MIT 2.008 Design and Manufacturing II

Spring 2021

Quiz 2

- All work for CREDIT must be completed in this quiz document
- Calculators are allowed

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**

Part 1: Short Answer/Multiple Choice/True False (12 points, 1 pt for each bracket, no partial credit for these)

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. **(1 point, all or nothing)**

b. [Flow line / Job shop / Transfer line / Cellular system] is the most flexible of the manufacturing system arrangements. **(1 point, all or nothing)**

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. **(2 points = 1 pt each)**

d. Which of the following statements about production lines is **false**? **(1 point, all or nothing)**
   i. A production line with buffers will have a higher production rate than a line without buffers.
   ii. A production line with large buffers will have a shorter cycle time than a line with small buffers.
   iii. A production 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. **(1 point, all or nothing)**

f. Assuming all other values stayed constant, the result of choosing a material that is superplastic (longer plastic regime before fracture), would create [less / same / more] springback. **(1 point, all or nothing)**

g. How can you **decrease** the springback in a sheet formed part? **(1 point, all or nothing)**
   i. Lubricate the mold before forming
   ii. Put the material in tension before forming
   iii. Chose a thinner material
   iv. Use a harder die

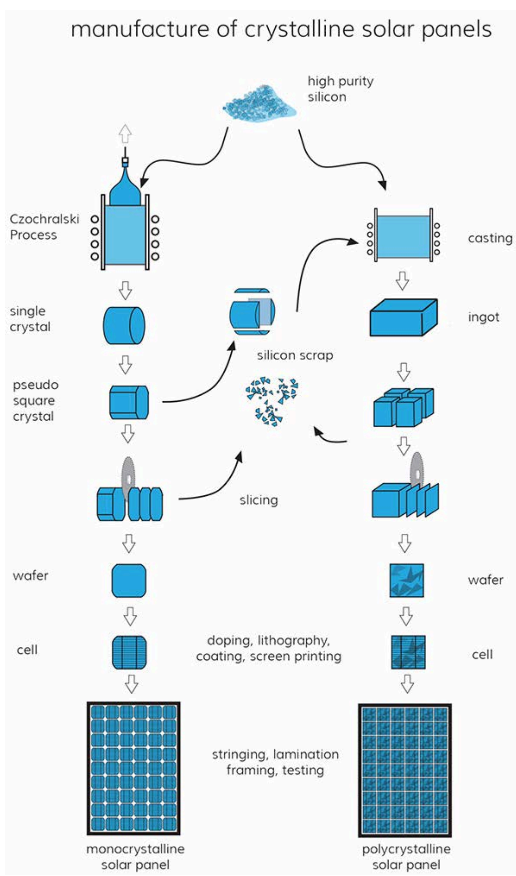
h. Chemical vapor deposition (CVD) processes generally operate at [higher/lower] temperatures than plasma enhanced chemical vapor deposition (PECVD) processes. **(1 point, all or nothing)**

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]. **(2 points = 1pt each)**

j. Fiber reinforced plastic composites can be produced to exhibit [anisotropic/quasi-isotropic/isotropic] mechanical properties. **(1 point, both selected, all or nothing)**

<u>Part 2: Layered Manufacturing, Process Planning, and Supply Chain</u> **(14 points)**

Below is a process diagram for fabricating a silicon solar cell and panel (both monocrystalline and polycrystalline cells).



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. **(2 pt)**

+1
Supply was cut-off when manufacturing shut down.

+1
There is now a spike in demand and lead times associated with each step in the supply chain so the retailers are not able to satisfy customers. This is roughly equivalent to when demand spiked in the Beer Game.

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? **(4 pt)**

+1 for ignoring the cassettes and racks extraneous information. Little's Law is applied to each machine.
+1 L = lambda * w meaning w = L / lambda = average time in system
+1 W = (20 / (1000 /day)) = 0.02 days = 24*0.02*60 = 28.8 minutes
+1 W = (25 / (2000 /day)) = 0.0125 days = 24*0.0125*60 = 18 minutes

c. Discuss how the average time in the system impacts quality control. What is a downside of the larger system though? **(2 pt)**

+1
The larger machine with higher production rate has less waiting time. This means if there is an issue that you will notice it faster.

+1
However, with 25 wafers in the machine at any given time there is a larger work-in-progress that might be affected if there is ever an issue noticed.

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. **(1 pt)**

+1
It effectively acts like a zero-buffer transfer line system when there is no buffer location for partially completed wafers to accumulate. This means that whenever there is a down subprocess, the entire system becomes blocked. Most likely, these machines are therefore extremely expensive and have very high efficiencies or are closely monitored.

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. **(2 pt)**

+1
Large or infinite buffers lead to higher work in inventory. Therefore, if bad parts are being manufactured, they may accumulate in buffers until they are noticed and production is fixed. This delay will greatly increase the number of poor quality parts and cost of poor quality. Whereas the fewer the parts in buffers, the more quickly production errors will be discovered.

+1
Space in a clean room is very expensive, so maintaining buffers in a clean room is costly.

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. **(3 pt)**

+1

We are completely focused on tau max here in each case. They can get this point if they don't say this specifically but are thinking about the problem in the correct way and get the below parts correct.

+1

In an infinite buffer system, the production rate will still be the production rate of the slowest machine (tau max), but if there's a large enough variation in the production rate of the machines – **different machines could be the bottleneck at different times which would influence the overall production rate.** Therefore if one machine barely has a slower operation than another but the slightly faster machine has extremely high variability, it is very likely that the faster machine actually becomes the bottleneck.

$$P = P_{min}$$

+1

In a zero buffer system, the production rate is dependent on the machine with the slowest operation time. **If the slowest machine has variability, then it will cause the average production rate to change.** If the variation is due to randomness (common cause), the average production rate will be approximately equal to the calculated production rate.

$$P = \frac{1}{\tau_{max}}\left(\frac{1}{1+\sum\left(\frac{MTTR_i}{MTTF_i}\right)}\right)$$

Part 3: Casting (28 points)

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? **(2 pt)**

+1
Left - Die cast. Right - sand cast.

+1 We can identify the ejector pins in 3 out of the 6 hexagonal points and also 4 ejector pin marks on the shaft. As a comparison, the sand casted part does not have any ejector pin marks and much rougher surface finish.

b. Why is one handle thicker than the other? **(1 pt)**

+1
Die casting uses much higher injection pressure so a thinner cross section can be produced (much higher pressure drop than die casting). The designers also had to increase the thickness of the support beams that connect the square shaft fitting to the hexagonal fitting for the sand casting. This is most likely due to the cooling rate being much longer in the sand casted version.

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? **(4 pt)**

Chvorinov's Rule for Casting:
+1 V/A calculation

+1

Die Casting: $tcool = C\left(\frac{V}{A}\right)^1$

V = pi*r^2*thickness
V = pi*(0.025m^2)*(0.003m) = 5.89 *10^-6 m^3

A = 2*pi*r^2 + pi*D*thickness
A = 2*pi*(0.025m^2) + pi*(0.05m)*(0.003m) = 4.4 * 10^-3 m^2

tcool = 80 s/m * (5.89 *10^-6 m^3) / (4.4 * 10^-3 m^2) = 0.11 s

*note that some use t/2 for V/A approximation, which is ok for estimate purpose
tcool = 80 (s/m) * (0.003m / 2) = 0.12 s

+1

Sand Casting:

$t = C\left(\frac{V}{A}\right)^2$

V = pi*r^2*thickness
V = pi*(0.025m^2)*(0.006m) = 1.18 *10^-5 m^3

A = 2*pi*r^2 + pi*D*thickness
A = 2*pi*(0.025m^2) + pi*(0.05m)*(0.006m) = 4.87 * 10^-3 m^2

tcool = 1,200,000 (s/m^2) * ((1.18 *10^-5 m^3) / (4.87 * 10^-3 m^2))^2 = 7.05 s

*note that some use t/2 for V/A approximation, which is ok for estimate purpose
tcool = 1,200,000 (s/m^2) * (0.006m / 2)^2 = 10.8 s

+1

These are most likely an underestimate for several reasons: 1) geometry is of course not as simple as the model cylinder used meaning solidification rate will be less, 2) Chrinov's rule can underestimate in general due to the exponent.

They can probably say either as long as they write something that makes sense with whatever assumption they say is increasing/decreasing.

d. Using the shrinkage allowance for cast iron, what would you suggest to be the minimum riser volume to avoid an undersized part? **(4 pt)**

+1
According to the slides, the shrinkage allowance for cast iron is 8-13 mm/m = 10 mm/m. Let's approximate this as 1% shrinkage allowance then.

+1
A 1% decrease in the cylinder dimensions would make it 4.95 cm diameter and 5.94 mm thickness.

+1
We will calculate the volume of shrinkage and set that roughly equal to the minimum riser volume (some material can be left in the riser afterwards depending on head height).

+1
Vmold = pi*(0.025m^2)*(0.006m) = 1.18 *10^-5 m^3
Vshrink = pi*(0.02475m^2)*(0.0054m) = 1.03 *10^-5 m^3
Vriser > Vmold - Vshrink = 1.18 *10^-5 m^3 - 1.03 *10^-5 m^3 = 0.15*10^-5 m^3 = 1500 mm^3

e. What would be the main problem of swapping the two materials for the two processes? **(1 pt)**

+1
The cast iron has a much higher melting temperature than the steel commonly used in a die cast tooling. You would not be able to properly heat the iron without also melting the steel.

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? **(3 pt)**

+1 Advantages:
- Better tolerances
- Better surface finish

+1 Disadvantages:
- Much higher cost
- Longer development time to remake the wax each time

+1 No. This does not seem like a part that requires better tolerances/surface finish in exchange for the higher cost and development time.

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 in detail. **(3 pt)**

+2 Drawing or explanation with their layout (they can choose either die or sand). Many cavities could be arranged in a radial pattern around a central sprue, or a branching runner system could be used. Some key features should be labeled. Focus should be on the layout rather than the individual part design.

+1 **In either case, each part should have a riser (located as close to the part as possible - the riser is useless if it is separated from the cavity by a quickly-solidifying runner!). Each cavity would need its own core, however it might be possible to arrange or re-design the core such that a multi-core piece could be used.** Unlike with injection molding, the machine limitations are fewer - there is no maximum surface area or clamping force to limit the size of the molds.

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: **(4 pt)**
    i. greater injection pressure.

+1
Die casting > sand casting.

+1 Remembering back to our equation for flow through a channel we know that viscosity and pressure are positively correlated. However, we also know that metal has high surface tension and if the features are small in the part it may be difficult for the molten metal to enter those crevices without extremely high pressure. It likely depends on the part dimensions and features, extremely small features like threads would require high injection pressure but otherwise injection molding has higher pressure.

    ii. greater fill time.

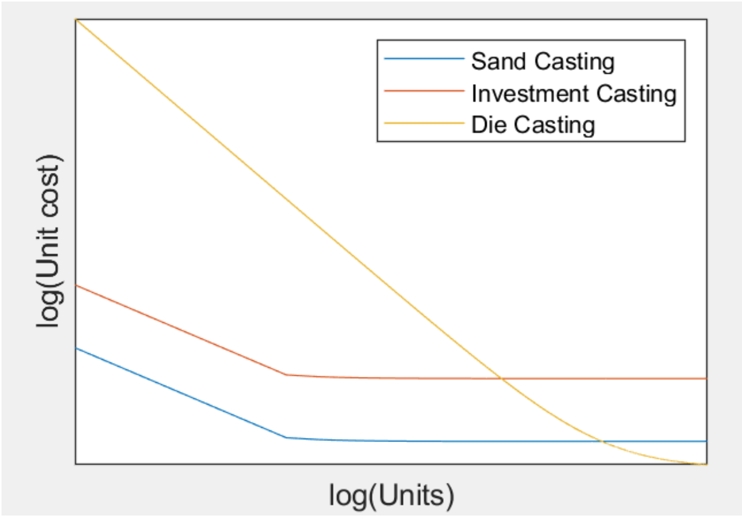
+1
Sand casting > die casting.

+1 Pressure and fill time are inversely correlated, all things being equal. Sand casting uses head pressure versus high pressure for die casting.

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? **(6 pt)**

+1 Material: cost will be roughly the same for all options because the volume does not change. Maybe you have thinner pieces for die casting so it's slightly less.
+1 Tooling: will be highest for die casting for low quantity and then almost zero at high quantity. For sand casting the tooling is constant throughout all quantities.
+1 Production: Sand casting by far has the highest amount of labor associated with it since they have to repack the mold every cycle. There is almost no labor cost for die casting at high quantities.

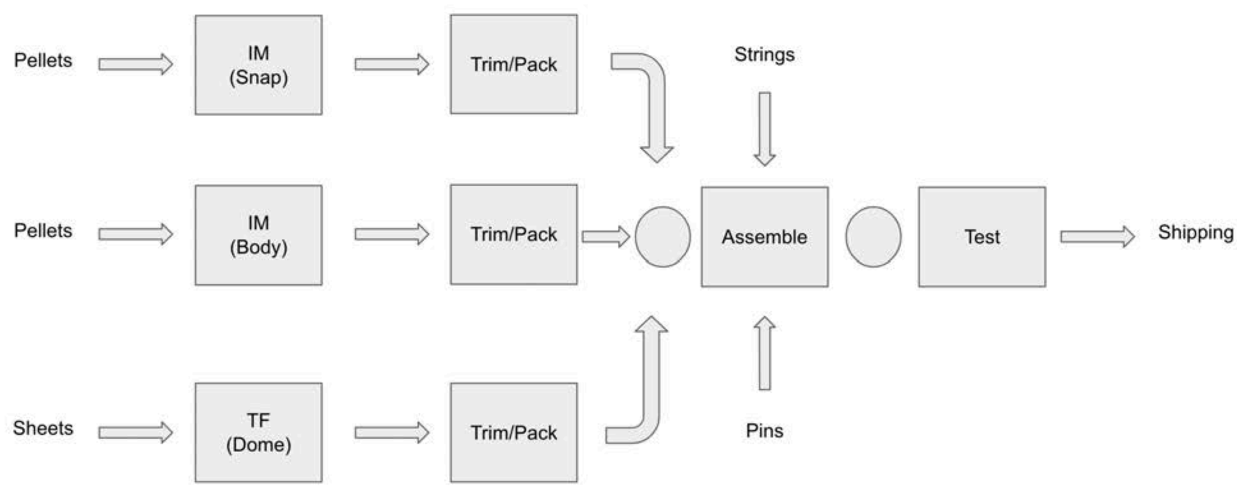
+2 For each or the two lines (sand and die) of the graph drawn correctly
(Bonus Point) This graph below is technically not smooth, there will be discrete points at which the mold for die casting needs to be replaced or economics of scale to trigger for labor cost or other variable costs. Unlikely anybody said this though.



+1
Unlike die casting that can produce parts in high volumes and once the mold is made, investment casting requires a separate mold for patterns in addition to significant equipment and workers/robots to assemble the patterns into a tree, coat the tree with ceramic, melt out the wax, pour the molten metal, and finally demold the parts. This could mean that the per-unit cost curve is somewhere in between sand casting and die casting where there is slight economics of scale but has significant up-front cost associated with the robot and variable cost of the wax pattern for each part.

Part 4: Systems **(34 points)**

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

Here is the solutions sheet.
https://docs.google.com/spreadsheets/d/1ZfUBYObIBVtuBvkwWmc-3ZhAneb8CR83yiSlVxYeAQE/edit#gid=901300415

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. **(6 pts)**

+3

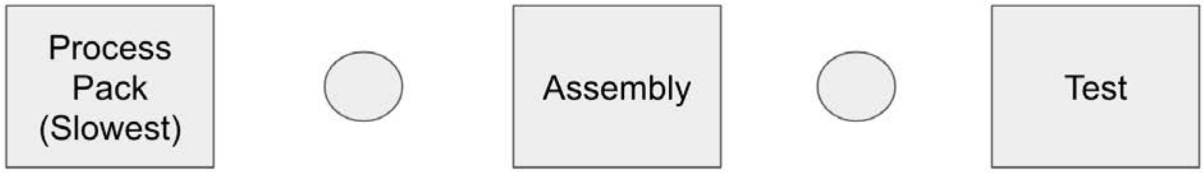
Our analysis begins with examining which process and pack has the slowest production rate (together, technically not ignoring pack, but okay if you did) and becomes the bottleneck upstream.

Production rate is e/tau. (Do not have to specifically say this, it is implied in future questions if you did it correctly). Calculations are the following (or you can just inspect and find the lowest one going forward as needed).

Machine	**Prod Rate**
IM Body	0.0240
IM Body Trim/Pack	0.4950
IM Snap	0.0400
IM Snap Trim/Pack	0.4950
TF-3D Dome	0.0178
TF-3D Dome Trim/Pack	0.4950
TF-AL Dome	0.0593
TF-AL Dome Trim/Pack	0.4950
Assembly	0.1980
Test	0.0182

+3

This will allow us to consider this as a three-machine, two-buffer system and use the zero/finite/infinite buffer tools from lecture.



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? **(4 pts)**

+1

The lower bound (zero buffer) can be solved analytically with Buzacott's formula (shown or could also be in excel).

$$P_{zero} = \frac{1}{\tau}\frac{1}{1+\sum_{i}^{k}\frac{MTTR}{MTTF}}$$

+1

We will be utilizing tau max since there are different tau's.

+1

They could either go by inspection and see that we should use the components of the TF-3D line to generate a series of four zero-buffer machines since it has the slowest, or they could calculate each of the three zero-buffer lines (of four machines each). Either way, the conclusion is that TF-3D is the bottleneck.

Zero Buffer	p/r	tau
TF-3D	0.125	50
TF-3D Pack	0.01	2
Assemble	0.01	5
Test	0.1	50
tau_max	50	
Pzero	0.01606425703	506602

+1

Production rate of 0.01626 or within error.

  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? **(4 pts)**

+1

With the change to the TF-AL mold, they could either go by inspection and see that we should use the components of the IM-Body line to generate a series of four zero-buffer machines since it has the slowest, or they could calculate each of the three zero-buffer lines (of four machines each).

+1

Either way, the conclusion is that IM-Body is the bottleneck.
Correct p/r for the IM-Body of 0.04.

+1

Tau max is still 50.

+1

0.01724. The lower bound (zero buffers) can be solved analytically through the same process as above.

Zero Buffer	p/r	tau
IM-Body	0.04	40
IM-Body Pack	0.01	2
Assemble	0.01	5
Test	0.1	50
tau_max	50	
Pzero	0.01724137931	543724

b. 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? Assume that the machines run 24/7/365 for this analysis. **(3 pts)**

(+1 point).

Intuitively, it would go next to the bottle-neck (which is the Test) because we want to keep the minimum production rate on either side of the infinite buffer as high as possible. We can also calculate that production rate for each case to be sure (did not have to do this) and then choose the best.

(+1 point). We convert 625,000/year to seconds by dividing by 365/24/60/60 and comparing to production rate.

(+1 point). The resulting production rate would be 0.018018 yo-yo's per second which is less than the necessary demand of 0.0198186199 yo-yo's per second. We can not meet demand.

Zero Buffer	p/r	tau
IM-Body	0.04	40
IM-Body Pack	0.01	2
Assemble	0.01	5
Test	0.1	50
tau_max1	40	
tau_max2	50	
Pzero1	0.02380952381	750857
Pzero2	0.01801801802	568216
Pairs/year	1,250,000	
Demand/year	625,000	
Demand/second	0.01981861999	
Works?	FALSE	
How?	Buffer next to bottleneck	
Why?	Separates slowest machines	

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). **(5 pts)**

+1
Choose to use the MATLAB long-line program for this reduced three machine two-buffer system. Use the p and r from each of the machines.

Finite Buffer	p	r	tau
IM-Body Line	0.004	0.1	40
Assembly Operation	0.001	0.1	5
Test Operation	0.005	0.05	50
tau_max	50		
N	29	22	
nbar	19.5851	17.1867	
Pfinite	0.905	0.0181	570802

+1

You must convert the 570,802 to parts per second which is 0.0181.

+1

Then since the maximum operational time is 50 second cycles, your target prodrate is 50*0.0181 which is 0.905 in the MATLAB output (which always calculates in the form of parts/cycle unless you can dictate the units in the continuous two-machine program).

+1

N are 29 and 22. You might have found slightly different optimal solutions. Key thing is that you were optimizing correctly for 0.905.

+1

The two nbar are 19.5851 and 17.1867. Key is to inspect these numbers. It's more important for the first buffer to be larger than it is for the second buffer. This is because the production rate is faster for the second side. You could inspect and know this by quickly looking at the efficiency and operation time.

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? **(3 pts)**

+1

Do not change any of the MTTF, MTTR, tau, or efficiencies in our system. Just the order of Test/Assembly in the MATLAB code.

+1

Find the N to be 62 and 18 (or something close to this). Of course, the difference is attributed to having a higher operation time to the center rather than having a low operation time in between two buffers.

+1

We notice that nbar has changed 47.9322 and 2.623, which combined together is pretty close to the previous option, however is still higher and perhaps not as efficient because the line is less balanced.

Finite Buffer	p	r	tau
IM-Body Line	0.004	0.1	40
Test Operation	0.005	0.05	50
Assembly Operation	0.001	0.1	5
tau_max	50		
N	62	18	
nbar	47.9322	2.623	
Pfinite	0.905	0.0181	570802

iii. Could you solve/approximate either (4di) or (4dii) with the two-machine line tools? Why or why not? Use the programs as needed. **(2 pts)**

+1 You can only sort of approximate 4di. No is a good answer too.

+1 If you eliminate the assembly step from the program because it is the fastest, then you could have a two-machine line with just process and testing with a buffer in the middle. Or you could show that if you took away the .

OR

+1 You can approximate very 4dii well.

+1 Only the second-case that has the fastest operation as the last machine properly approximates extremely well down to the two-machine case because the last step can basically be ignoredThe other balanced line is In fact, you can use both the continuous and deterministic tools, in one case finding the parts/cycle and in the other parts/time.

Two-Machine	p	r	tau

IM-Body Line	0.004	0.1	40
Assembly Operation	0.001	0.1	5
tau_max	40		
N	55		
nbar	6.4813		
Pfinite	0.9613		
NO			

Two-Machine	p	r	tau
IM-Body Line	0.004	0.1	40
Test Operation	0.005	0.05	50
tau_max	50		
N	150		
nbar	131.826		
Pfinite	0.909		
YES			

Continuous	p	r	tau	u
IM-Body Line	0.004	0.1	40	0.025
Assembly Operation	0.001	0.1	5	0.2
tau_max	40			
N	55			
nbar	0.0003362			
Pfinite	0.024			
NO				

Continuous	p	r	tau	u
IM-Body Line	0.004	0.1	40	0.025

Test Operation	0.005	0.05	50	0.02
tau_max	50			
N	150			
nbar	149.9716			
Pfinite	0.0182	0.91		
YES				

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? **(7 pts)**

+1

The maximum operational time is now 40 second cycles (with the testing station reduced below the tau of the IM-Body).

+1

Your target prodrate is now 40*0.0181 which is 0.724 in the MATLAB output (which always calculates in the form of parts/cycle unless you can dictate the units in the continuous two-machine program).

+1

Recalculate Test r as 0.025. Can also calculate efficiency. The rest of the metrics stay the same.

+1

Calculating from the budget of 100 that we can only have a maximum of N = 20 total. Place those randomly at first and converge later as needed.

Finite Buffer	p	r	tau
IM-Body Line	0.004	0.1	40
Assembly Operation	0.001	0.1	5
Test Operation	0.0091	0.025	25
tau_max	40		
N	4	16	
nbar	2.7504	12.6244	
Pfinite	0.724	0.0181	570802
minMTTF	2747		

+1

For the new testing operation it has to make sure that the machine has a p value of no higher than 0.0091.

+1

Plugging the 0.0091 into the p = tau/MTTF equation should be equivalent to the machine failing every 2747 seconds. Any higher of a p value and you won't reach your 0.724 (again, scaled back due to the new tau of 40 instead of 50 which is multiplied by 0.0181).

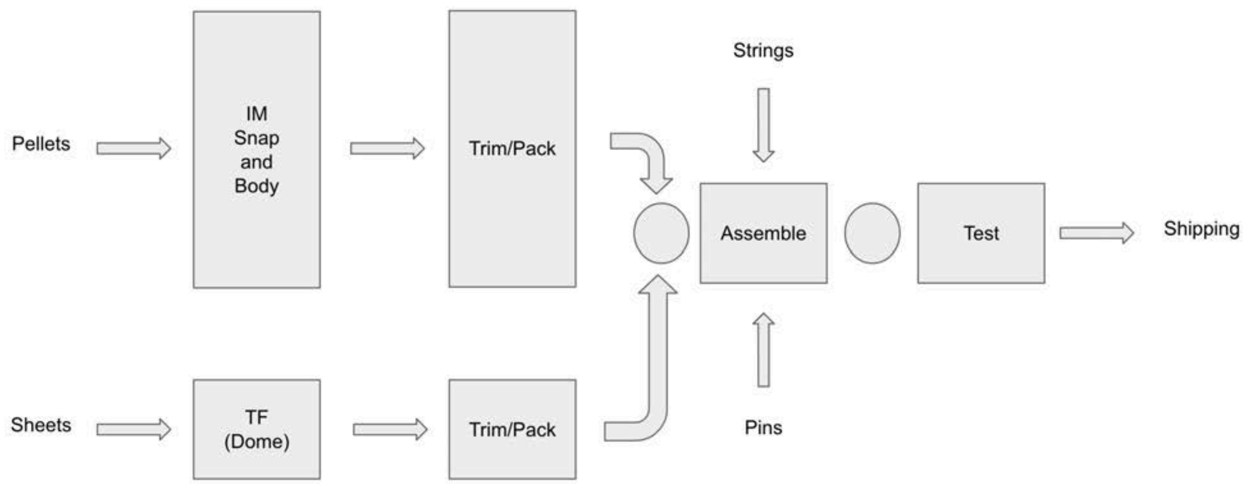
+1

We also notice now that the nbar is higher for the second buffer (12.6244) now compared to the first buffer (2.7504). This makes sense that our second buffer is filling up much more often because our testing machine is failing more often compared to before. We also note that both buffers are almost to their maximum level on average.

Problem 5 - Cost **(12 points)**

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
Production rate (yoyo/sec)	0.0238	0.0284
Machine Cost ($/day)	$0	$100
Labor Cost ($/day)	$2,400	$1,200
Total Cost ($/day)	$2,400	$1,300
Mold Cost ($)	$0	$20,000
Cost per part ($/yoyo)	$1.17	$0.53

(+3 point). Calculate the production rate of the Dual-IM machine system as 0.0284 within error. Infinite buffer formula with 2IM-Assemble-TestRobot. They probably needed to calculate the metrics of IM-Dual.
(+2 point). Production rate from the 2x regular IM machine system is 0.0238 within error. Infinite buffer formula with bottleneck-Assemble-TestRobot.
(+2 point). Calculate the total cost per day (or other unit) as the sum of machine and labor cost.
(+1 point). Note machine cost per day (or other unit) as $0 and $100/day.

(+1 point). Calculate labor cost per day (or other unit) as $50/hr and $100/hr meaning $2,400 and $1,200/day.
(+1 point). Note that mold cost is a fixed sunk cost in this scenario and $0 for old and $20,000 for the new machine.
(+1 point). To pay-off the mold cost we calculate the production volume (# of yoyo's we need to make on the dual machine) to break even on the investment. We require 31,321 Yo-Yo's to break even based on the $20,000 mold and the lowered rental+labor cost per day.
(+1 point) This equates to 12.72 days. Convert the yo-yo production units to the same units as the cost so that we can get cost/yoyo. Easiest way to do this is either move the cost per second or yoyo/day. Here we have shown per day. 2057 yoyo/day and 2461 yoyo/day for each and then ultimately $1.17/yoyo for 2 machines and $0.53 for new dual-machine. The cost savings per part is therefore $0.53/yoyo

They don't have to have all of the information written out like below but in case they do this should be all of the parameters for each case. If an error is carried through with Test-Robot from #4, it is OK.

Cost Breakeven	2 machines	1 machine
IM-New Cost (Rent)	$0	$100
People	2	1
Salary/hr	$50	$50
Labor cost/day	$2,400	$1,200
Total cost/day	$2,400	$1,300
Mold	$0	$20,000
Yoyo/second	0.02380952381	0.02849002849
Yoyo/day	2057.142857	2461.538462
Cost/part	$1.17	$0.53
Savings/part		$0.64
Savings/day		$1,571.79
Production volume		31321
Payback period (days)		12.72
Infinite Buffer	Pi	Pi
IM-DualBodySnap Line		0.02849002849
IM-Body Line	0.02380952381	
IM-Snap Line	0.03968253968	
TF-AL Line	0.05873715125	0.05873715125

Assembly Operation	0.198019802	0.198019802
Test-Robot Step	0.0293255132	0.0293255132
Pinf	0.02380952381	0.02849002849
Bottleneck	IM-Body	IM-DualBodySnap