**MIT 2.008 Design and Manufacturing II**

Spring 2021

**Quiz 2**

- All work for CREDIT must be completed in this quiz document
- Open book, open notes

**Name: ___________________________________**

| | | |
|---|---|---|
| Problem 1 | | Out of 12 points |
| Problem 2 | | Out of 14 points |
| Problem 3 | | Out of 28 points |
| Problem 4 | | Out of 34 points |
| Problem 5 | | Out of 12 points |
| **Total** | | **100 points** |

## <u>Part 1: Short Answer/Multiple Choice/True False</u>

For each of the following questions, **circle all correct answer(s)** that apply.

a. High-volume production makes injection molding and die casting economically viable due to the amortization of [variable / fixed / material / labor] cost.

b. [Flow line / Job shop / Transfer line / Cellular system] is the most flexible of the manufacturing system arrangements.

c. Adding a machine with $e < 1$ will [never / sometimes / always] decrease the total production rate of a line with zero buffers and [never / sometimes / always] decrease the total production rate of a line with infinite buffers.

d. Which of the following statements about production lines is **<u>false</u>**?
i. A line with buffers will have a higher production rate than a line without buffers.
ii. A line with large buffers will have a shorter cycle time than a line with small buffers.
iii. A line with small buffers is more likely to have its output affected by machine failures than a line with large buffers.
iv. A disadvantage of having large buffers is that there is a lot of work in progress.

e. [Zinc / magnesium / aluminum / ceramic] is often used in casting molds for high-temperature parts.

f. Assuming other values remain constant, choosing a material that is superplastic (longer plastic regime before fracture), would create [less / same / more] springback.

g. How can you **decrease** the springback in a sheet formed part?
i. Lubricate the mold before forming
ii. Put the material in tension before forming
iii. Chose a thinner material
iv. Use a harder die

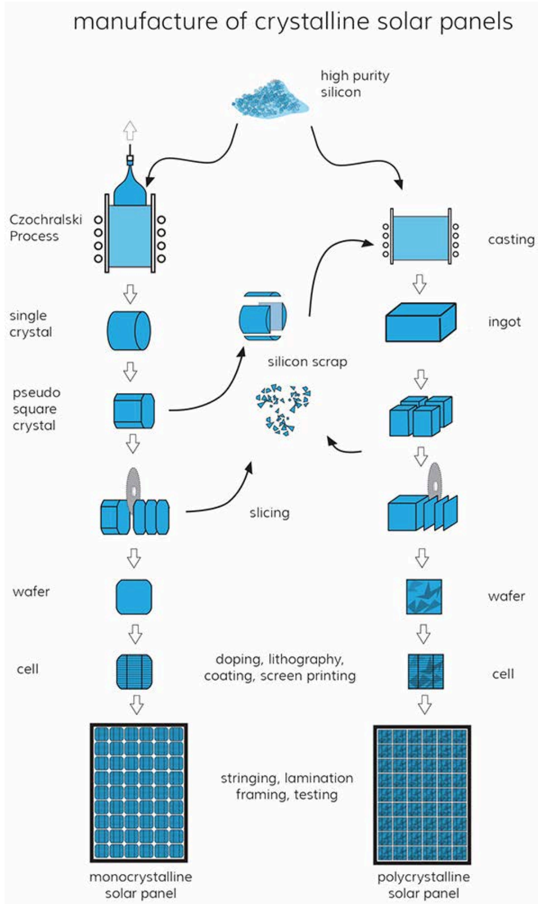
h. Chemical vapor deposition (CVD) processes generally operate at [higher/lower] temperatures than plasma enhanced chemical vapor deposition (PECVD) processes.

i. In chemical vapor deposition (CVD), the growth rate of the deposition film strongly depends on the process temperature. At high temperature, the surface reaction rate, k, is much greater than the transport parameter, hg. Therefore, the process is [reaction limited/transport limited] and the growth rate is governed by [k, hg].

j. Fiber reinforced plastic composites can be produced to exhibit [anisotropic/quasi-isotropic/isotropic] mechanical properties.

## Part 2: Layered Manufacturing, Process Planning, and Supply Chain

Considering the supply chain and fabrication of a mono-crystalline solar cell.






a. There is currently a shortage for semiconductors worldwide. Based on the lessons from the Beer Game and the supply chain outline of solar panels above, briefly discuss the impact of COVID manufacturing shutdowns on the supply of upstream pure silicon, crystal, and wafers, and the issue with simply restarting production to satisfy demand of downstream panels or other products.

b. Suppose the ASML EUV lithography machine (left) spec sheet quotes a production rate of 1000 wafers/day. It also has 20 discrete locations inside of the machine, constraining the number of wafers present in the system at any time. A normal storage cassette holds 50 wafers and the production rack nearby fits 100 cassettes. A larger model (right) has a production rate of 2000 wafers/day but has 25 discrete locations inside of the machine. What is the average time that it takes any single wafer to proceed through each of the lithographic systems?

c. Discuss how the average time in the system impacts quality control. What is a downside of the larger system though?

d. If there is no place in between each sub-process for a wafer to sit, comment on the importance of making sure each part of the machine is well maintained to minimize down time.

e. Consider the downside of having large buffers between each subprocess in the machine. Note 1 quality control concern and 1 cost concern, relative to clean rooms and this application specifically.

f. Each process inside the lithography machine has an average operation time. Remember that these operation times are **average** values. How would **variation** in the operation times of individual sub-processes influence the average production rate of this production line? You don't need to do a calculation here. Instead, combine what we learned about variation with the various models/equations for **both** infinite and zero buffer systems.

## Part 3: Casting

Compare the two stop valve handles below. The one on the left has been sand-blasted to help see some of the features while the right is still painted (note that the paint layer is thin and conformal, and surface texture arises from the underlying cast part). Assume one is cast iron (6mm thickness) and one is aluminum (3mm thickness).

a. What casting process was used to make each version of the handle? How can you tell?

b. Why is one handle thicker than the other?

c. Calculate the cooling time for each of the two versions. For simplicity, model the handles as a thin disk with dimensions 5cm diameter and thickness described above (aluminum = 3 mm, cast iron = 6 mm). Assume $C_{sand} = 1,200,000\ s/m^2$ or $C_{die} = 80\ s/m$. Do you expect these to be an overestimate or underestimate?

d. Using the shrinkage allowance for cast iron, what would you suggest to be the minimum riser volume to avoid an undersized part?

e. What would be the main problem of swapping the two materials for the two processes?

f. Relevant to this application, discuss at least 1 advantage and 1 disadvantage for if this valve handle was made by investment casting. Based on those pros/cons, would you suggest moving to this process for this part?

g. Imagine that you are designing a high-volume process for making the valve handles. What would your multi-cavity mold look like? Either draw or describe.

h. Consider the differences in thermal diffusivity, viscosity, and surface tension as well as what you know about the process itself. Be sure to support your answer with fundamental analysis or calculations. Explain which valve will experience:

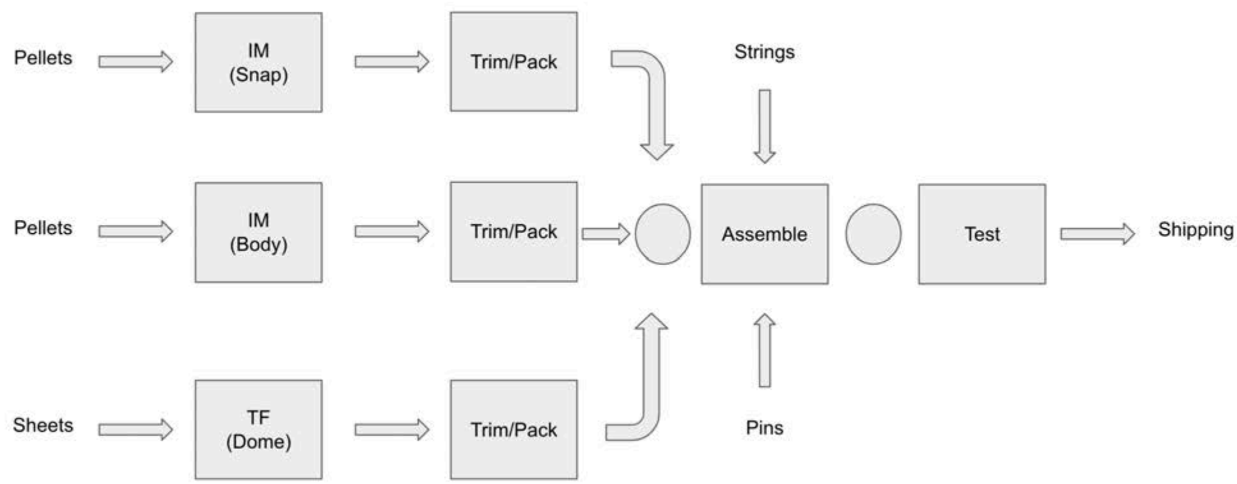
    1) greater injection pressure.

    2) greater fill time.

i. Consider that the manufacturing cost is the sum of equipment, tooling, material, and labor costs. Which of these costs are greater for sand casting, and which are greater for die casting? Sketch an approximate curve of cost per part (y-axis) versus production quantity (x-axis), for die casting and sand casting. Explain your curves using fixed and variable costs. Assume the quantity ranges from 1 to 100,000. How would the cost of investment casting compare to those?

## **<u>Part 4: Systems</u>**

Analyze your Yo-Yo manufacturing production line given the system design tools that you learned and discussed in lecture. See below for the starting transfer line. You will add, replace, or subtract features to this line and comment on the result. You may need to access some/all of the MATLAB programs that are currently embedded in Canvas. You may want to use Excel or other calculation formats to help with the other equations. Remember to show your work for all questions (if relevant, link a shared google sheet or screenshot a formula view) and to screenshot the MATLAB input/output if used.




Each box denotes a separate machine and operation on the line. Arrows denote how and which direction the Yo-Yo's move through the transfer line. There are no places for buffers unless a circle is present. The size of the buffers will be changed throughout the different questions below. Materials that are used within the machines/operations are denoted with text and do not constitute an operation themselves if not boxed.

**Important Notes:**

- There are enough Yo-Yo parts of each type already in the first buffer to accommodate assembly.

- Each upstream processing machine (IM/TF) as currently constructed creates two halves (essentially a two-cavity mold). This ensures there are enough parts for one single complete Yo-Yo assembly from each operation.
- Remember to include units for all your answers. Assume that the machines run 24/7/365 for this analysis.

To help with any calculation, this table is also in sheet form here via the view-only link below.
[https://docs.google.com/spreadsheets/d/13K8_uU7CL_05KBxZWVw1tlhTx3Rvft_Y5hTzZ8VZzK8/edit?usp=sharing](https://docs.google.com/spreadsheets/d/13K8_uU7CL_05KBxZWVw1tlhTx3Rvft_Y5hTzZ8VZzK8/edit?usp=sharing)

| **Machine** | **e** | **MTTR (sec)** | **MTTF (sec)** | **Tau (sec)** | **p** | **r** | **p/r** | **(1/e)-1** |
|---|---|---|---|---|---|---|---|---|
| IM Body | 0.9615384615 | 400 | 10000 | 40 | 0.004 | 0.1 | 0.04 | 0.04 |
| IM Body Trim/Pack | 0.9900990099 | 20 | 2000 | 2 | 0.001 | 0.1 | 0.01 | 0.01 |
| IM Snap | 0.8 | 1000 | 4000 | 20 | 0.005 | 0.02 | 0.25 | 0.25 |
| IM Snap Trim/Pack | 0.9900990099 | 20 | 2000 | 2 | 0.001 | 0.1 | 0.01 | 0.01 |
| TF-3D Dome | 0.8888888889 | 500 | 4000 | 50 | 0.0125 | 0.1 | 0.125 | 0.125 |
| TF-3D Dome Trim/Pack | 0.9900990099 | 20 | 2000 | 2 | 0.001 | 0.1 | 0.01 | 0.01 |
| TF-AL Dome | 0.8888888889 | 500 | 4000 | 15 | 0.00375 | 0.03 | 0.125 | 0.125 |
| TF-AL Dome Trim/Pack | 0.9900990099 | 20 | 2000 | 2 | 0.001 | 0.1 | 0.01 | 0.01 |
| Assembly | 0.9900990099 | 50 | 5000 | 5 | 0.001 | 0.1 | 0.01 | 0.01 |
| Test | 0.9090909091 | 1000 | 10000 | 50 | 0.005 | 0.05 | 0.1 | 0.1 |
| | | | | | | | | |
| Test-Robot | | | | | | | | |
| IM-Dual | | | | | | | | |

a. Draw a simplified/effective transfer line from the given layout that will allow you to apply the tools in the later questions. Make any assumptions necessary and explain your reasoning and strategy.

b. Assume there is no space at all in the entire production line, meaning there are zero-size buffers between all machines where the circles are present.

   i. Start with the 3D-printed TF-3D mold for the thermoforming. What operation is the bottleneck? What is the overall production rate in Yo-Yo's per year?

   ii. If we change to the aluminum TF-AL mold **(use the TF-AL mold for all questions going forward)**, does the bottleneck shift? Why or why not? What is the production rate in Yo-Yo's per year?

c. If you had only one infinite buffer to place and you could put it anywhere in the production line, where would it go to give you the highest production rate? Would that resultant line meet your demand if it was 625,000 Yo-Yo's per year?

d. Now assume that you have finite buffer space in your system for the two original buffer locations. If you didn't already, to ease this analysis, ignore the "Trim/Pack" stages of each process and use the p and r metrics of the slowest machine.

   i. What is the smallest buffer space that still accomplishes a production rate of 570,802 Yo-Yo's per year? Discuss both the difference (which buffer is larger and by what amount) between the optimized buffer sizes and average inventory as well as their significance (why did more inventory accumulate in one versus the other).

   ii. If you could carefully inspect the parts before the assembly step (effectively swapping testing/assembly operations so that the buffers are on either side of testing), how would it change the minimum buffer sizes required to reach the desired production rate? Explain in detail how those average inventory levels are affected and specifically why each increased/decreased?

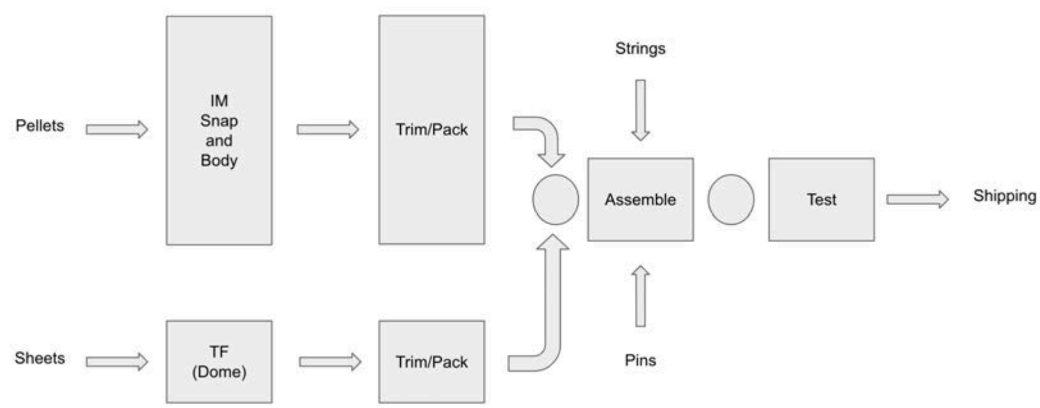
   iii. Could you solve/approximate either (4di) or (4dii) with the two-machine line tools? Why or why not? Use the programs as needed.

   iv. The production facility is forced to move from Cambridge to downtown Boston and you can only afford a very small **total** buffer size 20 sq. ft. space with your budget. On average, each Yo-Yo takes up 1 sq. ft. worth of space in the buffer. In order to maintain the same production level, you invest in machine vision and automated robotic yo-yo testing equipment that reduces the testing time (now after assembly again) down to 25 seconds. However, it is rumored to fail more often than your analog and manual devices. When discussing with the sales and technical representatives, what is the minimum MTTF that the testing equipment can have in order to still meet your demand in this smaller location (assuming fixed repair metrics)? How and why did the distribution in your average inventory levels change as compared to the previous question?

## Part 5: Cost

The lab staff proposes that we replace the two separate IM machines with a new IM machine capable of performing both IM operations (only one operator required at $50/hr). You know that the former IM setup has reliability issues from your previous analysis and requires two operators ($50/hr), but the machines/molds are already paid for and therefore their cost does not need to be considered. The new dual-IM machine would have less reliability issues and a higher production rate, but it has to be rented at $100/day and the multi-cavity mold is $20,000. Assuming infinite buffers, after how many days do you break-even on the cost savings from this investment (Yo-Yo's are sold for zero revenue)? Use the table below (add/subtract/label as needed) to help compare the two scenarios with the different metrics in each row. Each shift is 8 hours, but there are 3 shifts per day, so for simplicity our production is still 24/7/365. Continue to use the TF-AL option with the Test-Robot upgrade.

| | MTTR (s) | MTTF (s) | Operation time (s) |
|---|---|---|---|
| IM-DualBodySnap | 800 | 5000 | 30 |




| Cost or Rate Metric | 2-IM Machines | 1-Dual-IM Machine |
|---|---|---|
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