MIT 2.008 Design and Manufacturing II

Spring 2023

Quiz 2 - Part A, In-Class Component

May 10, 2023

- Closed Book
- All work for CREDIT must be completed in this quiz document
- You are allowed one double-sided, hand written 8.5” x 11” notes sheet
- Calculators are allowed

Name: ______________________________

Part A, In-Class Component		
Problem 1		Out of 10 points
Problem 2		Out of 40 points
Part B, Take-Home Component		
Problem 3		Out of 50 points
Total		**100 points**

<u>Problem 1: Short Answer Questions</u> (CREDIT IS ALL OR NOTHING)

Manufacturing Processes and Planning

a. Match the type of production and estimated quantity on the left with the corresponding product descriptions on the right.

Type of Production (Number Produced) | *Product*

Experimental (1-10)

B

A. Red Solo Cups

Small Batch (10-5000)

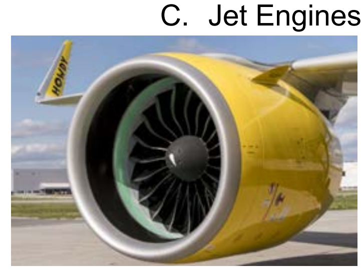
D

B. 2.007 Robot

High Volume (5000-100000)

C

C. Jet Engines



Mass Production (100000+)

A

D. MIT Brass Rats

b. Which one of these products is most likely made in a **job shop**? Which product most likely can only be made **at scale with dedicated machinery and special tooling**? Briefly explain the reasoning behind your choice of product for each scenario.

Job shops are associated with small quantity production processes, for parts with high levels of variation, which is characteristic of the uniquely designed, n = 1, 2.007 robots.

While it's true that the brass rats would require specialty molds, and no doubt would the jet engine may feature some special fixturing, the red solo cup is the only part here that MUST have dedicated machinery characteristic of mass production processes to produce the number of red solo cups for their relatively low cost.

Manufacturing Systems

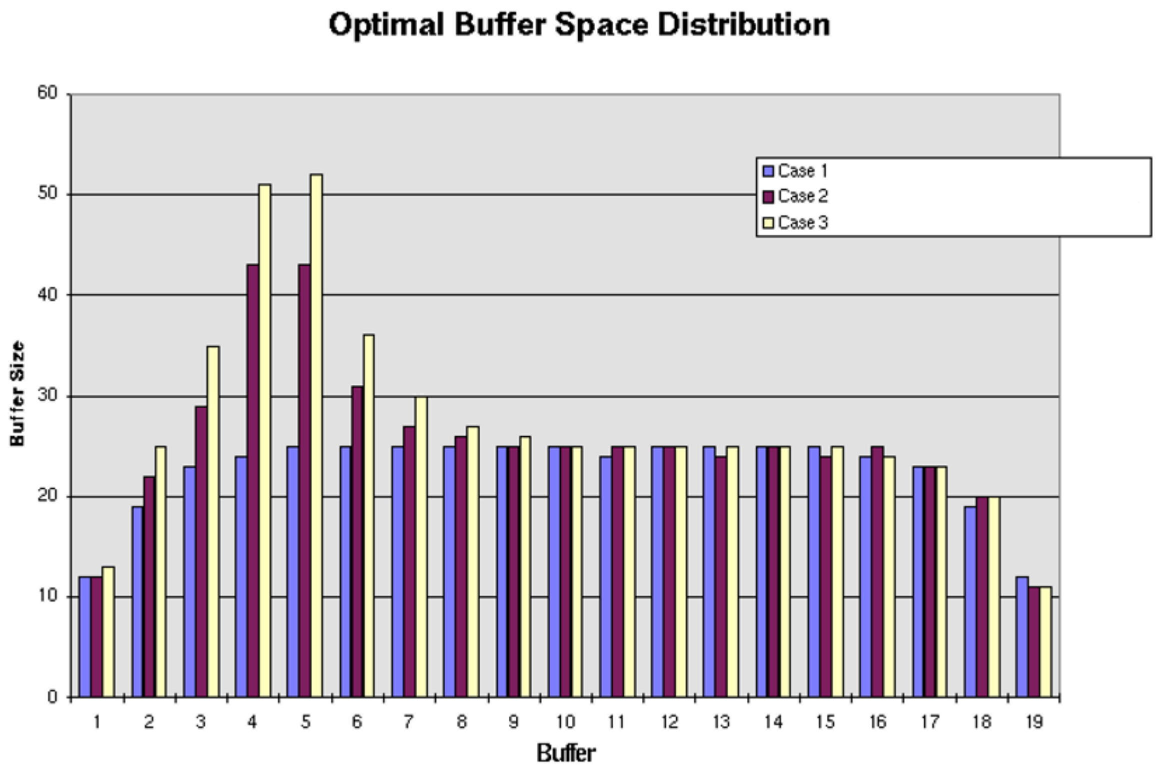
a. In the Lean Game, you were given the option to use a *poka-yoke*, i.e. adding click guides for the toy painting activity in order to reduce defects. What are two direct impacts this technique had on your process in the game, or could have in a real-world process? What's an example of a poka-yoke technique that you have implemented or could implement in your yo-yo manufacturing and assembly?

Adding a poke-yoke can help increase production rate of a process and reduce the overall amount of product defects.

Examples for poka-yokes for the yoyo making will vary but should center on how to reduce errors in manufacturing and manual assembly. Acceptable answers can range from fixturing solutions during machining of molds and assembly of final yoyos, implementation of in-process measurements, smart layout of the assembly line of yoyos etc.

We have been modeling 3 scenarios (Case 1, Case 2, and Case 3) for a 20-machine production line to determine the smallest allowable buffer capacity needed to meet our desired production rate. We have already determined the **optimal** buffer size for each of the 19 buffers, and the results for 3 different scenarios are shown in the image below.

In Case 1, all the machines are identical (same MTTF, same MTTR), while Case 2 and 3 contain a bottleneck. Based on the plot of buffer inventory vs buffer location, please answer questions b-c.



b. If all the machines are identical in Case 1, why do we see an "inverted bowl phenomenon" in which the required buffer capacity is smaller at the very beginning and end of the line?

Answers may use different language but this model has the built in assumption that the first machine is never "starved" or waiting for parts, nor is the last machine ever blocked from producing.

c. Where is the bottleneck machine in Case 2 and Case 3 and what evidence do you have to support your conclusions?

Machine number 5 (between buffers 4 and 5). Let's remember that this is a plot of optimal buffer sizing. We would have larger buffers surrounding the machine as there is accumulation in buffer 4 from the increased unreliability, but a reasonably large inventory after the machine in buffer 5 to ensure the line continues during downtimes of that machine. This could also be thought of as decoupling the bottleneck from the system.

Cost

a. You are considering a soft lithography process to prototype a microfluidics device in your lab and are interested in keeping a detailed account of expenses. How would you categorize the following costs necessary to complete the device? (Write V for variable cost, F for fixed)

   PDMS elastomer: _______ **V**

   Organic Solvents: _______ **V**

   Plasma treatment/bonding machine: _______ **F**

   Lab technician w/ hourly rate: _______ **V/F**

   Si wafer molds: _______ **F**

Additive Manufacturing

a. Which plastic additive manufacturing process is likely to give you the best surface finish and why? Fused Deposition Modeled (FDM) vs Stereolithography (SLA).

   SLA, the laser defining the features, results in the capability to produce smaller features, and a finer layerization than what is possible in the extrusion-based processes.

b. If fabricating a part with additive manufacturing, which of the following scenario(s) would **not be reasonable**. (Circle all that apply)

   Metal part with long thin overhanging features

   Custom hip implant, topology optimized for mass.

   Prototype of a new yoyo design

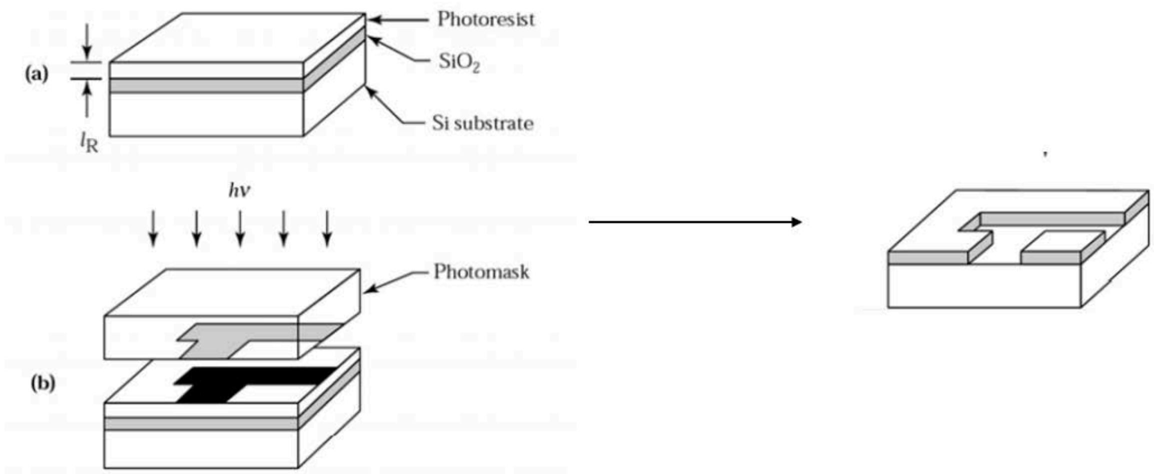
   New lids for a nationally distributed beverage

Layered Manufacturing

a. Name two factors that can impact the sharpness of your features during a photolithography process.

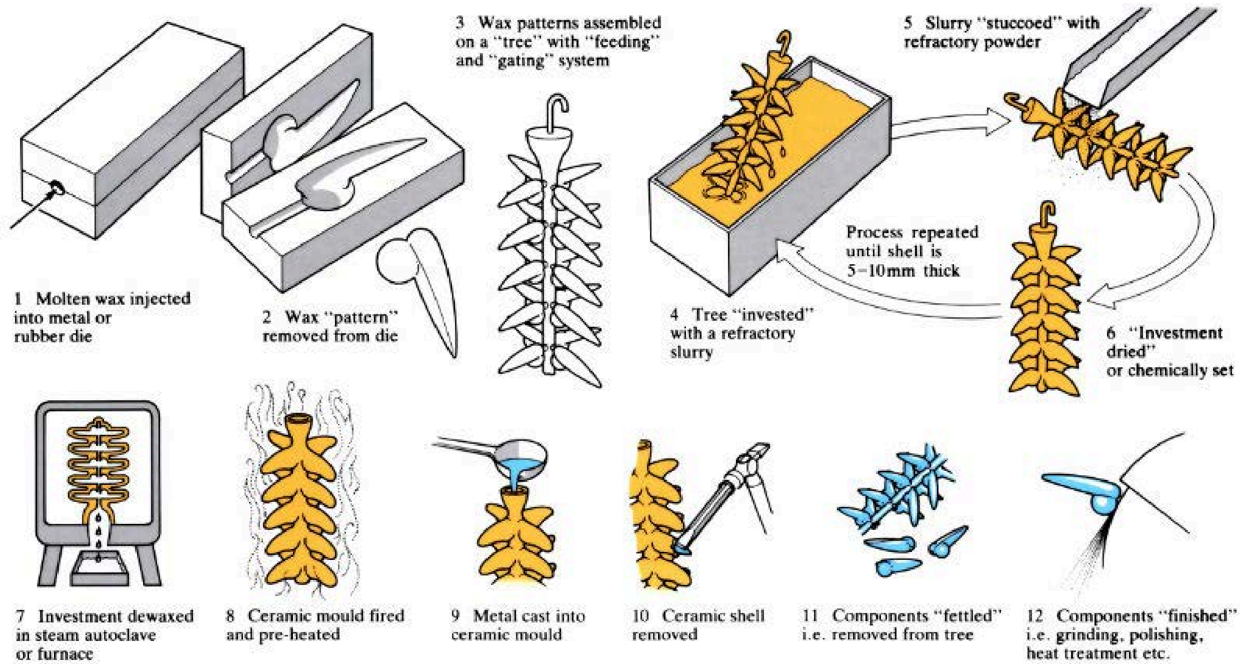
Answers may vary but can include, exposure level and focus of stepper or photolithography machine, typo of etchants used to define features, alignment of mask during process.

b. Circle the correct answer: Based on the mask in step b in the image below, the features produced on the substrate on the right were made with a (positive/negative) photoresist



Problem 2: Additive Manufacturing for Jewelry Production

You are a part of an MIT Mech E committee reevaluating the manufacturing method for the Brass Rat. Currently these rings are made from a process called investment casting in which a wax mold is created in the shape of the ring, covered in a ceramic shell, melted away and then cast with a metal in the remaining form. This process is depicted in the image below:

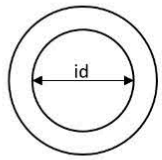


There has been increased interest in how additive manufacturing could decrease the lead time between the order and manufacturing of the rings. Your job will be to evaluate the potential of an option to print the rings directly using selective laser melting (SLM) of a precious metal powder.

a) Examine the image of the Brass Rat below, are there any features on the bezel displayed that you're concerned cannot be made with this selective laser metal process? Circle or call out on the image two potentially problematic design choices and how they might be addressed?

- The text features and finer details on beaver will be difficult to decipher depending on the minimum laser spot size available
- Long - thin fin line features may experience warping from thermal gradients during the printing process.
- Overhangs could be an issue depending on rinds print orientation

+2 (1 for each design choice)
+2 (1 for each solution)



Approximate dimensions for a size 7 Brass Rat
ring height = 10 mm
ring thickness (t) = 1.5 mm
inner diameter (id) = 17 mm

Machine Process Parameters
print layer thickness = 20 µm
laser spot size = .1 mm
linear scan speed = 20 mm/s
Interlayer speed = 5s
Build plate diameter = 80 mm

b) Given the above ring dimensions and process parameters, estimate the time in minutes to print one gold Brass Rat with the SLM process. You may approximate the ring as a hollow cylinder and should assume the infill path planning of the laser ensures no point is crossed multiple times in one layer.

Step 1: Find the total path length the laser must traverse

$$path\ length = \frac{print\ area}{spot\ size}$$

$$= \frac{A_{od} - A_{id}}{spot\ size}$$

$$= \frac{\frac{\pi}{4}(od^2 - id^2)}{spot\ size}$$

$$= \frac{\frac{\pi}{4}(20mm^2 - 17mm^2)}{.1m}$$

$$path\ length = 871\ mm$$

Step 2: Divide by linear scan speed to find the time to infill a layer

$$time\ infill = \frac{path\ length}{scanning\ speed}$$

$$= \frac{871\ mm}{20\ mm/s}$$

$$time\ infill = 43.6\ s$$

Step 3: Calculate number of layers in print

$$number\ of\ layers = \frac{ring\ height}{print\ layer\ thickness}$$

$$= \frac{10\ mm}{.02\ mm}$$

$$number\ of\ layers = 500$$

Step 4: Combine previous steps and problem info to calculate total time

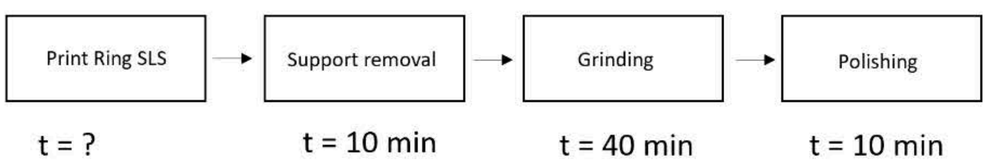
$$total\ print\ time\ = n_{layers}(t_{infill} + t_{interlayer})$$

$$= 500(43.6\ s + \ 5\ s)$$

$$total\ print\ time\ = 24300\ s\ or\ 405\ min$$

+ **10 (5 for reasoning, 5 for correct answer)**
  (3 points were removed for correct reasoning and calculation work flow, but units error/ use of wrong parameter)

c) You’re given the following process diagram. In order to ensure that the printing process is not the only bottleneck, how many rings would you have to simultaneously produce? How many machines would you need to meet this demand without changing any other parameters?



Step 1: Figure out max time for t.
Upon inspection it cannot exceed 40 min order to be the sole bottleneck in the process.

Step 2: Set up proportion and solve (note: the solution to part c will depend on part b. Appropriate credit should be given for part c regardless of the correctness of the answer provided in part b)

$$\frac{1\,part}{40\,min} = \frac{x\,parts}{405\,min}$$

$$(40x) = (405)$$

$$x = 10.125\,parts\ or\ 11\,parts,$$

Same number of machines!

+8 (2 points for bottleneck identification, 2 points for method, 4 points for correct answer)
If answer is incorrect due to carry over error but reasoning is there full credit.
10 or 11 machines was accepted as an answer, because rounding may have impacted answer

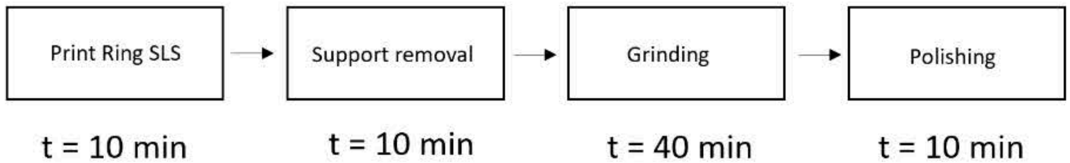
d) The initial cost for one of these machines is $100,000 USD, and the manufacturers of the SLM machine, EOS, tell you this is worth the investment given your ring target price for the new additively manufactured rings of < $2000 and an expected order size of 500 rings. Using what you have learned about manufacturing costs and the manufacturing processes, explain why this is or isn't a fair argument. Give 2 supporting reasons.

It depends! This could be a poor argument, at least for 1 run of rings. While the straight math would reveal a cost per ring of about $1600, which is below the threshold, this doesn't include other variable costs such as labor and overhead, and material cost and gold powder will surely be costly. Furthermore, that calculation also assumes no machine down time, no failed parts etc.

However, if you are considering the life of the machine and using it over many years, it is possible that eventually the capital costs will be diluted. This argument is more difficult to make without information about the variable costs involved in this process.

+4 (2 points per each reason and justification)

e) The committee finds a nearby manufacturing facility with non-dedicated machines that is willing to take on the task. They even managed to tune the process to reduce effective operation time for the first step to under 10 min! What is the production rate of their manufacturing line, shown below in units of parts/hr? The estimated MTTR is 30 min while the MTTF is 1200 min for each machine.



Here we can use Buzzcott's zero-buffer formula

$$prod\ rate = \frac{1}{\tau_{max}} x \frac{1}{1 + \sum_{i=1}^{k} \frac{MTTR_i}{MTTF_i}}$$

$$= \frac{1}{40} x \frac{1}{1 + 4(30/12000)}$$

$$prod\ rate = .0227\ parts\ per\ minute\ or\ 1.36\ parts\ per\ hour$$

+8 (2 points for buzzcott eq, 2 points for use of Tau_max, 4 points for correct answer)

2 points were given for finding a prod rate as a base line.

f) Another member on the team proposes a happy medium: SLA printing of the wax molds used in investment casting. Does this address any of the concerns brought up in this problem regarding rate limiting steps or feature quality? Why or why not. See the image below which compares the initial finish of a part made with investment casting of a 3D printed wax mold on the left with the initial printed part from SLM.

The rate limiting step or bottleneck in this problem was the grinding step and the image shows that the 3D printed wax molds still process visible linearization, so the grinding and finishing process will still need to take place in order to produce desired part finish. This means the for the customer likely with a similar operation time. It is possible that the Traditional casting of the 3D mold can help retain some of the finer detailed features.

+6

(+ 2 for recognition of rate limiting process step
+ 2 for correct reasoning on process impact
+ 2 just for answering the question. (this meant to give students credit even if they had a reasonable answer that demonstrated knowledge of additive manufacturing etc, even if they didn't make the connection between surface finish and process time from both images.)