chart. Examining the whole chart and calculating the standard deviation of the averages (0.53), one can show that

Cp = 0.50 which compares the specification range to the process width.

and

Cpk = min (Cpkl, Cpku) = (-0.53, 1.55), which measures how close the process centre is to the nearest specification. Given that



	Cp	Cpk
Red (Bad)	< 1.00	< 1.00
Yellow (OK)	1.00 - 1.33	1.00 - 1.33
Green (Good)	> 1.33	> 1.33

This process is NOT in control and is NOT capable

Note to examiners:

Better answers will take a closer look at the charts and will see that as time evolves, the process moves towards being IN control and IS capable after subgroup 15. This provides useful observation as to the cause and effects.

Possible Causes for the Characteristic X Charts

Process

- The process is carried out before the machine has stabilized which may have caused the large process dispersion in the output mean.

Material

- Sudden changes in materials or parts. Cast iron is a difficult material to machine as it has very low ductility and could therefore lead to crumbling chips and significant dimensional variations
- Changes in material dimensions may cause increase/decrease in the output mean

Machine Equipment

- Tool breakage, chipping etc or
- Operator mistakes or set-up conditions may change process mean

iv)

Possible Remedies X Charts

Process

- Make at better assessment of the thermal characteristics of the machine tool and materials
- Give machine sufficient time to stabilise before machining commences

Material

- Take precautions against changes in dimensional changes
- Make sure the parts are at the same temperature and the part material is of the same quality

Machine / Equipment

- Check for chipped off/breakage of tool
- Check machine feeds/speeds are appropriate for the material. Adjust process setting accordingly.

Operator

- Train operator etc. Proper guidance and motivation should be given to avoid mistakes

Examiners Comments

This question focussed on statistical process control in a machining environment. It was the most popular question in Section A answered by 80% of the class. On the whole candidates performed well with a small number of low scoring answers.

Part a) asked the students to describe the principles of SPC and the means by which control charts are constructed and employed. Low scoring answers failed to identify details of the causes of variation and often gave cursory descriptions of the types of charts that are employed. High scoring answers were rich in detail and gave examples of the types of charts that can be used in SPC and their critical features.

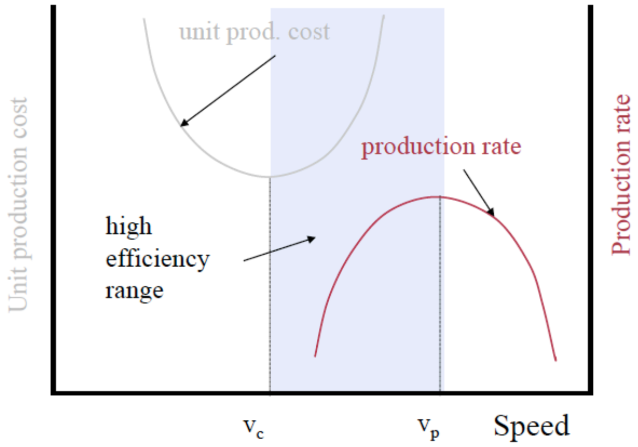
Part b) focussed on the application of SPC in a machining environment that employed drilling operations with large batch and size variations. Very few candidates gave thoughtful answers, although those that did were able to describe a scenario for the application of SPC techniques by investigating the deviation of hole diameters.

Part c) was a standard SPC question that required the production of X-bar and R charts for a machining operation. Most candidates were able to provide detailed charts that incorporated UCL, LCL, USL, and LSL values. Many candidates failed to identify that fact the data was not centred on the specification limits. As a result, they were unable to give good reasons for the possible causes of variation. Low scoring answers often gave poor justifications for the causes of variation.

Question 2 Crib

a) The economics of metal cutting is of vital interest to manufacturing engineers because:

1. Production cost and production rate are critically important for a manufacturing operation.
2. Increasing production rate means producing more from the available resources.
3. Decreasing production cost means less expenditure for the same volume of production.
4. Machining at low cutting speeds and feed rates increases production cost because of higher machine and operator usage times
5. At high cutting speeds and feed rates, the production cost is also high because of the increased costs of frequent tool replacement, tool re-working, and high power consumption.
6. If the conditions are so selected to maximize the production rate and minimize the production cost, profit can be maximized.
7. The manufacturing engineers role is to minimise the production time and the production cost. These are two contradictory criteria cannot be met simultaneously and a compromise must be made
8. In general feed rates must be set at the maximum possible. Cutting speed has the dominant influence on tool life, which influences the cost of tooling
9. Selecting cutting speeds can be considered in a number of ways: optimum cutting speed for minimum production cost (Vc), or maximum production rate (Vp).
10. Better answers will discuss the existence of the high efficiency operating range as shown in the figure below,



b) We have to consider the following.

- A Batch, N_b, of identical parts
- We replace the tool whenever it is worn (or regrind it)

Therefore

- Total non-productive time = $\mathbf{N_b t_l}$

  Where t_l = time to (load the stock + position the tool + unload the part)

- Total machining time = $\mathbf{N_b t_m}$

  Where t_m = time to machine the part

- Total tool change time = $\mathbf{N_t t_c}$

  Where t_c = time to replace the worn tool with a new one

  And N_t = total number of tools used to machine the entire batch.

- Tool Cost = $\mathbf{C_t}$
- Cost per unit time for machine and operator = M

This gives us the following equation for the average cost per item (C_{pr}).

$$C_{pr} = Mt_l + Mt_m + M\frac{N_t}{N_b}t_c + \frac{N_t}{N_b}C_t$$

None productive cost/item

Machining cost/item

Tool change cost/item

Tool cost/item

Note to examiners:
Some answers may stop at this point. Complete answers will go further by considering the *machining time* and the *tool life* as follows:

Machining time can be further developed as follows: (Note: special care should be taken for calculating "L &V" in turning operations)

Average cost per item: $$C_{pr} = Mt_l + Mt_m + M\frac{N_t}{N_b}t_c + \frac{N_t}{N_b}C_t$$

If L = length of tool path
V = cutting speed

$$t_m = \frac{L}{V} \qquad M\frac{L}{V} = MLV^{-1}$$

N_tC_t = total number of tools used to machine the batch

Taylors tool life relationship can be considered as follows

$$\frac{v}{v_r} = \left(\frac{t_r}{t}\right)^n$$

where

v = cutting speed
t = tool life
n = constant
t_r = measured tool life for a given cutting speed v_r

where

$$t = \text{tool life} \rightarrow \quad N_t = (N_b\, t_m)/t \quad \rightarrow \quad N_t / N_b = t_m / t$$

$$\frac{N_t}{N_b} = \frac{t_m}{t} = \frac{t_m}{t_r} . \left(\frac{v}{v_r} \right)^{1/n}$$

this gives the following relationship for the average cost of a component as a function of velocity.

$$C_{pr} = Mt_l + MLV^{-1} + \frac{L}{v_r^{1/n} . t_r} (M\, t_c + C_t) V^{(1-n)/n}$$

Cost per item as a function of V

c)

i) *For maximum production rate.*

$$V_{max} = \frac{80}{\left[\left(\frac{1}{0.13} - 1 \right) 2 \right]^{0.13}}$$

V_{max} = 57.1 m/min

Machining time in a turning operation can be given as

$$T_m = \frac{\pi D L}{v f}$$

where T_m is the machining time (min), D = workpiece diameter (mm), L = workpiece length (mm), f = feed (mm/rev), and v = cutting speed. In our case we have

$$T_m = \frac{\pi . (0.1) . (0.5)}{(57.1) . (0.25) . (10^{-3})} = 11.05\ min/item$$

Tool life $T = \left(\frac{80}{57.1} \right)^8$ = 14.84 *min/tool*

We see that the number of pieces per tool = 14.84/11.05 = 1.34 (use a value of 1 to avoid failure in the 2nd work piece)

The average production cycle time is therefore

T_c = 5.0 (handling time) + 11.05 (machining time) + 2.0/1 (tool change time) = 18.05 min/piece

Hourly Production rate = 60/18.05 = 3.32 pc/hr

The cost per item is therefore

$$C_{pr} = \underset{\substack{\uparrow \\ \text{None productive cost/item}}}{Mt_l} + \underset{\substack{\uparrow \\ \text{Machining cost/item}}}{Mt_m} + \underset{\substack{\uparrow \\ \text{Tool change cost/item}}}{M\frac{N_t}{N_b}t_c} + \underset{\substack{\uparrow \\ \text{Tool cost/item}}}{\frac{N_t}{N_b}C_t}$$

C_{pr} = (0.5 x 5) + (0.5x11.05) + (0.5 x (2.0/1))+ (3/1) = **£12.05/item**

For minimum cost.

$$V_c = C\left(\frac{0.13}{1-0.13} \cdot \frac{0.5}{0.5x2+3}\right)^{0.13}$$

V_c = 47.70 m/min

Machining time in a turning operation can be given as

$$T_m = \frac{\pi.(0.1).(0.5)}{(47.7).(0.25).(10^{-3})} = 13.08\ min/item$$

Tool life $T = \left(\frac{80}{47.7}\right)^8$ = 62.60 min/tool

We see that the number of pieces per tool = 62.60/13.08 = 4.78 (use a value of 4 to avoid failure in the 5th work piece)
The average production cycle time is therefore

T_c = 5.0 (handling time) + 13.08 (machining time) + 2.0/4 (tool change time) = 18.58 min/item

Hourly Production rate = 60/18.58 = 3.22 pc/hr

The cost per item is therefore
C_{pr} = (0.5 x 5) + (0.5x13.08) + (0.5 x (2.0/4))+ (3/4) = **£10.04/item**

ii) HSS tool materials have much lower speeds than alternatives such as cemented carbides and ceramic tools. The low tool life of HSS and high cost of downtime in order to change tools has a significant affect on the economics of machining. Cemented carbides or ceramic tools should be used at much higher speeds. In addition tool inserts have a number of edges per insert, lower tool changing times, and these disposable tools generally achieve higher production rates and lower production costs per product.

Examiners Comments

This question focussed on the economics of metal cutting. It was a very unpopular question answered by 20% of the class with candidates perhaps being put off by the apparent complexity of the question. It was in fact quite straightforward and those candidates that attempted this question did very well.

Part a) asked the students to identify why the economics of metal cutting is of vital interest to machining operations. Most candidates gave good answers and were able to detail the benefits of applying the analysis.

Part b) required the candidates to develop a basic equation for the average cost per item of a machined part. On the whole, most candidates were able to offer a workable equation. Better answers incorporated machining time and tool life by incorporating Taylor's tool life equation into their answer.

Part c) this section was a standard application of the speed for minimum costs and the speed for maximum production rate. Most candidates were able to develop the analytical route that enabled them to make correction predictions of hourly production rate and cost per item for the two production conditions (maximum rates, and minimum costs). Most candidates were able to give considered discussions on the choice of tool material in this case.

Question 3 Crib

(a) (i) *The main tasks required of a PLC are:*

- *Receive and interpret part schedules*
- *Ensure the production of one or more parts is completed*
- *Communicate part completion reports to factory computer network*
- *Coordinate the functions of different automated machines/devices*
- *Distribute operational commands to machines/devices*
- *Receive status/task complete reports from machines/devices*

(ii) *Differences between PLCs and PCs in an industrial control context are numerous. Some of the main issues (many discussed in lectures) are:*

- *reliability: PLCs rarely crash and are able to run 24/7*
- *programmability: programmability is standardised on PLCs. It is often more cumbersome*
- *safety: PLCs are equipped to programme for safety measures as a matter of standard operation*
- *ruggedness: PLCs come with built in I/O isolation*
- *security: there are fewer instances of security breaches with PLCs although this has occured*
- *cost: for the amount of computing power PLCs are far more expensive*
- *Computing capability: PCs are a more flexible and extendable platform*

(b)

- *ladder logic: programming as a ladder of logic steps: simple, visual and intuitive*
- *SFC: programming as a graphical flow chart: visually appealing, follows flow chart logic, allows nesting*
- *Function block diagram: extending ladder like approach by adding libraries of functions: easy reuse, allows nesting*
- *Structured text: programming language approach: similar to standard programming languages, easy for programmers to use*
- *Instruction list: low level assembler like code: efficient coding*

Use of standards enables re use of code/code modules/code librariessimplifies the task of plc programmersenables tools for developing and analysing PLC programmes to be developedenables multiple manufacturers PLC devices to be usedsimplifies portability of code

(c)

(i)

Rung No	*Explanation*
1	*Turns on conveyor*
2	*Sets condition for tall item to be detected*
3	*Sets condition for heavy item to be detected*
4	*If item tall and heavy – paint red*
5	*If item short and heavy – paint blue*
6	*If item tall and light – paint yellow*

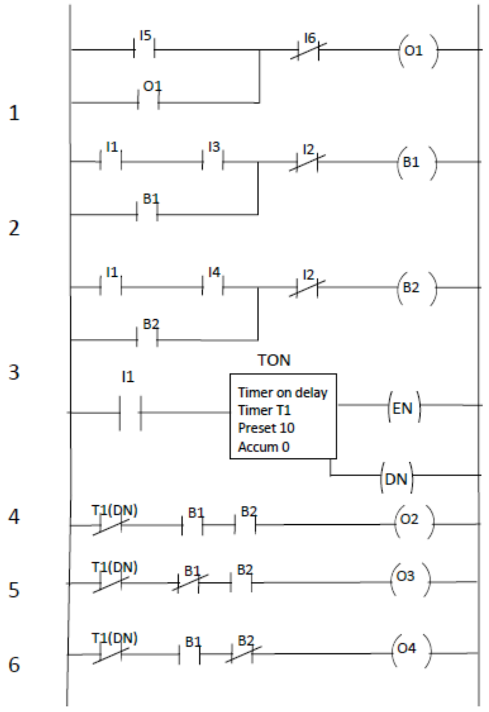
Good answers will also cover the use of the latch and unlatch constructs in rungs 1,2,3 and will note that painting will only take place when the item is in the spray zone.

State or internal variables B1 (resp B2) are used to designate the combined states of an item being tall (resp heavy) and also in the spray zone region.

It is noted that in this configuration the conveyor must be both manually started and stopped.

(ii) *A timer is required to ensure that the 10 seconds limit is adhered to. Hence essentially the spray will stop if either the spray zone exit limit switch activated or 10 seconds passes from the time the Spray zone entry limit switch activated.*

A possible amended ladder logic is illustrated below:



(iii) *Numerous aspects of the ladder code need to be changed in order for there to be full automation. A list of some of the possible amendments that might be discussed at this point include:*

- *introduction of a batch counter rung to determine the number of items processed in any given batch*
- *additional logic is required to ensure that more than one item doesn't enter the spray zone at a time [currently managed via manual inspection]*
- *additional logic is required to handle the situation where the timing system stops the spray painting after 10 seconds and the ability to diagnose the potential issue [e.g. paint on limit detector, parts stuck on conveyor, conveyor stopped etc]*

Assumptions being made here:

- operations at the loading and unloading ends of the conveyor are out of the scope of this analysis

- testing and spraying both occur within the two limits

Examiners Comments

This question was very popular and about 66% of the class attempted this question and those that attempted it did quite well, with very few poor responses.

The question related to the use of PLCs for factory automation

The first section asked students to discuss the role that PLCs play in factory automation. Part a) on the functions of PLCs was generally answered well particularly in terms of the downward functions of the PLC rather less so on the upward network functions across the factory. Part b) then asked students to compare PC and PLC functions in an automation context. Some students knew this well and a smaller number had a very limited understanding of this comparison.

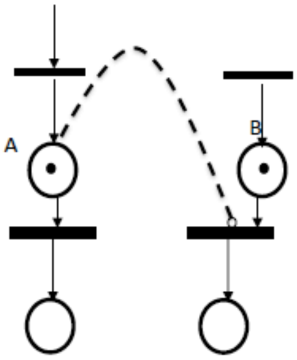
Part b) focussed on programming languages and students did well answering the section on standards for programming and also the benefits from such an approach. A few students simply guessed here and did rather less well.

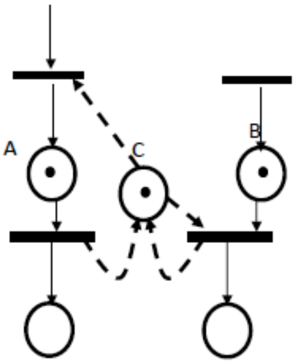
The final part of the question discussed a piece of ladder logic prepared for a conveyor painting system. Students needed to interpret and then amend the ladder logic to handle extensions to the base functionalities. The interpretations were done very well while the extensions were only moderately well done with only a few students really grasping all of the requirements for full automation.

Question 4 Crib

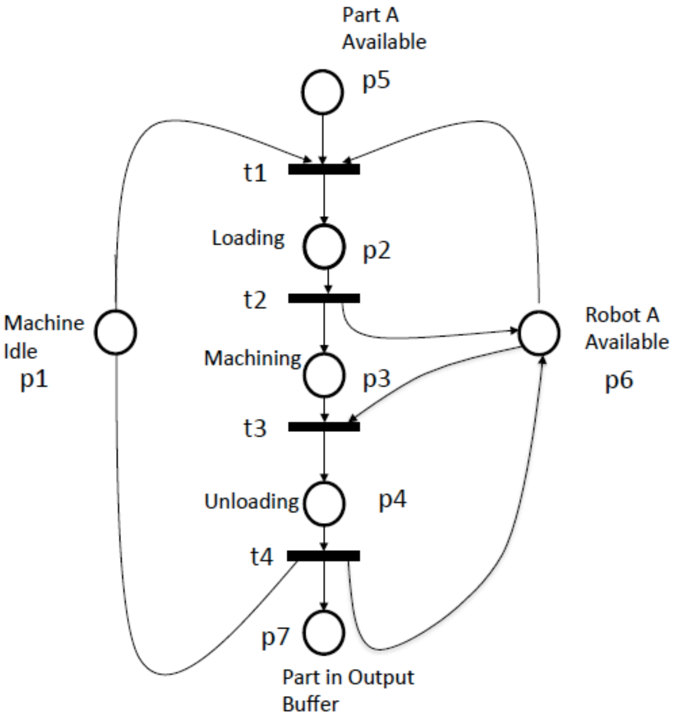
a) i) An inhibitor arc is essentially a piece of NOT logic in which the existence of a marking in a particular place can inhibit the firing of another transition. This can be used to reserve priority for a future operation while holding a subsidiary operation back in a queue.
The use of the inhibitor arc is illustrated in the figure on the left hand side below

ii) An alternative to an inhibitor arc – for example – could involve the introduction of a subsidiary place (c) in the diagram on the right. this performs effectively the same function and means that the inhibitor can be built from standard PN components.

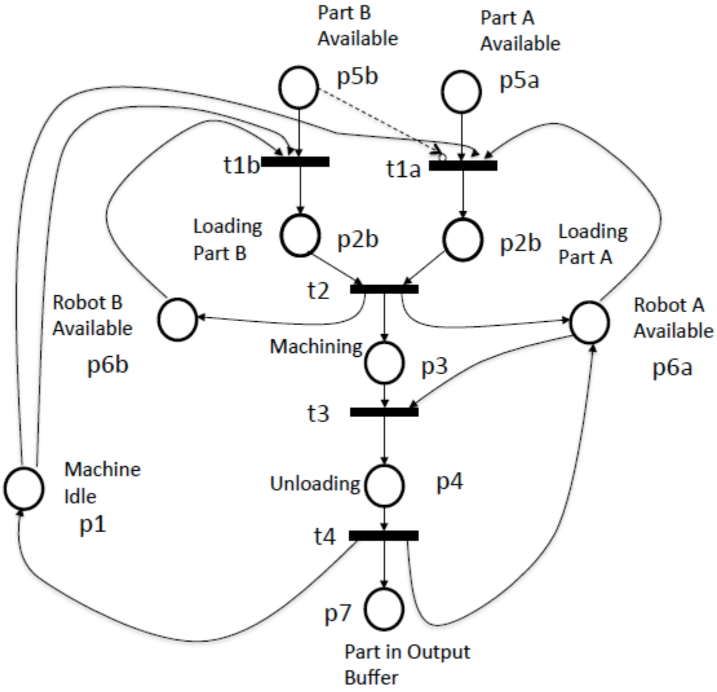




b)
A possible amended version of the PN is given below. In this diagram it is assumed that the robot is separately available for loading and unloading tasks..



(ii)



Assumptions

- assuming Robot A is doing all unloading
- Robots A and B can potentially run in parallel
- sensors exist to indicate all transitions

- an inhibitor arc can be implemented

(iii)

Additional specific and important issues which might be raised include:

- the capacity of the output buffer and the restrictions this might place on incoming parts
- the potential for deadlock with robot A or B committing to loading before unloading has been completed
- the need to sure one robot is stationery while the other is moving to avoid collision

Examiners Comments

This question was less popular and related to petri net modelling and the coordination of production machines. Approximately 34% of the class attempted this question.

Section a) related to the issues of inhibition and prioritisation in petri net models. Some really good answers were generated here. Weaker students were confused with the difference between ensuring causality of operations and actually inhibiting one operation while another takes place.

Section b) involved a simple amendment and then significantly extending a petri net model of a robot loading and unloading operation. The significant amendment involved adding a second part and a second robot to the operation and then synchronising two parts entering the machining environment. The simple amendment was done very well with most students managing to rework their PN accordingly under appropriate assumptions. The major extension was more variable. A few students did this very well while a number did rather poorly at this.

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13th June 2018