METIIA Paper 2 2024
Q1 Crib

a) These sources of error include:

1. **Machine Tool Sources:**
    - **Precision and Condition:** The accuracy, stiffness, and overall condition of the machine tool affect the quality of the machining process.
    - **Vibrations:** Machine-induced vibrations can lead to poor surface finish or dimensional inaccuracies.
    - **Wear and Tear:** Over time, wear and tear on machine components can lead to decreased performance and precision.
2. **Cutting Tool Sources:**
    - **Tool Material and Geometry:** The material and design of the cutting tool determine its suitability for specific materials and operations.
    - **Tool Wear:** Progressive wear of the cutting tool affects the surface finish and dimensional accuracy.
    - **Tool Deflection:** Under high cutting forces, the tool may deflect, leading to inaccuracies.
3. **Workpiece Material:**
    - **Material Properties:** The hardness, toughness, and ductility of the workpiece material influence the cutting forces and tool wear.
    - **Inhomogeneities:** Variations within the material, such as inclusions or grain structure, can affect machining consistency.
4. **Cutting Conditions and Parameters:**
    - **Cutting Speed, Feed, and Depth of Cut:** These parameters directly influence the rate of material removal, surface finish, and tool life.
    - **Coolant and Lubrication:** The use and type of coolant or lubricant can impact tool life, surface finish, and thermal aspects of the machining process.
5. **Operator Skill and Experience:**
    - **Setup and Alignment:** Proper machine setup and alignment by the operator are crucial for accurate machining.
    - **Decision Making:** The operator's decisions on cutting parameters and adjustments during the process can significantly impact the results.
6. **Environmental Factors:**
    - **Temperature and Humidity:** Ambient conditions can affect both the machine and the workpiece, potentially leading to thermal expansion or other issues.
    - **Dust and Debris:** Accumulation of dust and debris in the machining environment can affect machine performance and precision.
7. **Process Planning and Control:**
    - **Program Accuracy:** In CNC machining, the accuracy of the programming code is critical.
    - **Quality Control:** Effective quality control measures ensure that issues are detected and corrected promptly.

b)

What are Control Limits?

Definition:

- Control limits are calculated from process data and define the bounds of common cause (or natural) variation in a process.

- They typically consist of an Upper Control Limit (UCL) and a Lower Control Limit (LCL).

Calculation:

- Control limits are usually set at ±3 standard deviations from the process mean in many control chart types. This ±3 sigma range encompasses 99.73% of the natural variation in a stable process.

Purpose:

- Control limits help in identifying the presence of special cause variation – variations that are due to specific, identifiable sources and not inherent to the process.

Why Do Control Limits Change Over Time?

Process Improvements:

- If a process undergoes changes or improvements (like machinery upgrades, changes in materials, or process optimization), the inherent variability of the process might change, leading to new control limits.

Statistical Re-Evaluation:

- Over time, as more data is collected, there might be a need to re-evaluate the control limits statistically to ensure they accurately represent the current process performance.

Shifts in Process Mean or Variability:

- Changes in the process mean (central tendency) or variability (spread) due to factors like tool wear, operator changes, or environmental factors necessitate recalculating control limits.

Changes in Product Design or Specifications:

- If the product design or specifications change, the process may need to be adjusted accordingly, affecting the control limits.

External Factors:

- External factors such as changes in supplier materials, environmental conditions, or regulatory requirements can impact the process, leading to a need for updated control limits.

Quality Improvement Initiatives:

- As part of continuous improvement practices like Six Sigma or Lean, efforts to reduce process variation will result in narrower control limits.

c) i)

Constructing X-bar and R Charts:

- For the X-bar chart, plot the daily means on a control chart, with control limits determined based on the process capability.
- For the R chart, plot the daily ranges on a control chart, similarly determining control limits.

Daily Mean (X-bar) and Range (R) for the Diameters:

- Day 1: X-bar = 50.00 mm, R = 0.4 mm
- Day 2: X-bar = 50.26 mm, R = 0.3 mm
- Day 3: X-bar = 49.90 mm, R = 0.4 mm
- Day 4: X-bar = 50.30 mm, R = 0.4 mm
- Day 5: X-bar = 49.90 mm, R = 0.4 mm

Constructing control limits for X-bar and R charts involves using the sample data to estimate the process variability and then applying statistical formulas to set these limits.

1. **Calculating Control Limits for the X-bar Chart:**
    - The control limits for an X-bar chart are typically set at $\bar{\bar{X}}$ ± A2×$\bar{R}$, where $\bar{\bar{X}}$ is the average of the sample means. $\bar{R}$, is the average of the sample ranges, and $A2$ is a factor based on the sample size (in this case, 5). The $A2$ factor can be found in the SPC table in the body of the question.

2. **Calculating Control Limits for the R Chart:**
    - The control limits for an R chart are set at D3×$\bar{R}$ for the lower control limit (LCL) and D4×$\bar{R}$ for the upper control limit (UCL). $D3$ and $D4$ are also factors based on the sample size and can be found in the SPC table.

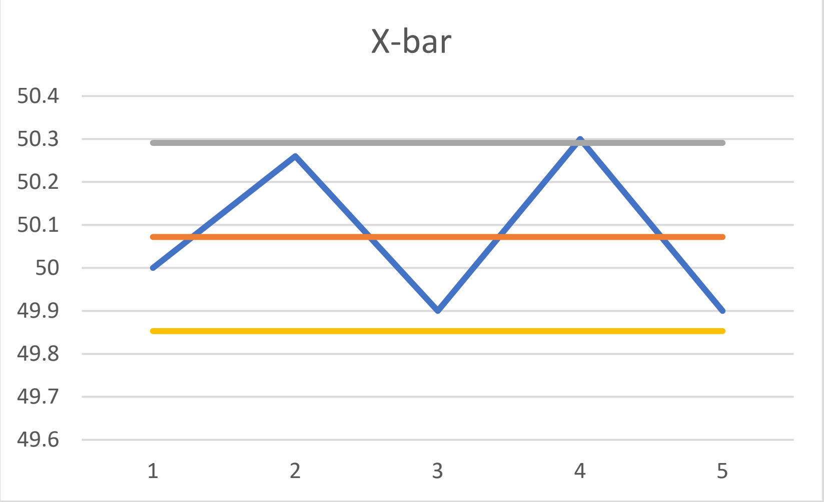
Let's proceed to calculate these control limits using the data provided:

- For a sample size of 5, values from standard SPC table are A2=0.577, D3=0, and D4=2.114.
- First, we calculate $\bar{\bar{X}}$ (the average of the sample means) and $\bar{R}$, (the average of the sample ranges).
- Then, we apply the formulas to set the control limits for both the X-bar and R charts.

Based on the calculations, the control limits for the X-bar and R charts are as follows:

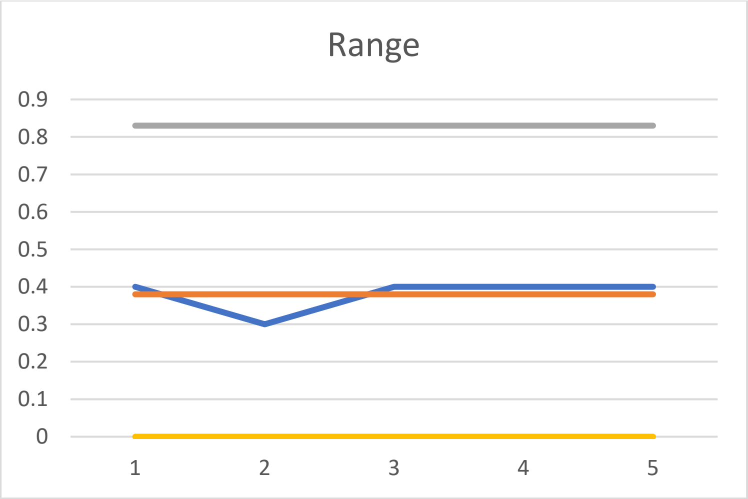
For the X-bar Chart:

- The average of the sample means $\bar{\bar{X}}$ = 50.072 mm.
- The average of the sample ranges $\bar{R}$ = 0.38 mm.
- Upper Control Limit (UCL): $\bar{\bar{X}}$ +A2×$\bar{R}$ = 50.072+0.577×0.38 = 50.291
- Lower Control Limit (LCL): $\bar{\bar{X}}$ −A2×$\bar{R}$ = 50.072−0.577×0.38 = 49.853



For the R Chart:

- The average of the sample ranges $\bar{R}$ = 0.38 mm.
- Upper Control Limit (UCL): D4×$\bar{R}$ = 2.114×0.38 = 0.803
- Lower Control Limit (LCL): D3×$\bar{R}$ = 0×0.38 = 0 (since D3 is 0 for a sample size of 5).



Comment:

- From the calculated values, it appears that most days have similar variability (as indicated by similar R values). However, the mean diameter fluctuates slightly above and below the target of 50 mm, especially on Day 2 and Day 4, where it goes slightly above. The patterns indicate potential process instability.

c) ii) C_{pk} is the minimum value of CPU or CPL where

$$CPU = \frac{USL - \bar{\bar{X}}}{3\sigma}$$

and

$$CPL = \frac{\bar{\bar{X}} - LSL}{3\sigma}$$

Where σ is the standard deviation of the process.

Which gives CPU = (50.5 – 50.072)/(3 x 0.2246) = 0.428/0.6738 = 0.635

and CPL = CPU = (50.072- 49.5)/(3 x 0.2246) = 0.572/0.6738 = 0.849

in which case C_{pk} = 0.635.

Despite none of the data points exceeding the specification limits, the Cpk value is still below the ideal benchmark of 1.33. This outcome can occur in a process that is consistent but not perfectly centred within the specification limits or has a slightly higher variation.

- **Capability:** Based on the Cpk value which is < 1.33, the process is not fully capable, as it's not consistently meeting the specification limits with a high degree of reliability.
- **Control:** The determination of whether the process is in control depends on the analysis of the control charts. Given that some data points are very close to the control limits (x-bar chart), suggests that the process is just about in control, although the

patterns suggest special cause variation may be the underlying reason for the variation around the mean.

c) iii)

- For a process that is in control but not capable, the focus should be on reducing process variation and centring the process within the specification limits. This might involve
    - examining and optimising various aspects of the process, such as machine calibration, tooling, material consistency, or environmental factors.
    - investigate and identify the root causes (e.g., machine calibration, tool wear).
    - Regular monitoring and maintenance of the equipment, along with periodic training for operators, can help in maintaining process control.

Examiners Comments.

Question 1

This question related to machining operations and applying SPC techniques to study the performance of a turning operation.

Section a) required students to identify the sources of error in machining operations. A good number of students gave comprehensive answers, although many students lost marks by citing a rather limited collection of sources of error, offering low levels of detail.

Section b) asked for a discussion of control limits and why they changed over time. Confusion here was quite common, with a number of answers confusing the statistical response of a production system with specification limits. There were some comprehensive answers, highlighting excellent understanding of the topic.

Section c) required the production of control charts for a set of manufacturing data. Answers to part i) were correct for the vast majority of the responses, although those of part ii) were less comprehensive and let down by mistakes in calculation or using incorrect expressions for finding Cpk. Part iii) delivered a mixed bag of responses, lower scoring answers gave limited recommendations, whilst higher performing students dug deep into the data and showing good insights and offered effective recommendations.

Question 2

a)

i) Here are four challenges:

1. **Porosity:**
    - **Incomplete Melting:** If the laser energy is insufficient to fully melt the powder, it can lead to porosity within the part, affecting both density and strength.
    - **Gas Entrapment:** During the melting process, gas may become trapped within the melt pool, leading to porosity upon solidification.
2. **Thermal Stresses and Distortion:**

    - **Residual Stresses:** The rapid heating and cooling cycles in LPBF create significant thermal gradients, leading to residual stresses which can cause warping or even part failure.
    - **Distortion:** Without proper support structures or process control, parts can distort, affecting dimensional accuracy and mechanical properties.
3. **Layer Adhesion and Inter-Layer Bonding:**
    - **Layer Adhesion:** Insufficient bonding between successive layers can weaken the part, as the interface between layers can be a weak point.
    - **Consistency Across Layers:** Variability in layer thickness or density across layers can lead to inhomogeneities in the microstructure, impacting strength.
4. **Microstructural Defects:**
    - **Grain Structure:** The rapid solidification inherent in LPBF can lead to non-uniform grain structures, which can impact mechanical properties.
    - **Cracks and Micro Voids:** Rapid cooling rates can lead to the formation of cracks or micro voids within the part.

ii)

In Laser Powder Bed Fusion (LPBF) part resolution and surface finish are critical quality attributes that are influenced by various factors related to the process parameters, material characteristics, and machine capabilities. Understanding and optimizing these factors is key to achieving high-quality parts. The main factors that influence part resolution and surface finish are:

1. **Layer Thickness:**
    - Thinner layers generally yield higher resolution and smoother surfaces, as they allow for finer details and gradual transitions. However, they also increase the build time.
2. **Laser Spot Size and Beam Quality:**
    - A smaller laser spot size can produce finer features, enhancing resolution. Beam quality also affects the precision with which the laser can melt powder particles.
3. **Scanning Speed:**
    - The speed at which the laser scans the powder bed influences the melt pool dynamics. Faster speeds can lead to rougher surfaces due to rapid solidification, while slower speeds allow for smoother surfaces but can increase the risk of overheating and distortion.
4. **Hatch Spacing:**
    - Tighter hatch spacing (the distance between adjacent scan lines) can improve surface smoothness but may increase the likelihood of heat accumulation.
5. **Powder Particle Size Distribution:**
    - Finer powder particles typically result in smoother surfaces as they pack more densely and melt more uniformly. However, too fine powders can be challenging to handle and may affect flowability.
6. **Material Properties:**
    - Different materials have varying melting behaviours, thermal conductivities, and surface tension characteristics, all of which affect surface finish and part resolution.
7. **Machine Stability and Calibration:**
    - Mechanical stability and precision of the LPBF machine, including the consistency of powder layer deposition and laser positioning accuracy, play a significant role in determining part quality.
8. **Orientation and Support Structures:**

  - Part orientation in the build chamber affects the surface quality, especially for overhanging features. Support structures are necessary for certain geometries but can leave marks on the surfaces they support.
9. **Post-Processing Techniques:**
  - Methods like sandblasting, chemical smoothing, and machining are often used to improve surface finish after the build process. These can significantly enhance the appearance and properties of the final part.
10. **Atmosphere Control:**
  - The presence of oxygen or other reactive gases during the build can affect surface quality. Using an inert atmosphere (like argon) can help in achieving better surface finishes.

b)
i)

Volumetric Energy Density (VED):

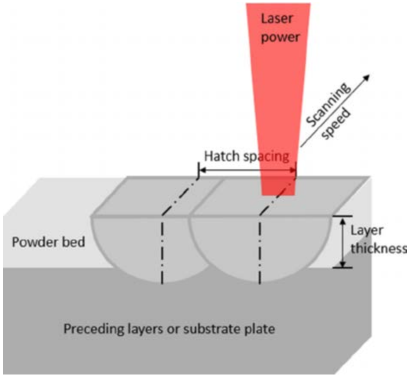
Definition:

- Volumetric Energy Density is a measure of the energy delivered per unit volume of material (J/mm^3). It is calculated by considering the laser power, scan speed, hatch spacing, and layer thickness.
- Formula: VED=P/(v·h·t), where *P* is the laser power, *v* is the scan speed, *h* is the hatch spacing, and *t* is the layer thickness.

Melt Rate (MR):

Definition:

- The build rate in LPBF refers to the speed at which a part is constructed, typically measured in volume per unit time (e.g., mm^3/s).
- It is influenced by the scan speed, layer thickness, and the strategy used for covering the build area.
- Formula: MR = v ·h·t,



Relationship between VED and Build Rate:

- At a given set of process parameters, an increase in VED generally implies a decrease in melt rate, as more energy is being focused into a smaller volume, necessitating slower scan speeds or thinner layers.
- Conversely, a lower VED can allow for a faster melt rate but may lead to insufficient melting and bonding of the powder particles.

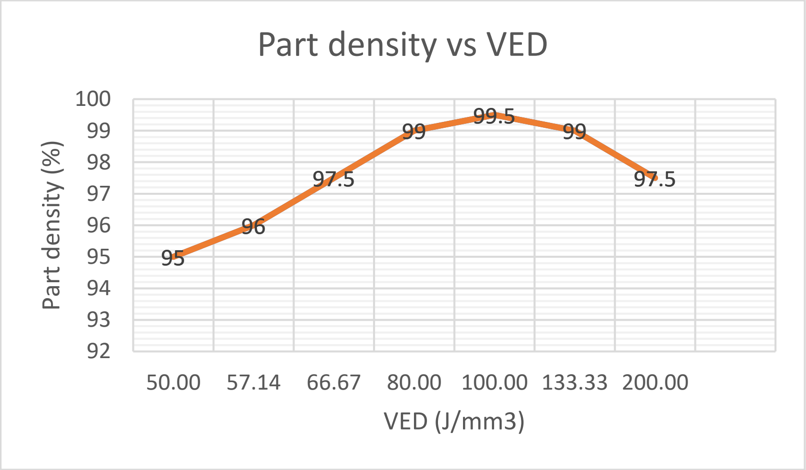
Impact on Part Quality:

- A higher VED typically improves part density and mechanical properties but can lead to increased residual stresses and distortions due to the higher heat input.
- Lower VED may result in reduced part density (higher porosity) and weaker mechanical properties, but with reduced thermal stress.

Optimisation:

- The key is finding an optimal balance where VED is sufficient to ensure good part quality (density, strength) without excessive residual stresses, while also maintaining a reasonable melt rate for efficiency.
- This optimisation is often material-specific and can be influenced by the geometry of the part being built.

b)
ii)
The sketch of density vs VED is given below



In LPBF VED vs density often delivers a highly now linear relationship. Here are the primary reasons for the non-linear relationship:

1. **Threshold Energy Density**: There is a threshold level of energy density below which the powder particles do not fully melt, leading to poor bonding and low part density. This threshold depends on the material's properties, such as its melting point and thermal conductivity.
2. **Increased Density with Energy Input**: As the energy density increases above the threshold, the part density typically increases. This is because sufficient energy is provided to fully melt the powder particles, allowing for better bonding and densification. This response is shown in the curve between a VED of 50 and 100 J/mm^3.
3. **Overheating and Evaporation**: Beyond a certain point, in this case a VED of 100 J/mm^3, further increases in energy density can lead to overheating. This can cause issues like evaporation of constituents (especially in alloys), degradation of material properties, and the formation of defects such as gas porosity and keyholes.

In this case it is clear that the optimum VED for maximum part density is 100 J/mm^3.

Better answers will further discuss the following points

Balling Effect: High energy densities can lead to the balling effect, where the molten material tends to form spherical shapes rather than spreading evenly. This phenomenon disrupts the layer-wise building process, leading to irregularities and lower density in the final part.

Heat Accumulation and Thermal Stresses: In LPBF, repeated exposure to high energy densities can lead to heat accumulation in the part, resulting in thermal gradients. These gradients can induce residual stresses, warping, and even crack formation, which negatively affect the part density and overall quality.

Process Parameters and Scan Strategies: The interaction between VED and other process parameters (like scan speed, layer thickness, and hatch spacing) also plays a role. Different combinations of these parameters can lead to varying levels of energy absorption and heat distribution, influencing the part density.

c)

i) In Laser Powder Bed Fusion (LPBF), the scanning strategy refers to the pattern or sequence in which the laser moves across the powder bed to selectively melt and fuse the powder particles, layer by layer, to build a 3D part. The scanning strategy is a critical aspect of LPBF as it significantly influences the quality, mechanical properties, and surface finish of the final product. Key elements of scanning strategies in LPBF include:

Scan Pattern: This describes the geometric path that the laser follows over the powder bed. Common patterns include raster (back and forth lines), island (smaller, discrete sections), spiral, or zig-zag. Each pattern affects the heat distribution and the resulting part properties differently.

Scan Vector Length: This is the length of each individual laser scan. Shorter vectors can reduce residual stresses and distortions but may increase build time. Longer vectors are more efficient but can lead to higher thermal gradients.

Rotation of Scan Vectors: Often, the orientation of the scan vectors is rotated by a certain angle (often 67 to 90 degrees) with each new layer. This rotation helps to distribute residual stresses more evenly throughout the part, reducing anisotropy and the likelihood of distortion or crack formation.

Hatch Spacing: This refers to the distance between adjacent scan lines. Closer hatch spacing increases the part's density but also the build time and thermal stress. Wider spacing is faster but can lead to lower part densities.

Scan Speed and Power: The speed at which the laser moves and its power level are crucial parameters. They must be optimised to ensure sufficient melting of the powder without causing overheating or other defects.

Better answers may include the following.

Contour Scanning: In addition to scanning the interior (infill) of a layer, most parts also require contour scanning, where the laser traces the part's outer boundaries. This often occurs at different speed and power settings to improve surface quality and accuracy.

Overlapping and Offset Strategies: To ensure proper fusion and minimize porosity, scan tracks may overlap slightly. Similarly, the starting point of each scan vector may be offset from layer to layer to avoid consistent weak points.

Layer Thickness: While not strictly part of the scanning strategy, the chosen layer thickness can affect the optimal scanning strategy, as it influences the amount of powder available to absorb the laser energy

c)
ii)

Advantages

Improved Mechanical Properties: An optimized scanning strategy can significantly enhance the mechanical properties of the printed part, such as tensile strength, fatigue resistance, and ductility.

Increased Part Accuracy and Surface Quality: Optimizing the laser scanning paths and parameters leads to better control over the melting process, resulting in higher dimensional accuracy and improved surface finish.

Disadvantages

Increased Complexity and Lead Time: Developing an optimised scanning strategy can be complex and time-consuming. It often involves extensive simulations and experimental trials to understand the effects of various scanning parameters on part quality. This complexity can increase the lead time for process development, especially for new materials or intricate geometries.

Increased Operational and Equipment Costs: Implementing an optimised scanning strategy often requires advanced software, more sophisticated control systems, and potentially more powerful or precise laser systems.

Examiners Comments

Question 2

This was a very unpopular question despite AM being a very popular topic with the students. The question focused on LPBF and an analysis of energy requirements for melting and scanning strategies. This perhaps stretched the students real understanding of the process. Those students that tackled this question gave excellent responses on the whole, demonstrating knowledge of the process and its subtleties.

Section a) required students to discuss the challenges to achieve high part densities and strength. And the factors that influence part resolution. Two very strong answers here, with one being rather limited.

Section b) asked for an analysis of VED and MR. With the final section asking for a plot of density against VED. The two leading answers demonstrated excellent knowledge of the process, with knowledge of melt dynamics and power loading being evident.

Section c) required a discussion of laser scanning strategies. This was a non-trivial question that required good understanding of the process. In particular the trade-off between speed and quality. The two strong answers gave detailed discussions of the mechanisms at work.

SECTION B

Question 3

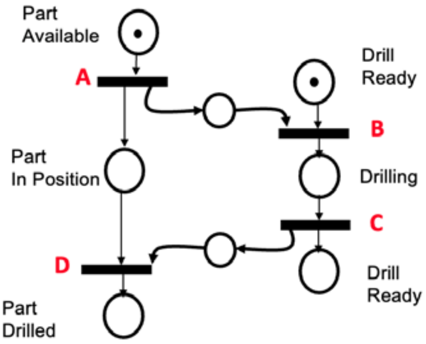
a) Demonstrate, using appropriate diagrams, the way that petri nets can manage issues of:

- *i) Causality of operations;*
- *ii) Operations required to occur concurrently;*
- *iii) Prioritisation of one operation over another.*

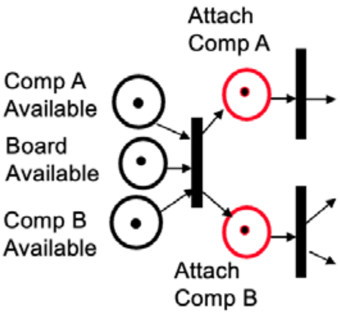
In each case provide examples of where such issues might arise in an industrial automation setting

[30%]

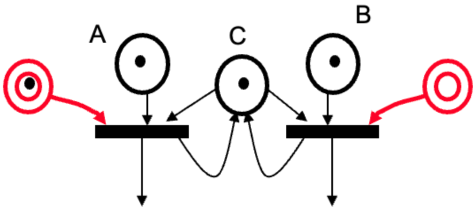
i) Causality - ensuring correct sequence of operations via sequential firing of transitions via synchronisation
Example: Position part (A) -> start drill (B) -> stop drill (C) -> remove part (D)

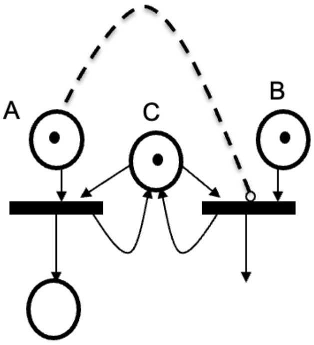


ii) Concurrency - ensuring 2 or more states/operations can be enabled simultaneously
Example: Attaching two components to a circuit board



iii) Priority - ensuring one operation (perhaps requiring a common resource) takes place in preference to another. e.g. Loading of two parts with one resource. This can be via external control (left) or using an inhibitor arc (right).





b) The Petri Net in Fig. 1 models the material flow for an existing production line. Parts A and B are first machined in separate CNC machines, and finished parts are stored in separate Work in-Progress (WlP) buffer areas. Finally, both parts are transferred for assembly.

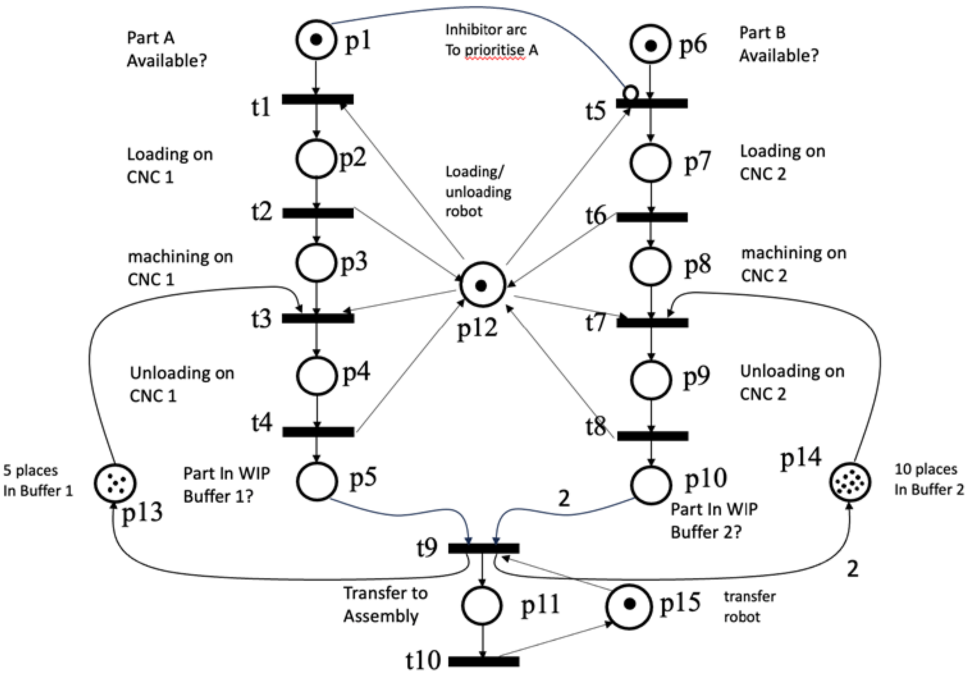
The production line has to be modified to incorporate the following factors:

- Add a material handling robot, which is used to load parts to, and unload parts from, both CNC machines.
- Limit the space in WlP Buffer 1 (for part As) to five parts and WlP Buffer 2 (for part Bs) to ten parts
- Introduce an additional transfer robot able to transfer 1 part A and 2 parts Bs at the same time to the transfer station.

i) Redraw this Petri Net to incorporate the required changes, ensuring that Part A has priority over Part B in loading, that there is deadlock-free operation. Clearly explain the role of each new place, transition, arc, weight, token you have introduced in your diagram. State any assumptions you have made.

[40%]

One possible solution is given in the figure below although there are numerous potential solutions that can address all of the issues raised in the question.



Places

- p12 - loading/unloading robot is available/idle
- p13 - available places in Buffer 1
- p14 - available places in Buffer 2
- p15 - transfer robot is available/idle

Arcs

- arc from p1 to t5 - inhibitor arc to ensure Part A prioritised in loading
- arcs to and from p12, p15 - shifting robots from idle to in use and vice versa
- arcs to and from p13, p14 - creating / removing an available place in buffer. These arcs are positioned to ensure deadlock free operation in unloading buffers

Tokens

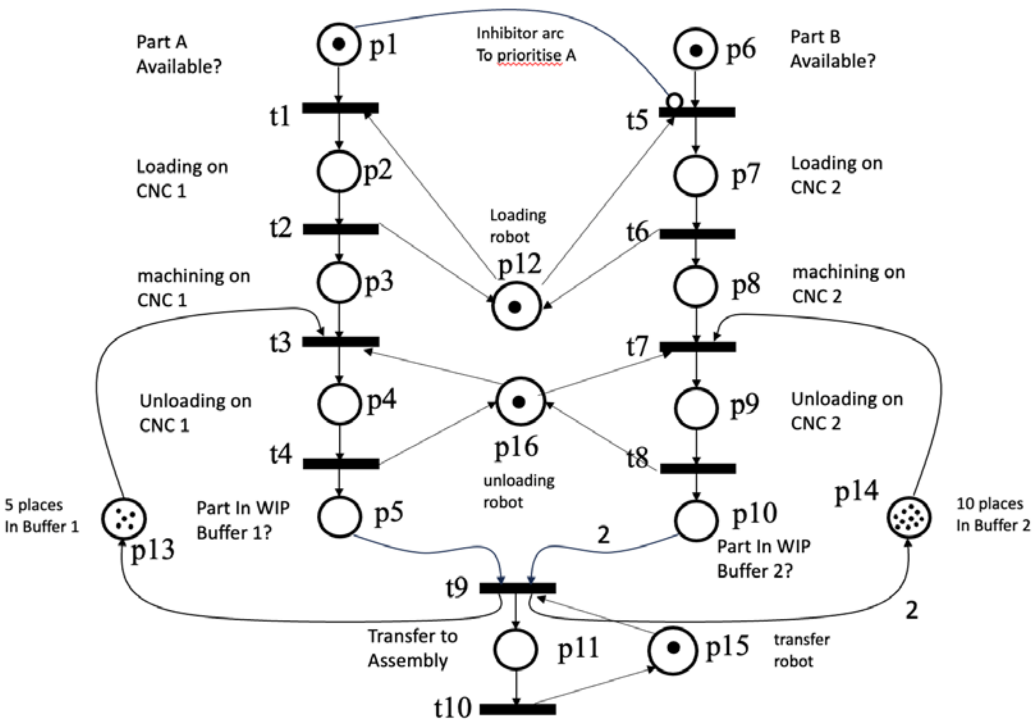
- added to all new places indicating robots available with p12, p15 and buffer space available p13, p14

Weights

added a weight of 2 to arc between t9 and p14 (but not to p14 to p7)

ii) How would your model change if separate loading and unloading robots were available and were able to operate simultaneously? If it was subsequently decided that for safety reasons that one could only operate while the other was idle what effect would that have?
[30%]

A sketch may be introduced here but is not required if a clear explanation is given. Separate loading and unloading robots would be relatively straightforward to introduce and would increase the loading and unloading throughput.



However, if the safety constraint is added then much of the throughput gain will be lost although it is noted that there will still be some advantage. In terms of the petri net it could be seen to be identical to the original one produced for part i) where the “robot available” state refers to the combined availabilities of the two robots, and the usage of the two robots is a single logical unit for the combined resource as only one can be used at a time.

Examiners Comments

Question 3

This question related to the analysis and completion of petri net models of automated systems

Section a) asked students to show how petri nets could be used to describe typical automation conditions - causality, concurrency and priority in operation. Quite a number of students were confused about causality and its representation but the other two parts were done well.

The remaining sections then focussed on the completion and extension of a petri net model of a pair of machining lines coupled to an assembly operation.

In Section b) were asked to complete a provided petri net model to add and describe a set of additional functionalities to ensure fully automated and safe operation of the process. Many students did the drawing part of this section very well but descriptions of the new operations and identification of assumptions were mixed in quality.

Section c) required students to consider an extension to this system where an additional robot was to be included. Many students simply seemed to be short on time for this section and answers were often brief and sketchy.

Question 4

a) Machine and cell level operations play a key role in the control hierarchy of a factory. Stating any assumptions,

i) discuss key operations and decisions typically made at each of these levels providing examples;

[10%]

Level	Operation	Decisions	Example
Cell	Make or assemble a part	When to commence operations on a machine? When to move part from one machine to another? Coordinate different machine movements?	*How to ensure a robot delivers a part to a 3D printer?* *How to ensure bottles on conveyor are filled correctly?*
Machine	Perform one or more tasks	Which tools to be used on machine? When to start a task? What support is needed?	*When to turn on coolant for machine tool?* *How to ensure a robot arm moves from A to B?* *How to heat a tank to the correct temperature?*

ii) identify issues which need to be considered if the operations are to be automated in each case?

(10 marks)

Level	Automation Issues
Cell	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 Coordinate flow of parts across cell
Machine	trigger start and end to different tasks to be performed ensure support services in place (coolant, swarf removal, clamping etc) checking quality of completed task

	report completion of work on part

iii) identify any further issues which need to be considered if the automated system in each case is to operate continuously in a "stand-alone" mode, with little or no human support?

(10 marks)

Level	Issues for Stand alone Operation
Cell	Material/Part quality control Error trapping, detection and diagnosis Monitoring and reporting functions Redundancy in sensing Fail safe measures Automation of part handling
Machine	Automation of part handling Automation of operation variety management Automation of tool and machine monitoring, maintenance functions Automation of fixturing Automation of tool management Homing cycle

b) A gear box manufacturer is upgrading its in-house production capabilities. Up until now the main steel casings have been cast and machined by a supplier prior to assembly of the gear-box in house. However, supply chain issues and increased requests for customisation from customers make it appealing to finish the machining of the casings in house prior to assembly. The machining required typically consists of several turning and drilling operations - the exact number and type depending on the gear box specification. The manufacturer has acquired a suitable machining centre and is in the process of integrating it into the factory. To begin, the machine will be manually loaded and unloaded.

(Note that there will be many different ways to address this question so the example solutions provided here are just indicative of one approach)

i) Give the type of product and machining operations what will be the main tasks requiring automation at this point?

Key points to note:
- finishing the machining of the casings - high quality of output needed
- several turning and drilling operations - multiple operations to be coordinated on machine
- manually loaded and unloaded - safe human interface needed
- requests for customisation - machining operations will need to be regularly changed and updated

using the responses in part a) ii) as a starting point to identify automation requirements in this scenario:

- trigger start and end to different tasks to be performed: identify turning and drilling operations required and acquire/develop CNC programmes for each. Programme sequence of these operations and the different set up requirements between operations.
- ensure support services in place: coolant flow, swarf removal, clamping will all need to be programmed and set in place prior to any machining operation takes place
- checking quality of completed task: because this is a finishing operation final product quality is important and dimensions and surface quality will need to be inspected.
- report completion of work on part: manual unloading and loading means machine environment must be safe and deactivated prior to and at completion of machining operation.

ii) Increased demand means that the machining centre will need to run up to 24 hours per day with little or no human input. Develop and justify a plan for this development, identifying any additional systems you would need to introduce. State any assumptions you make.

Key points to note:

- *Increased demand - higher workrate of machining centre*
- *machining centre will need to run up to 24 hours per day* - limited downtime opportunities, limited routine maintenance
- *little or no human input* - increased reliance on automated processes - effectively stand alone operation

using the responses in part a) iii) as a starting point to identify automation requirements in this scenario:

- Automation of part handling - introducing robotic handling of parts in and out of machine
- Automation of operation variety management - direct intepretation of order requirements to execute the required tasks
- Automation of tool and machine monitoring, maintenance functions - increased level of monitoring and alarming will be required
- Automation of fixturing - all fixtures clamps etc will need to be automatically managed from within the CNC control system
- Automation of tool management - given the cusomtisation requirements tool storage, retreival and insertion/removal will need to be coordinated. This may require a PLC to support depending on the CNC capabilities of the machine tool
- Homing cycle - some simple coordination of idle positions of both CNC and robot needed

c) Because of local labour shortages the gearbox manufacturer in b) subsequently decides that it would like to connect the machining operation directly to the downstream gear box assembly operation and fully automated the entire process. An identical second machining centre is purchased to balance the machining and assembly throughputs. Stating *any assumptions, discuss automation requirements for such a modification, especially if the operation will need to run stand alone for significant periods of time.*

The major shift here is that the operations now need to be fully integrated in terms of material flow and also control system coordination. Students may comment on the need for line balancing / scheduling of operations but it is assumed here that this will have been sort out prior to considering automation needs.

Assuming that the assembly operation is already automated and that there is no additional automation of the assembly operations themselves other than at the machining interface then following issues would need to be considered:

A key issue is that PLC capabilities will be required to coordinate both the machining and assembly operations whereas previously these two operations would have been managed separately. The additional automation issues would include:

- Receive and interpret part schedules - adapt these to include machining as well as assembly requirements to trigger production execution
- Coordinate flow of parts across machining and assembly including any material handling (conveyor, AGV etc) and intermediate part storage locations and their access as required
- Ensure the production of one or more parts is completed - introduce some form of part tracking across the machining and assembly operations that includes an intermediate storage.
- Communicate part completion reports to factory computer network
- Coordinate the functions of different automated machines/devices - ensure that production levels are matched and that there is not excessive buidling up of WIP
- Receive status/task complete reports from machines/devices

Some students may also discuss further the requirements for fully stand-alone operation although this was not directly asked in the question and would then address points raised in a) iii) in the context of this situation e.g.

- Material/Part quality control
- Error trapping, detection and diagnosis
- Monitoring and reporting functions
- Redundancy in sensing
- Fail safe measures
- Automation of part handling

Examiners Comments

Question 4

This question was attempted by only 8 students and referred broadly to material covered across most of the second half of the course relating to automation requirements at different levels of the factory. In this sense it was quite a challenging question and required students to think beyond the basic material provided in lectures.

Section a) asked broad questions relating to automation at different levels of factory operations and responses were in general quite good although there there were no outstanding solutions.

The remaining two sections asked candidates to consider the case of a factory making gear boxes to add some new production and automation developments to its operations.

Section b) asked student to consider factors from the proposed development that would impact on automation and particularly where operations would need to be left to run stand alone with minimal supervision. Responses were quite varied in nature but most candidates made good attempts and the better efforts picked up key issues the factory was facing in their responses.

Section c) the required an issue of systems integration for the factory to be considered
Again, responses were shorter in general than might have been expected as students appeared out of time in completing this question.