MIT 2.008 Design and Manufacturing II

Spring 2022

Quiz 2 - Part B, Take-Home Component

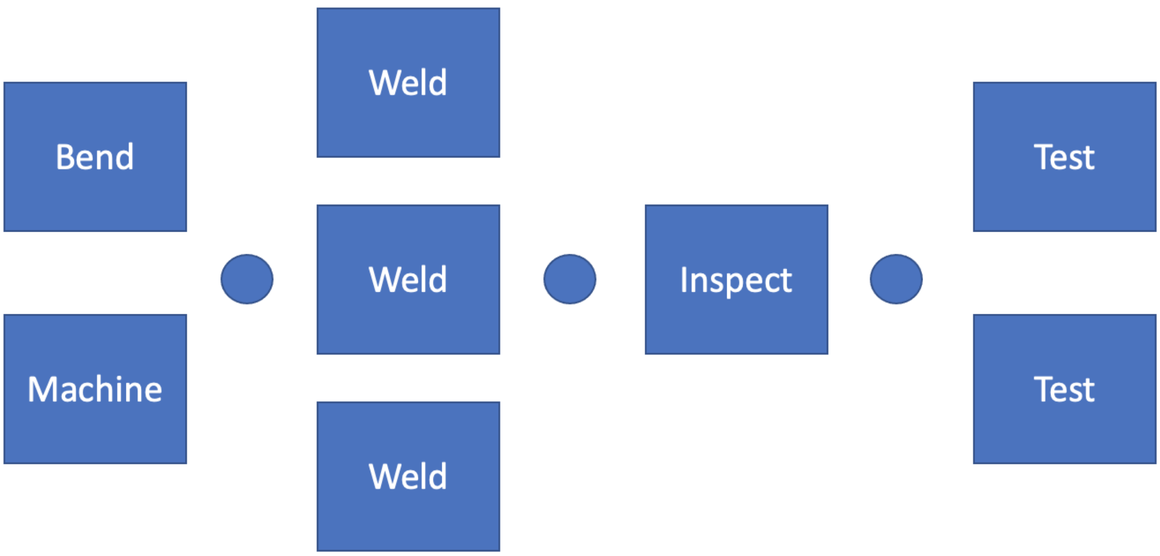
- All work for CREDIT must be completed in this quiz document
- All work must be completed individually and cannot be discussed with classmates.

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 3:</u> Manufacturing Systems (50 pts)

Expanding on the scenario from Part A, to better analyze the assembly line, you have been asked to perform a manufacturing systems analysis on the hub-bracket assembly for the Saildrone mast base. The process has brackets bent on a press and hubs machined on a CNC. Each of these are placed into an intermediary buffer. From there, the three manual welders take one of each to weld together and deposit into another intermediate buffer. The inspector ensures the welded joints meet the required levels of quality through an ultrasonic system. Once inspected, the hub-brackets undergo product testing with two workers in parallel. This constitutes the entire assembly line under investigation. **The operation time and efficiency parameters associated with each process station are listed below in the table.**

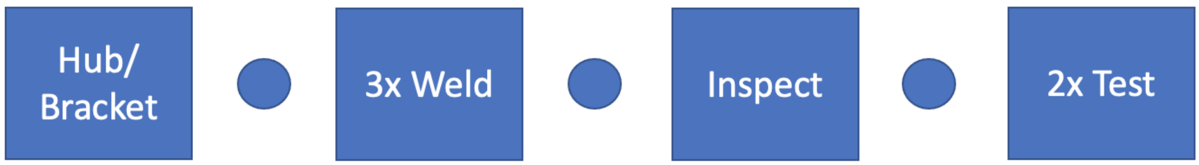


Machine	e	MTTR (sec)	MTTF (sec)	Tau (sec)	p	r
Bend	0.8889	2000	16000	60	0.00375	0.030
Machine	0.8000	5000	20000	360	0.01800	0.072
Weld	0.5000	10000	10000	300	0.03000	0.030
Inspect	0.9756	1000	40000	120	0.00300	0.120
Test	0.9697	1000	32000	400	0.01250	0.400

Key Assumptions:
- A human operator acts as a variable machine with irregular downtime.
- There is only buffer space in the designated circles and unless otherwise outlined starts at zero.
- The hub bracket parts move left to right.

a) What simplifications or assumptions do you need to make in order to utilize the analytical solutions in MATLAB? Draw this new line. **(14 pts)**

The welding and testing process steps are easy to reduce down, since they can be made into an effective machine with ⅓ the operation time and ½ the operation time respectively. The inspect step does not require any additional simplification. For the hub and bracket, we choose the slowest one to serve as the simplified step. Here it is clear that the machined bracket is slower than the bending using P = (1/tau)*e.



Machine	Each Prod Rate	Eff Prod Rate
Bend	0.0148	0.0148
Machine	0.0022	0.0022
Weld	0.0017	0.0050
Inspect	0.0081	0.0081
Test	0.0024	0.0048

Solutions calculation document:
https://docs.google.com/spreadsheets/d/18dWntGkFqhxu_r6K0D8ewo--TVDx0R5yEs1DCyaca_o/edit?usp=sharing

Simplification

- **Idea of simplifying to a line/or sketch (2pt)**

Machine/Bend

- **Prod rate of machine & bend (3pt)**
- **Choosing Machine as slowest machine (2pt)**

Multiple machines

- **Dividing tau by n (2pts)**
- **Dividing p and r by n (2pts)**
- **New/Effective production rates (2pts)**

Others

- **Prod rate of Inspect (1pt)**

Students who had incorrect or incomplete necessary simplifications for (a) and (b) lost points here but got full credit in all future questions with the “carry-through” disclosure

b) If you had the option to place an infinite buffer anywhere, where would it go to have the maximum effect? **(3 pts)**

We want to find the bottleneck. **Looking at the individual production rates of each process, we can see that the slowest is the Hub/Bracket with the 0.0022 effective production rate. We would want to put an infinite buffer between that Hub/Bracket station and the Welding station.** Anywhere else in the line would cause the first batch of stations to have worse production.

1 pt for reasoning/production rate comparisons
1 pt for using the term "bottleneck" or an equivalent
1 pt for correct answer

c) Each buffer between machines only has space for a maximum of 25 hub-brackets. Can you meet the demand of 100 hub-brackets per day? Explain the distribution of parts in your buffers if so. **(9 pts)**

Yes. Here are the input parameters for the Long Line MATLAB program.

```
k = 4;
r = [0.072 0.010 0.120 0.200];
p = [0.01800 0.01000 0.00300 0.00625];
N = [25 25 25];
```

```
prodrate =
    0.4722    0.4722    0.4722
nbar =
   17.2586    1.1652    1.2344
```

We expect the majority of the parts to accumulate in the first buffer since this is next to the bottleneck and another slow station (machine and weld). The inspection station afterwards is faster.

100	parts/day	
4.166666667	parts/hr	
0.06944444444	parts/min	
0.001157407407	parts/sec	
360	sec/cycle	tau_max
0.4166666667	parts/cycle	

Since 0.4722 > 0.4167, we can meet the demand.

Students may have also converted the other way and scaled up the parts/cycle into parts/day to make sure that the result gave more than 100 parts/day.

For those students that did not simplify the line and used a tau_max of 400 as well as the wrong p and r, plus they would have gotten this carry-through error and compared to 0.463.

```
k = 4;
r = [0.072 0.030 0.120 0.400];
p = [0.01800 0.03000 0.00300 0.0125];
N = [25 25 25];
```

```
prodrate =

    0.4851    0.4851    0.4851


nbar =

   20.0131    0.9063    0.9334
```

100	parts/day	
4.166666667	parts/hr	
0.06944444444	parts/min	
0.00115740740 7	parts/sec	
400	sec/cycle	tau_max
0.462962963	parts/cycle	

1 pt for correct r's (carry-through errors if necessary)
1 pt for correct p's (carry-through errors if necessary)
1 pt for correct N's/k
1 pt for turning parts/sec into parts/day
1 pt for converting with tau_max
1 pt for using 360 as tau_max
1 pt for correct answer/interpretation
1 pt for knowing using nbar and knowing that it was related to parts in buffers
1 pt for buffer reasoning of first buffer most (carry-through errors if necessary)

d) What is the minimum total buffer size that you need to meet this demand? **(3 pts)**

For a correct simplification of the line, we could either achieve a result of 4, 4, 4 using the MATLAB program or 0, 0, 0 utilizing Buzacott's formula and either the MTTF/MTTR or p/r values. Both are acceptable for full credit.

```
k = 4;
r = [0.072 0.010 0.120 0.200];
p = [0.01800 0.01000 0.00300 0.00625];
N = [4 4 4];
```

```
prodrate =

    0.4430    0.4430    0.4430


nbar =

    2.6665    0.6817    0.6275
```

The minimum total buffer size is N1 + N2 + N3 = Ntot = 4 + 4 + 4 = 12 total.

Some students may also have said that N2 or N3 could be zero since the program does not allow an input of N less than 4 and just had the total have been N1 in that case.

For those students that did not simplify the line and used tau_max of 400, they would have needed finite buffers.

Based on the distribution of parts in the buffer, we know that we only need to focus on making sure Buffer 1 has enough parts. After several iterations, this gets us just above 0.462.

```
k = 4;
r = [0.072 0.010 0.120 0.200];
p = [0.01800 0.01000 0.00300 0.00625];
N = [17 4 4];
```

```
prodrate =
    0.4626    0.4626    0.4626
nbar =
   12.1389    0.7689    0.6943
```

The minimum total buffer size is N1 + N2 + N3 = Ntot = 17 + 4 + 4 = 25 total.

Some students had carry-through errors and thus had the following result to be greater than their 0.4629, where Ntot was 11+4+4=19.

```
k = 4;
r = [0.072 0.030 0.120 0.400];
p = [0.01800 0.03000 0.00300 0.0125];
N = [11 4 4];
```

```
prodrate =

    0.4643    0.4643    0.4643


nbar =

    8.3821    0.6610    0.6757
```

1 pt for N iteration to achieve prodrate
1 pt for correct N's (carry-through or differences okay)
1 pt for adding them up into total buffer space with Ntot (N1+N2+N3)

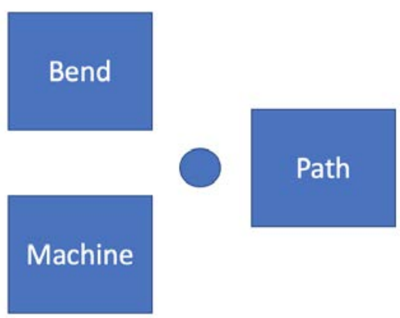
To accommodate increasing demand of 150 parts/day now, management purchases a new Path Robotics system (Figure 1) that has speedy automation to replace the 3 manual welders, a vision system to make the inspector unnecessary, and because of the excellent precision quality, does not require any post-process testing either. The reliability and operational metrics are listed below along with the same bending and machining step.

Figure 1: Path Robotics Automated Welder and Inspector

Machine	e	MTTR (sec)	MTTF (sec)	Tau (sec)	p	r
Bend	0.8889	2000	16000	60	0.00375	0.030
Machine	0.8000	5000	20000	360	0.01800	0.072
Path	0.7143	2000	5000	360	0.07200	0.180

e) Can you meet the increased demand? What is the minimum total buffer size that you need now? Explain the approximate relationship of nbar to N for this optimum case. **(9 pts)**

Yes, we can now meet demand. We will now use the deterministic two-machine system since the Path robot replaces everything downstream of the bending and machining operations.



The minimum buffer size that we need is 5 to reach the 0.625 parts/cycle.

```
r1 = 0.072;
p1 = 0.018;
r2 = 0.180;
p2 = 0.072;
N = 5;
```

```
prodrate =

    0.6272

nbar =

    3.2616
```

The nbar here is approximately half (or ⅔) of N. This makes sense because the line is almost balanced between the bend/machine portion and the Path robot when inspecting the effective production rates of the two-machine system.

150	parts/day	
6.25	parts/hr	
0.1041666667	parts/min	
0.001736111111	parts/sec	
360	sec/cycle	tau_max
0.625	parts/cycle	

1 pt for showing or saying new effective 2-machine system diagram
1 pt for correct r's
1 pt for correct p's
1 pt for new prodrate target calculation with 150 parts/day
1 pt for new tau_max of 360
1 pt for N iteration (carry-through errors)
1 pt for basic definition of nbar lower than N
1 pt for finding production rate of path robot (e/tau = 0.0020)
1 pt for saying nbar is roughly half or slightly more than half because machine and robot are approximately equal production rates now with edge towards machine)

f) What is the average time that your hub bracket is in the manufacturing line for this Path Robotics line and minimum buffer size? **(8 pts)**

Lambda = prodrate output from MATLAB = 0.6250 parts/cycle = 150 parts/day
We need to realize that nbar is on average how many parts are in the buffer but also there is always on average one part in the machine station, bending station, and path robot.
nbar = nbar output from MATLAB = 3.26 + 1 (machine) + 1 (bend) + 1 (path) = 6.26
Little's Law

$$\bar{n} = \lambda * W$$

W = nbar/lambda = average wait time
W = nbar/prodrate = 6.26parts / 0.6250parts/cycle = 10.01 cycles = 10.01*360 seconds = 3603 seconds = 60.05 minutes

Rather than adding 1 for each machine, you could have instead added the wait time for the buffer (nbar/prodrate) and then added the two tau's for each of the machines so that the formula is W1+Wbuffer+W2. While they give different answers, both are acceptable forms of answering this question.

1 pt for using/mentioning Little's Law
1 pt for correct Little's Law equation n = lambda*w
1 pt for rearranging Little's Law

1 pt for substituting nbar in for n
1 pt for also adding in 1 for each of the 3 systems
1 pt for substituting the prodrate for lambda
1 pt for using tau max to scale up cycle time to seconds
1 pt for correct calculations/answer

g) What is the maximum failure rate that Path Robotics can have before it drops below the previous demand of 100 parts/day using the same minimum buffer size? **(4 pts)**

```
r1 = 0.072;
p1 = 0.018;
r2 = 0.18;
p2 = 0.224;
N = 8;
```

```
prodrate =
    0.4166
nbar =
    4.0614
```

100	parts/day	
4.166666667	parts/hr	
0.06944444444	parts/min	
0.001157407407	parts/sec	
360	sec/cycle	tau_max
0.4166666667	parts/cycle	

A failure rate of 0.22 is the maximum before dropping it down to 0.416 parts/cycle which is equivalent to the 100 parts/day.

1 pt for iterating p2 with same other p's and r's as previous question
1 pt for new parts/cycle or parts/day calculation corresponding to 100 parts/day
1 pt for using correct tau_max
1 pt for correct p2 failure rate calculation (or subsequent MTTF number)