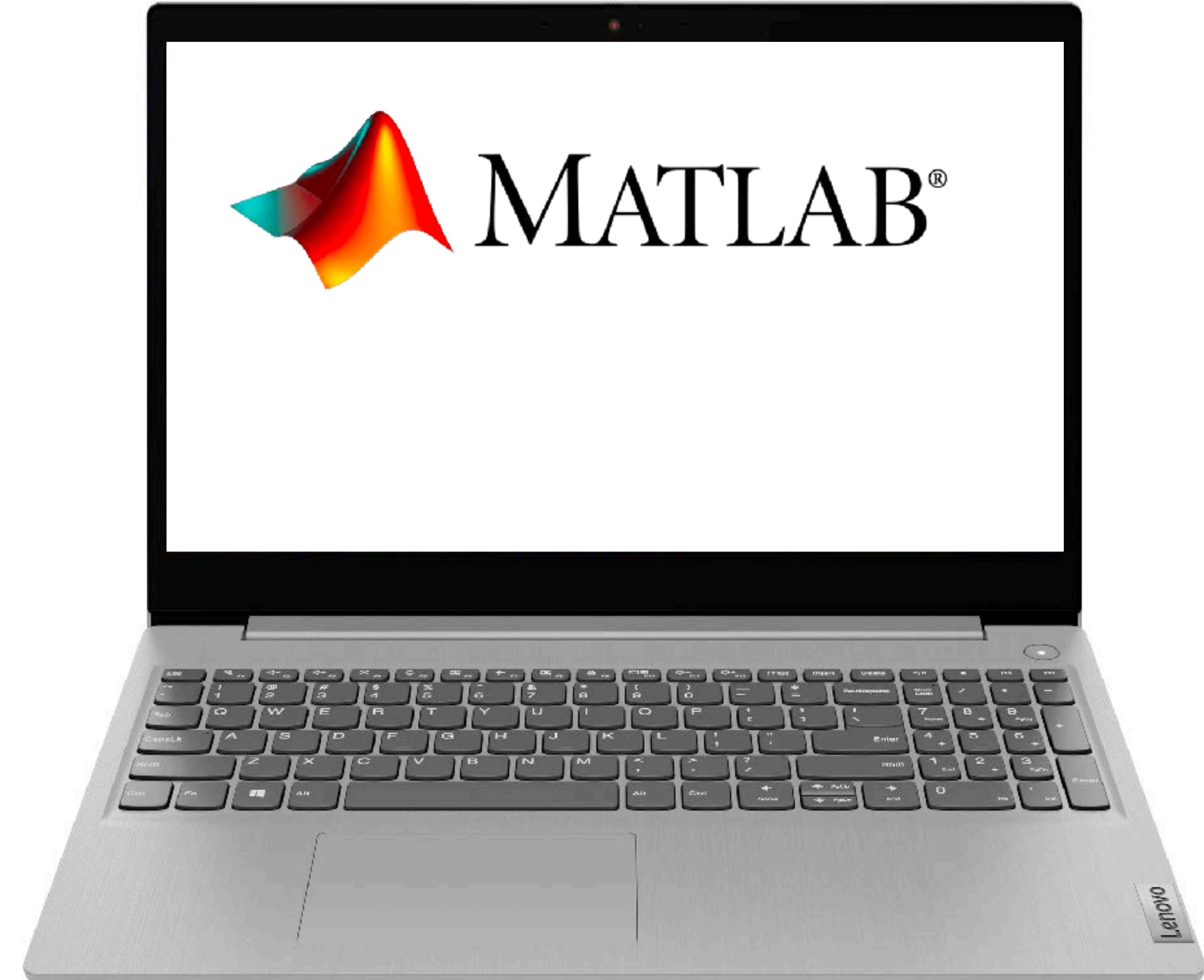


Manufacturing Systems IV

Modeling Transfer Lines in MATlab

1

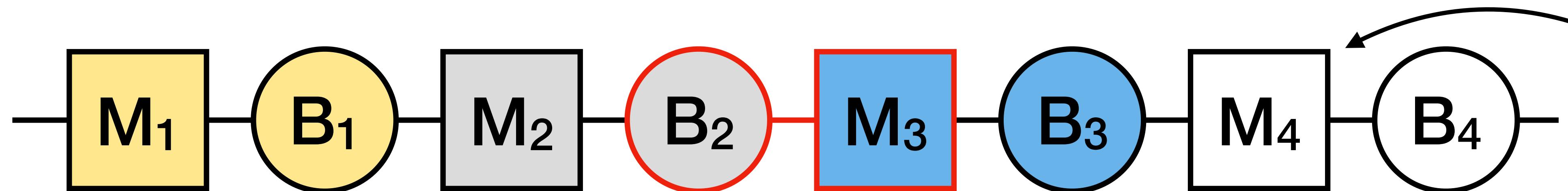
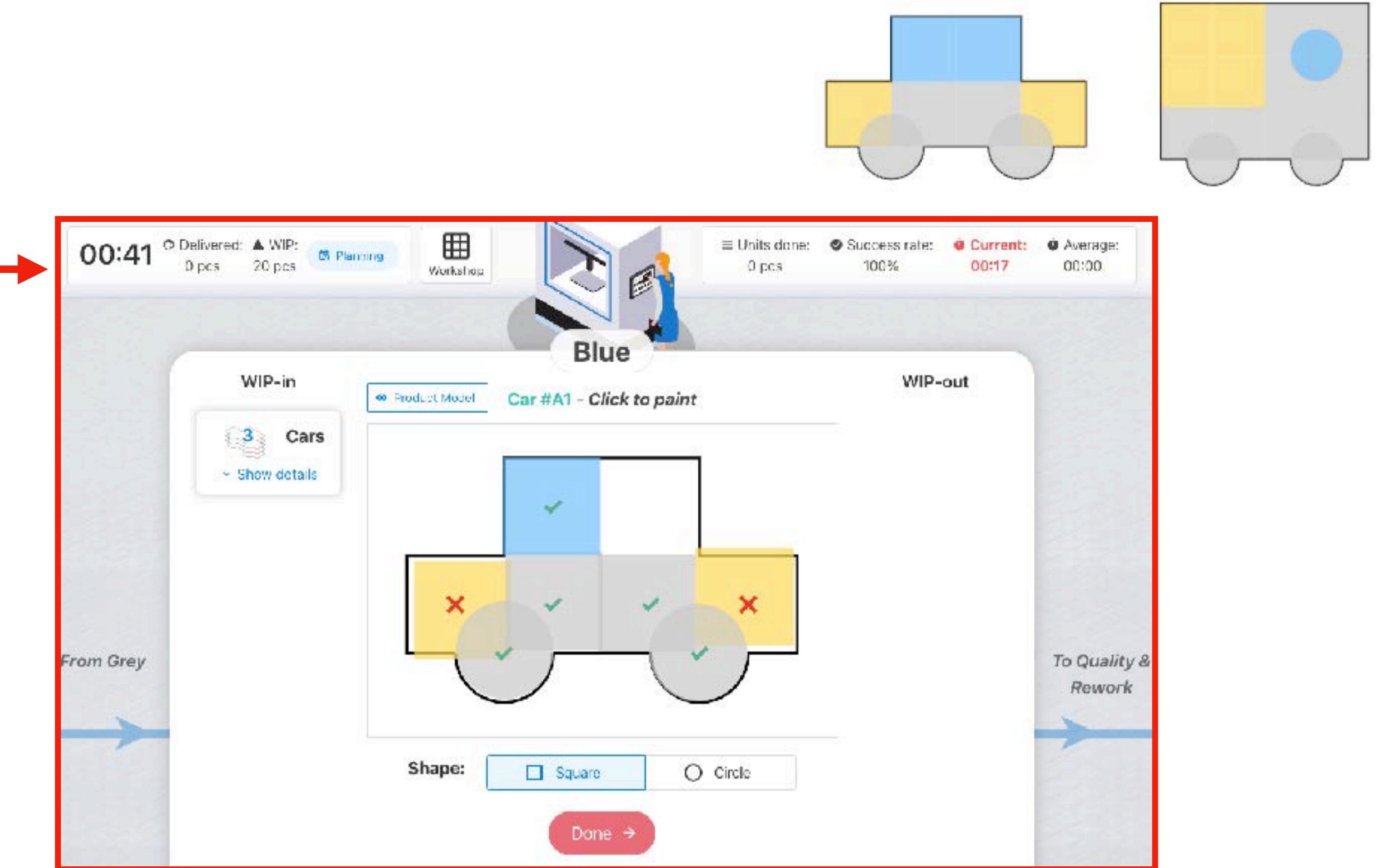
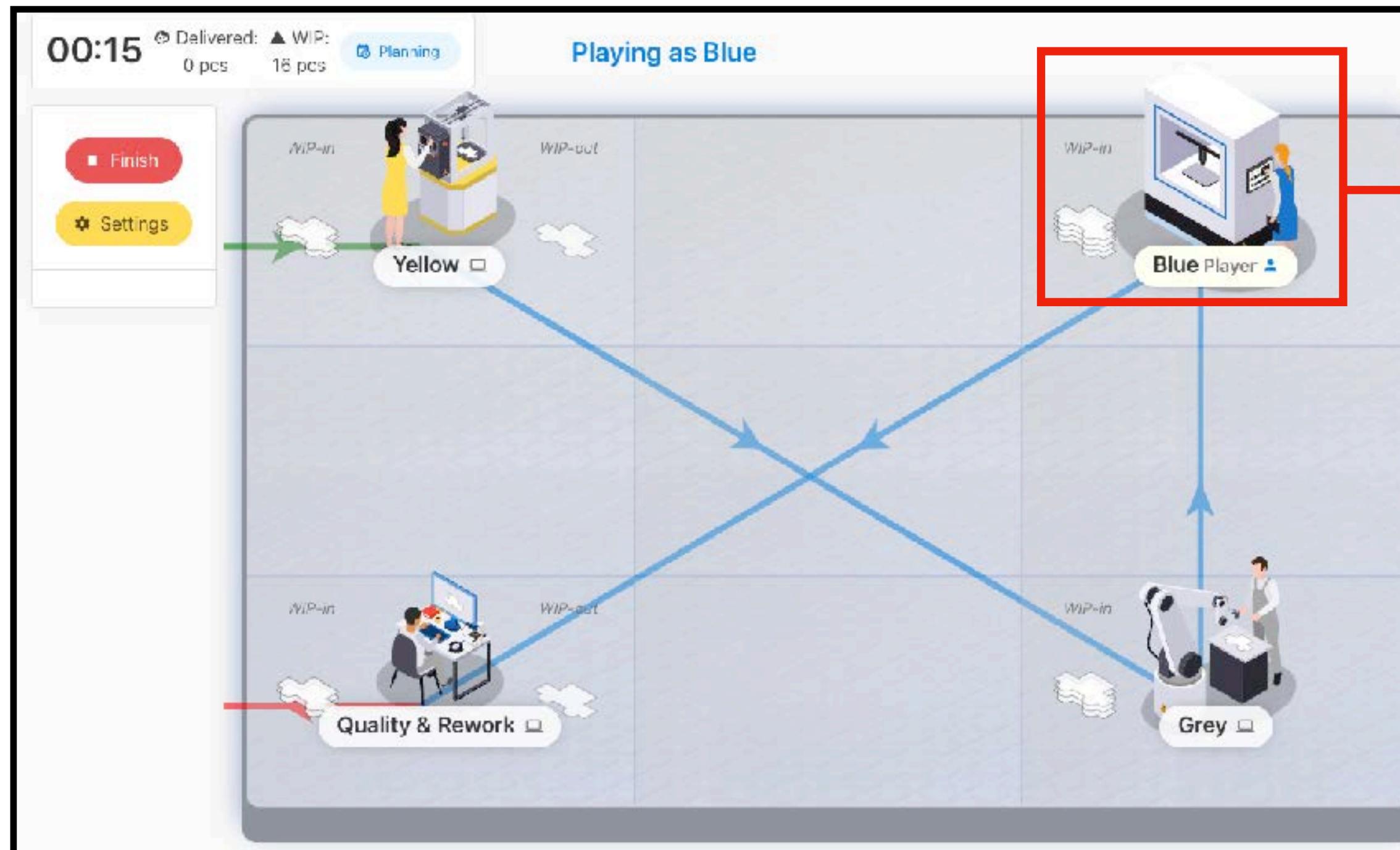


Manufacturing Systems IV

Modeling Transfer Lines in MATLAB

2

Lean Game



Quality & Rework: can change to any tool, any color, and can remove paint

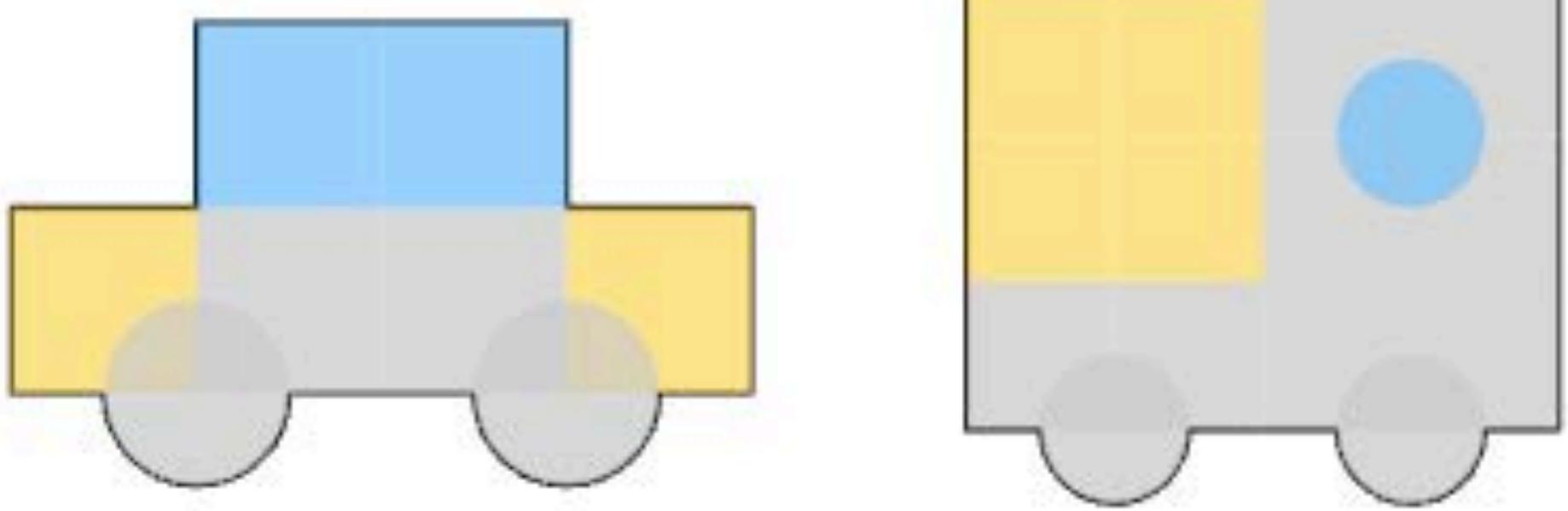
Manufacturing Systems III

System Design and Simulation #2: Lean Game

3

Agenda

1. play [Round 1](#) - Basic Factory (communication encouraged!)
2. understand the results by following the Challenge packet
3. play [Round 2](#) - four “Lean” improvements automatically implemented
4. play [Round 3](#) - all (four more) “Lean” improvements automatically implemented



Move Stations: allows you to reorganize the station locations in the workshop

Reduce Batch Size: change the required number of units in a batch

Auto-inspect Work (Jidoka): any/all stations will be able to remove the paint dots after placing them

Balance Workload: any/all stations can be configured to allow for tool changing, not just Quality & Rework

Level Production Plan (Heijunka): change the production schedule to make it more even

Add Click-guides to Reduce Defects (Poka-yoke): guides will help you choose where to click to make painting easier

Kanban (Pull System): pieces will automatically move to the next station

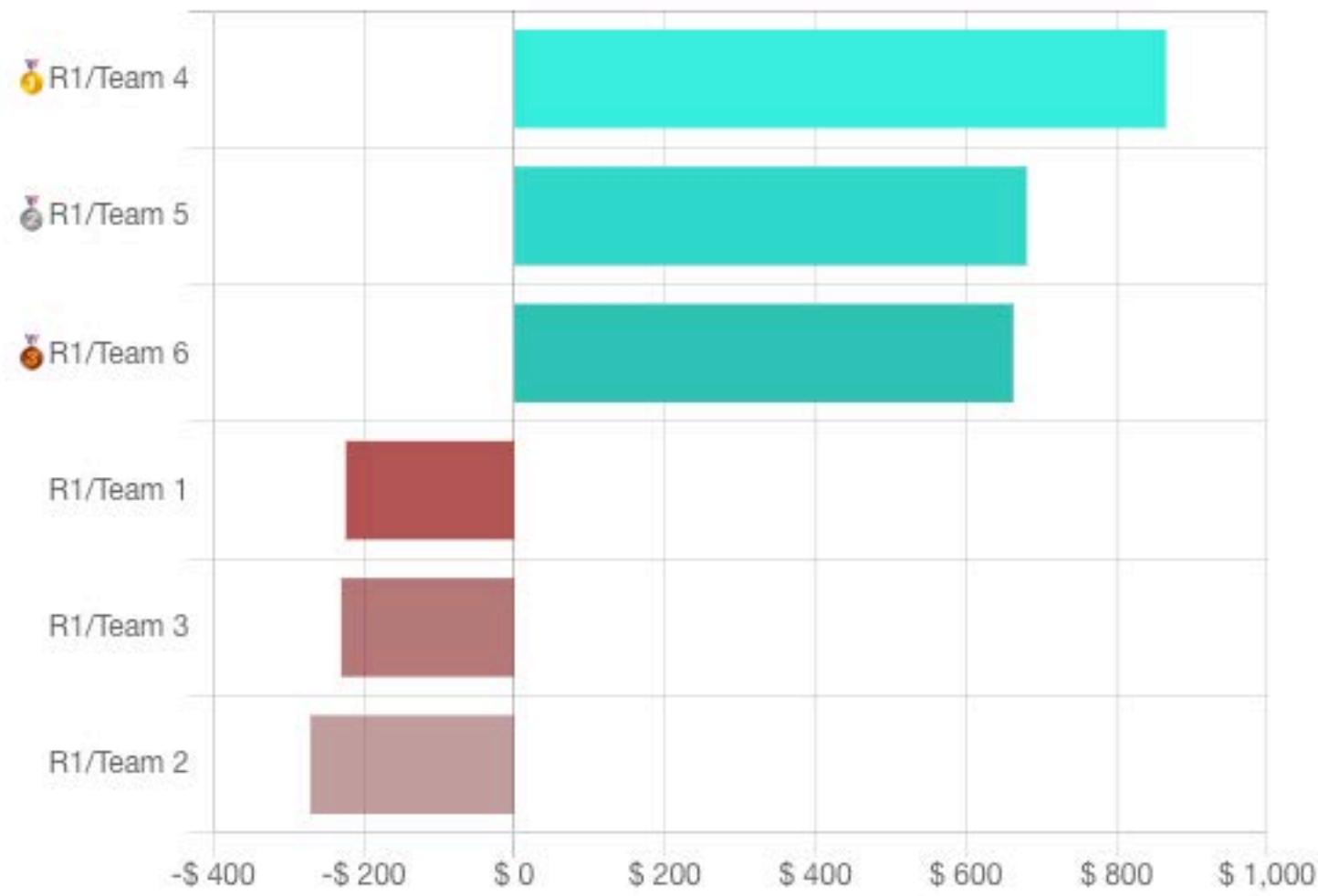
Reduce Tool-changeover Time (SMED): tool changeover times happen faster

Manufacturing Systems IV

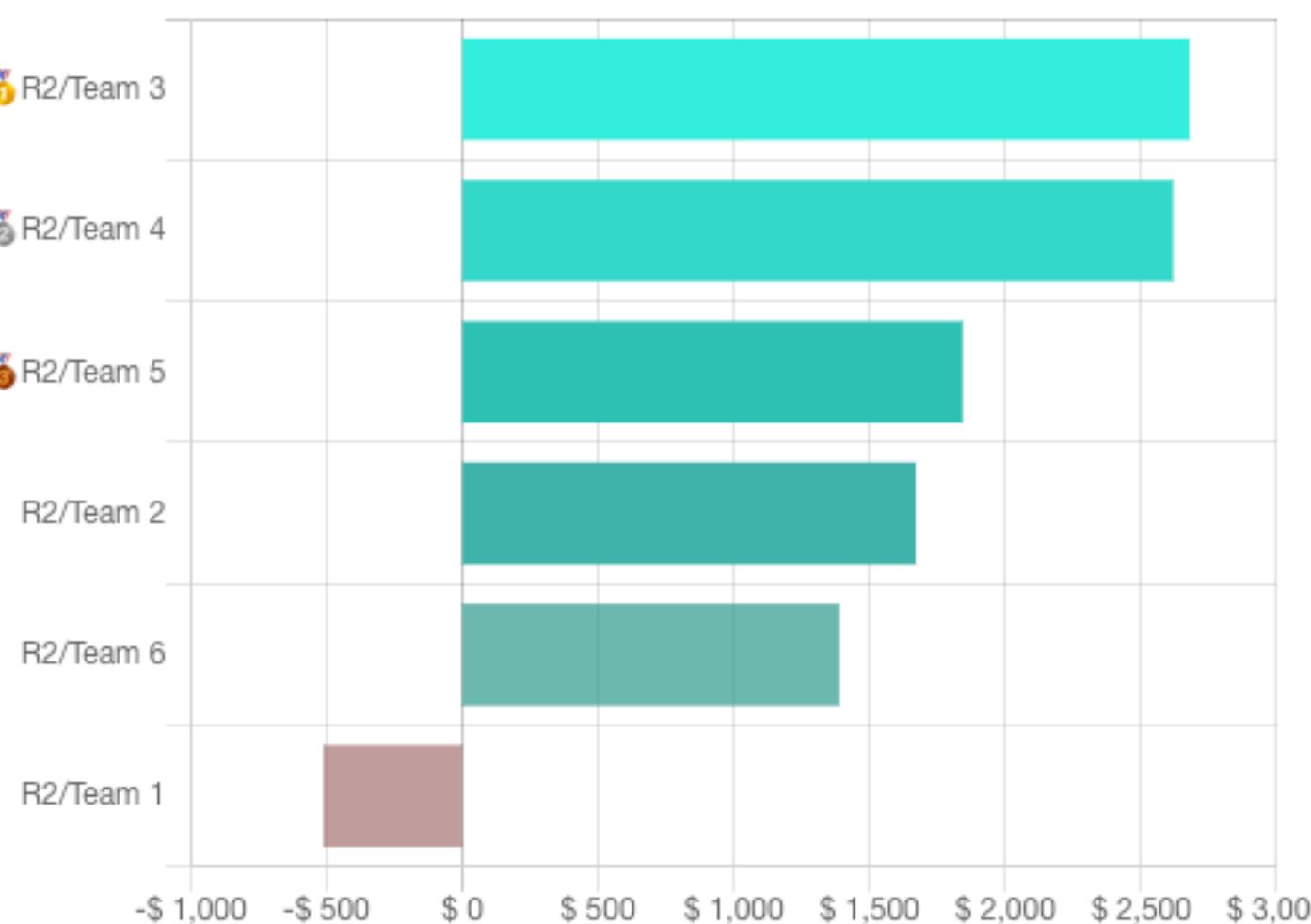
Modeling Transfer Lines in MATLAB

Lean Game Results

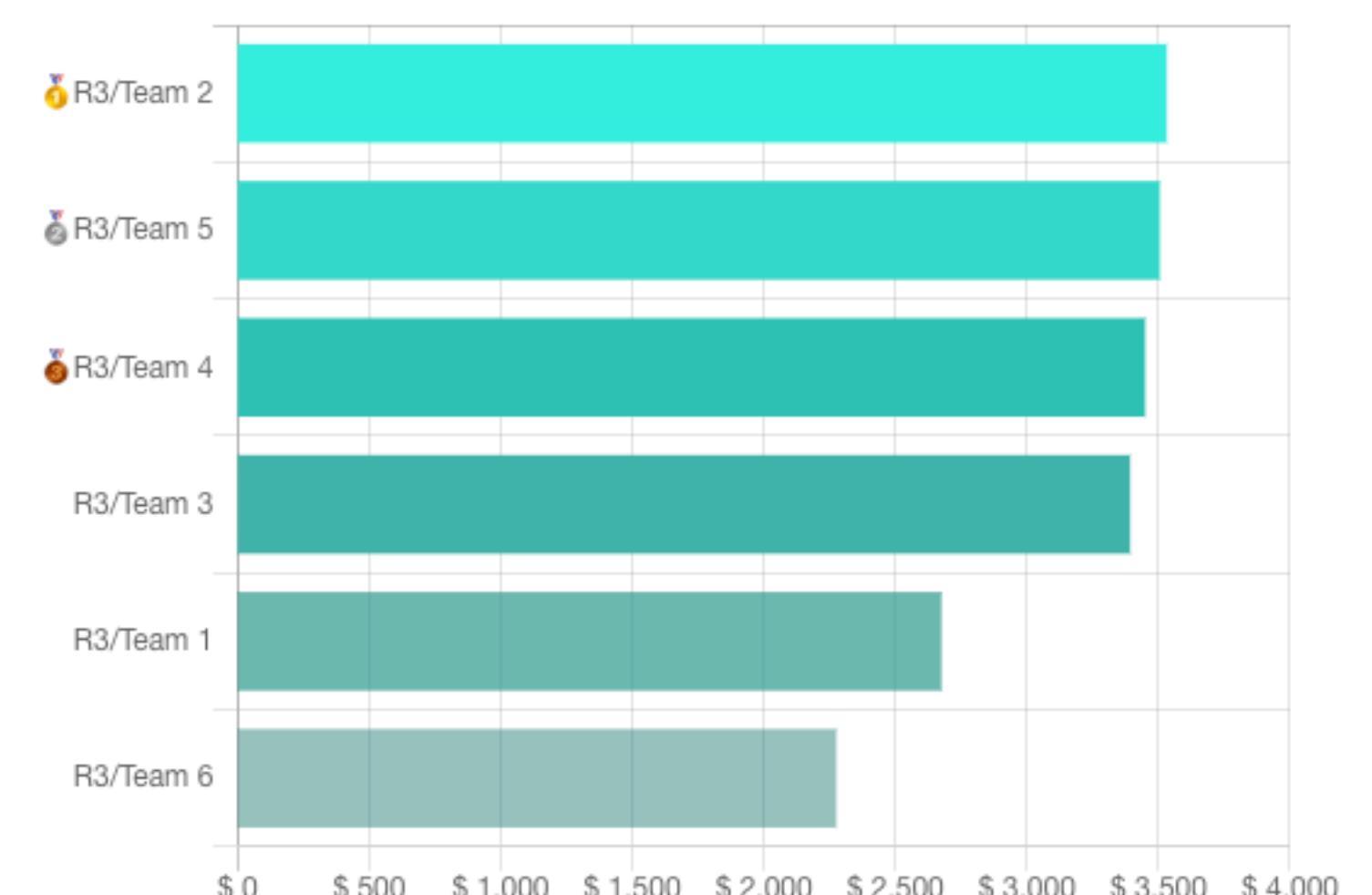
Round 1



Round 2



Round 3



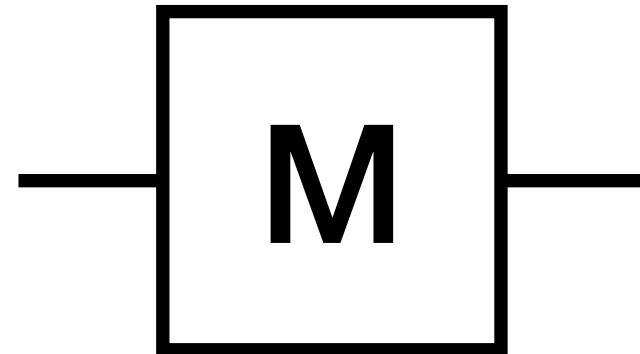
Manufacturing Systems II

System Considerations: Layouts and Production Rates

Production Rates

Case I

- one machine
- everything works



operation time = τ time/part

production rate = $\frac{1}{\tau}$ parts/time

Disruptions/Random Events

- machine failure
- operator absence
- starvation/blockage
- set-up change
- demand change

Manufacturing Systems II

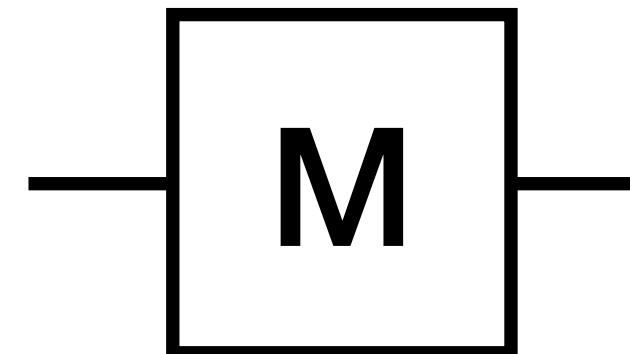
System Considerations: Layouts and Production Rates

6

Production Rates

Case II

- one machine **that can break down**
- everything else works



MTTF: Mean Time to Failure (Uptime)

MTTR: Mean Time to Repair (Downtime)

$$\text{efficiency} = \frac{\text{Uptime}}{\text{Total Time}} = \frac{\text{MTTF}}{\text{MTTF} + \text{MTTR}} \text{ %, utilization}$$

$$\text{operation time} = \tau \text{ time/part}$$

$$\text{production rate} = \frac{\text{efficiency}}{\text{operation time}} = \frac{1}{\tau} * \frac{\text{MTTF}}{\text{MTTR} + \text{MTTF}} \text{ parts/time (avg)}$$

Manufacturing Systems II

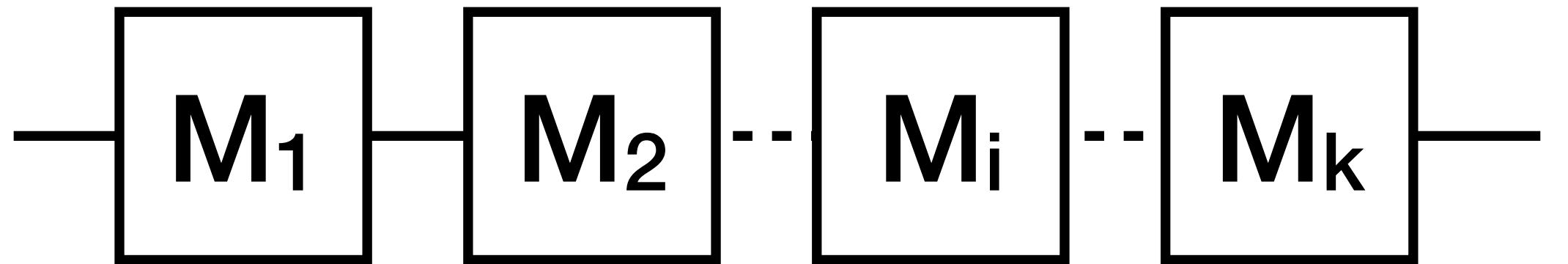
System Considerations: Layouts and Production Rates

7

Production Rates

Case III

- multiple machines (same operation time)
- everything works
- no buffers



operation time = τ time/part

$$\text{production rate} = \frac{1}{\tau} \text{ parts/time}$$

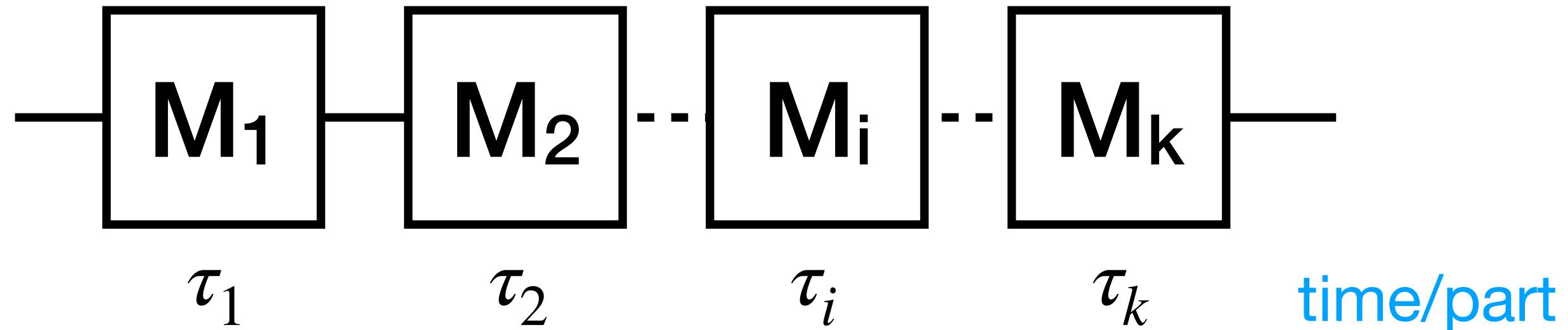
Manufacturing Systems II

System Considerations: Layouts and Production Rates

Production Rates

Case IV

- multiple machines (different operation times)
- everything works
- no buffers



dictated by the bottleneck

operation time = τ_i time/part

production rate = $\frac{1}{\tau_{max}}$ parts/time

Manufacturing Systems II

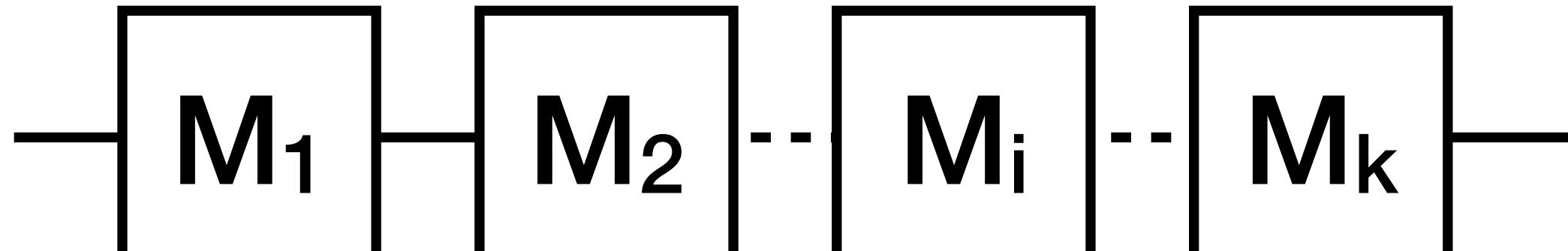
System Considerations: Layouts and Production Rates

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Production Rates

Case V

- machines **that can break down**
- everything else works
- no buffers



operation time = τ time/part

Assumption: ODF (Operation-Dependent Failure),
cannot fail while staved/blocked

MTTF: Mean Time to Failure (Uptime)

MTTR: Mean Time to Repair (Downtime)

$$\text{efficiency} = \frac{\text{Uptime}}{\text{Total Time}} = \frac{\text{MTTF}}{\text{MTTF} + \text{MTTR}}$$

combine **efficiencies** for all machines
to create one “effective” machine to
get the **average production rate**

can still calculate “on paper”

Manufacturing Systems II

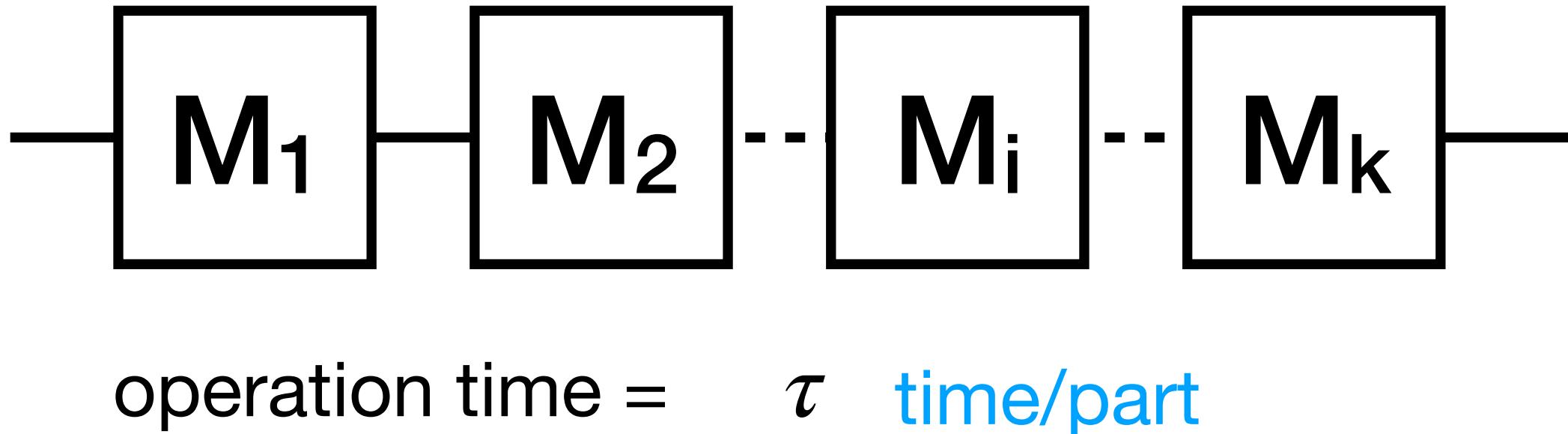
System Considerations: Layouts and Production Rates

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Production Rates

Case V

- machines **that can break down**
- everything else works
- no buffers



operation time = τ time/part

Assumption: ODF (Operation-Dependent Failure),
cannot fail while staved/blocked

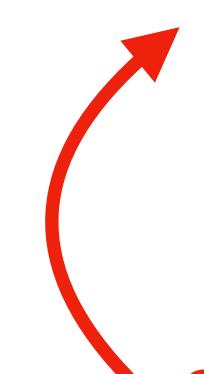
MTTF: Mean Time to Failure (Uptime)

MTTR: Mean Time to Repair (Downtime)

$$\text{efficiency} = \frac{\text{Uptime}}{\text{Total Time}} = \frac{\text{MTTF}}{\text{MTTF} + \text{MTTR}}$$

Buzacott's Zero-Buffer Line Formula

$$\text{average production rate} = \frac{1}{\tau} \frac{1}{1 + \sum_{i=1}^k \frac{MTTR_i}{MTTF_i}} \text{ parts/time}$$



different operation times? $\tau \rightarrow \tau_{max}$

Manufacturing Systems II

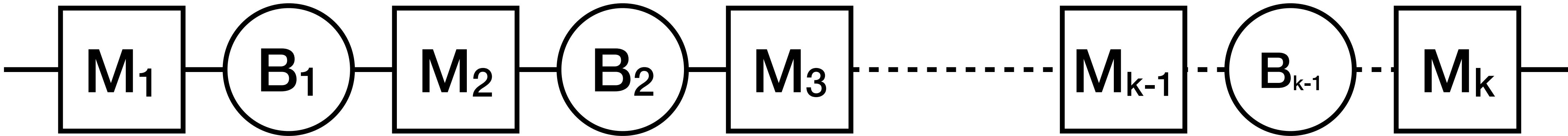
System Considerations: Layouts and Production Rates

11

Production Rates

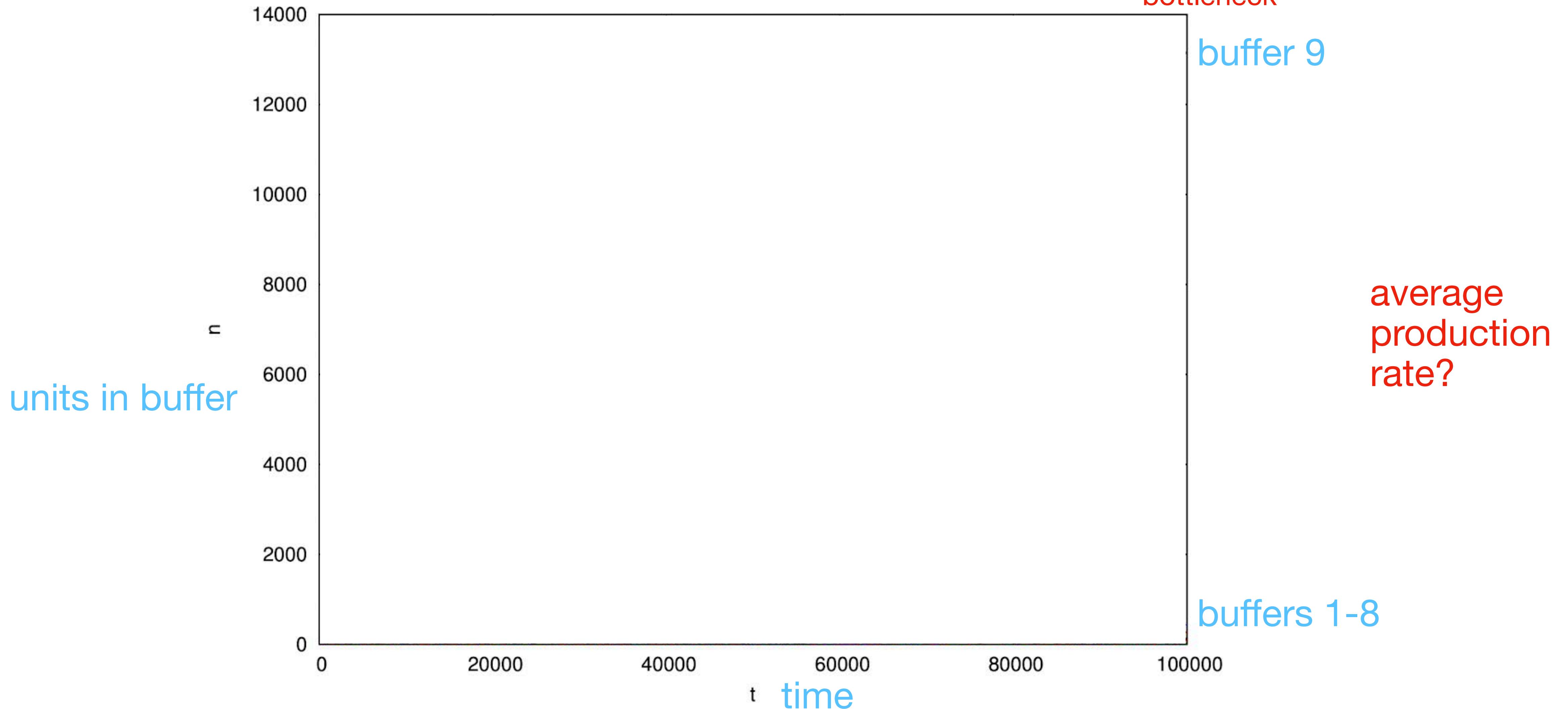
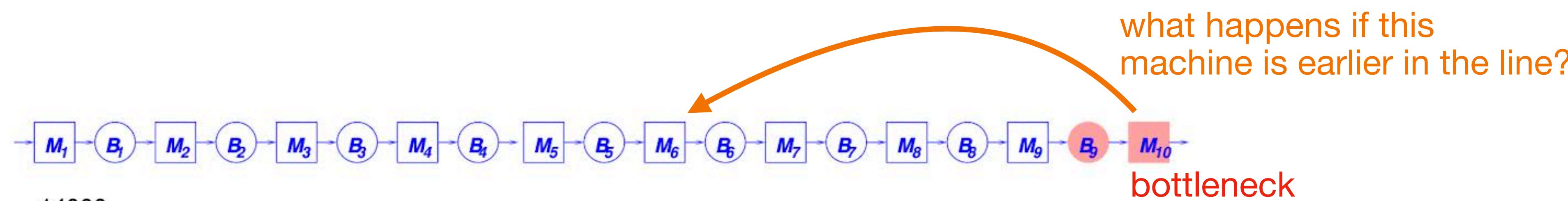
Case VI

- machines **that can break down**
- everything else works
- buffers in between machines



buffers = 0? [Case V, Buzacott's formula](#)

buffers = ∞ ?



Manufacturing Systems II

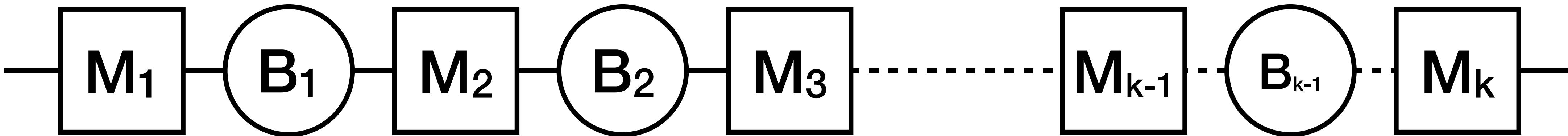
System Considerations: Layouts and Production Rates

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Production Rates

Case VI

- machines **that can break down**
- everything else works
- buffers in between machines



buffers = 0? Case V, Buzacott's formula MIN

buffers = ∞ ? production rate: bottleneck MAX

buffers = finite?

no simple formula
need computational tools

Manufacturing Systems II

System Considerations: Layouts and Production Rates

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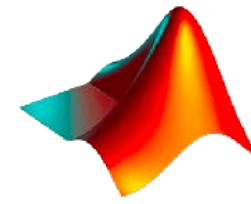
developed by Dr. Stan Gershwin

to learn more, take 2.853/2.854 or 2.854x

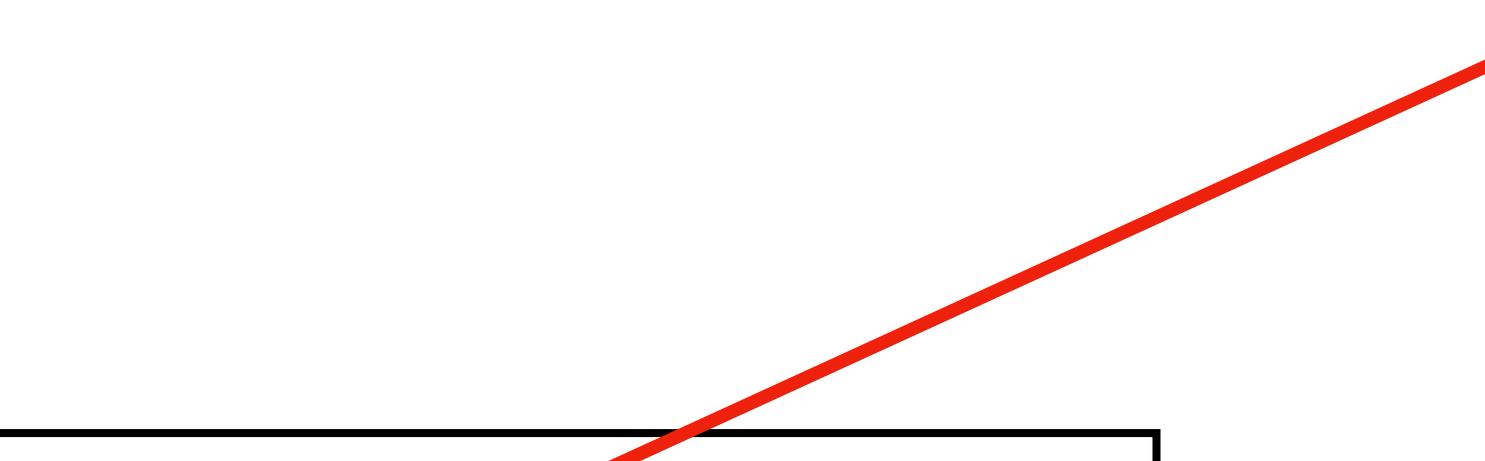
[using these tools will be on Quiz 2!](#)

Manufacturing Systems II

System Considerations: Layouts and Production Rates



MATLab Scripts in Canvas



Two-machine Line

The script below uses the values displayed for r_1 , p_1 , r_2 , p_2 , and N and calculates the rate that parts exit a two-machine, one buffer line (`prodrate`). The input and output values will be displayed in the "Output" section underneath.

All parameters are initially set to zero. Replace the zeros with more appropriate values. Leave all other text as is.

To test your values, click "Run Script". This exercise is ungraded so you do not need to click "Submit".

A plot of hypothetical profit is shown for buffer sizes of 1 to the value of N you chose. Your task is to determine the values that result in maximum profit.

Script

```
1 % Input parameters:  
2 % Change the values for r1, p1, r2, p2, and N  
3 % Click "Run Script" to calculate prodrate and nbar  
4 r1 = 0;  
5 p1 = 0;  
6 r2 = 0;  
7 p2 = 0;  
8 N = 0;  
9  
10 % Calculate deterministic processing time  
11 [prodrate,nbar] = D2Mv2(N,r1,r2,p1,p2)  
12 % Visualize hypothetical profit for all buffer sizes 1 to N  
13 % pCoeff = 10000; % Modify this value to fit the example  
14 % c = 10; % Modify this value to fit the example  
15 % viewSolution
```

Assessment:

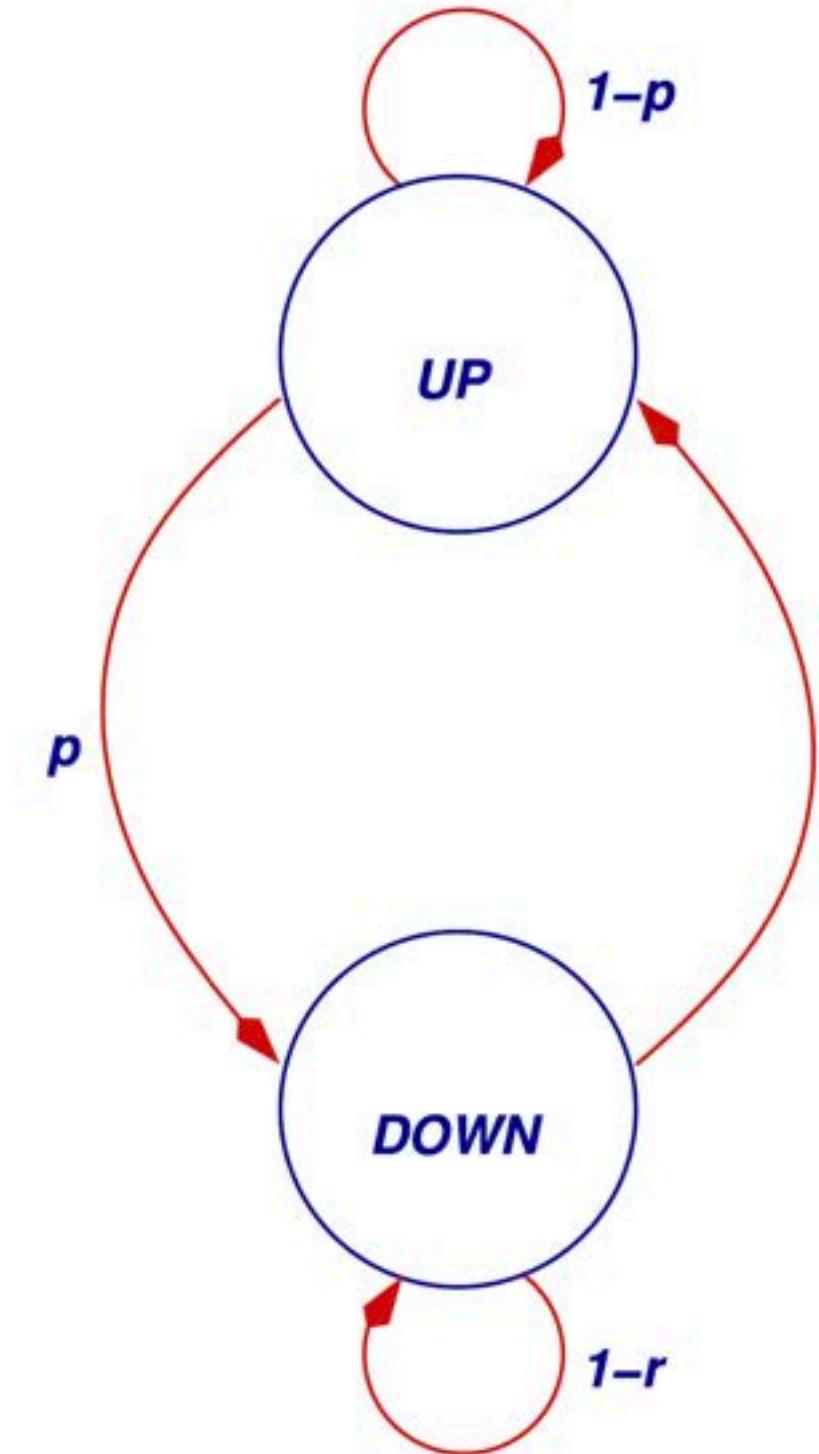
Code ran without error

Manufacturing Systems II

System Considerations: Layouts and Production Rates

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Markov Chain Representation



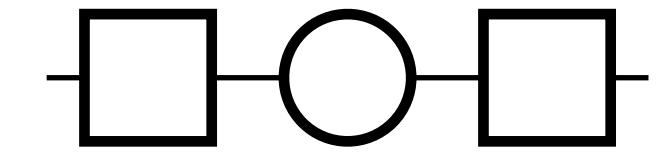
every time step is an operation time (τ)

$r = \frac{\tau}{MTTR}$	probably of repair during a time step (operation time)
$p = \frac{\tau}{MTTF}$	probability of a failure during an operation
$e = \frac{r}{r + p}$	efficiency of an effective machine
$\mu = \frac{1}{\tau}$	production rate of a reliable machine
$P = e\mu = \frac{e}{\tau}$	average production rate of an unreliable machine
$\frac{1}{\tau} * \frac{1}{1 + \sum_{i=1}^k \frac{p_i}{r_i}}$	Buzacott's with p and r

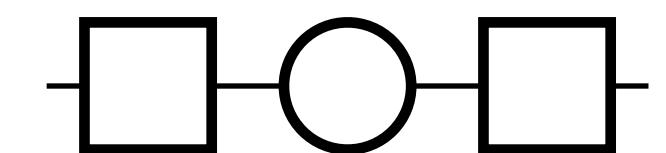
become comfortable with these definitions to fully utilize MATLAB scripts
remember τ and MTTR/MTTF are all average times

Scripts

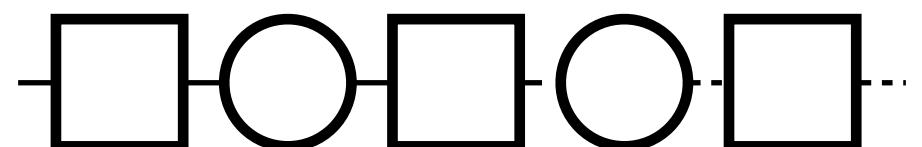
1. Deterministic Two Machine Line



2. Continuous Two Machine Line



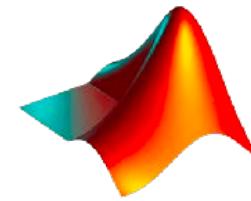
3. Long Line



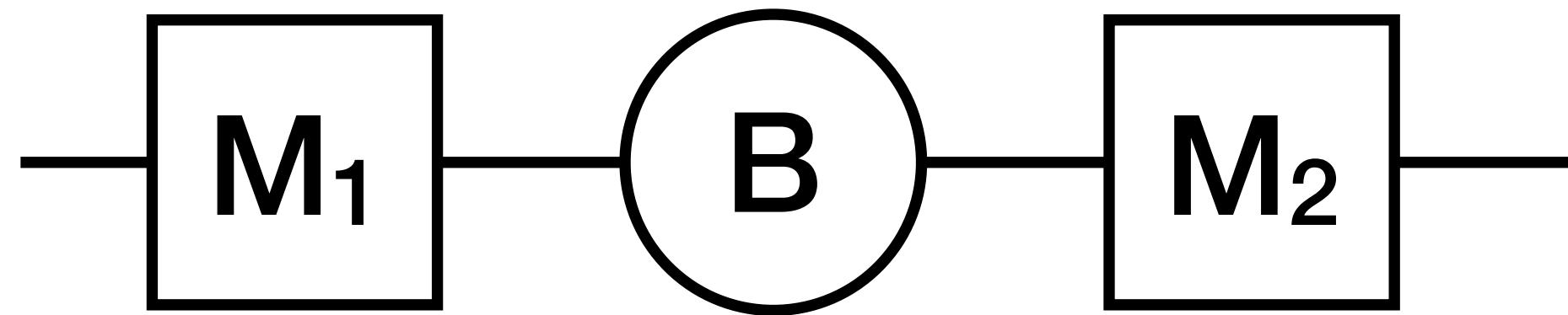
Manufacturing Systems II

System Considerations: Layouts and Production Rates

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1. Deterministic Two-Machine Line



inputs:	r_1	N	r_2
	p_1		p_2

outputs:	prodrate: average production rate	P
	nbar: average inventory in the buffer	\bar{N}

When to use? traditional, discrete per-part machines/systems
same production rate for the two machines

$$r = \frac{\tau}{MTTR} \quad \text{probably of repair during a time step (operation time)}$$

$$p = \frac{\tau}{MTTF} \quad \text{probability of a failure during an operation}$$

⚠ script assumes operation time $\tau = 1$

what if it wasn't 1?

then “prodrate” is the line efficiency

so, multiply “prodrate” by $1/\tau$ to get the equivalent production rate of the line you are analyzing

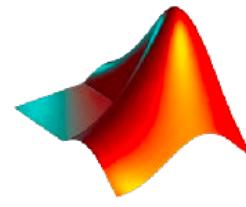
what if the two τ 's were not the same?

utilize τ of the slowest machine

Manufacturing Systems II

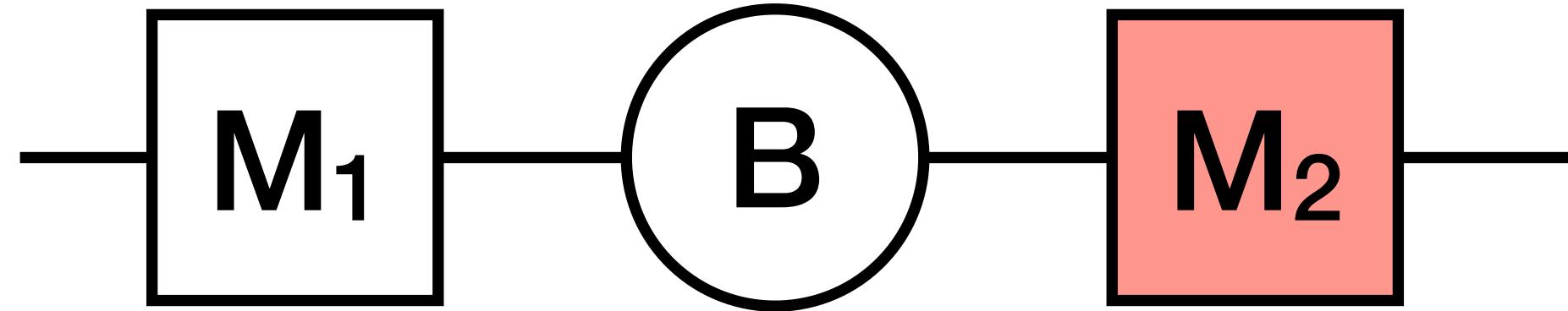
System Considerations: Layouts and Production Rates

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1. Deterministic Two-Machine Line

Example 1:

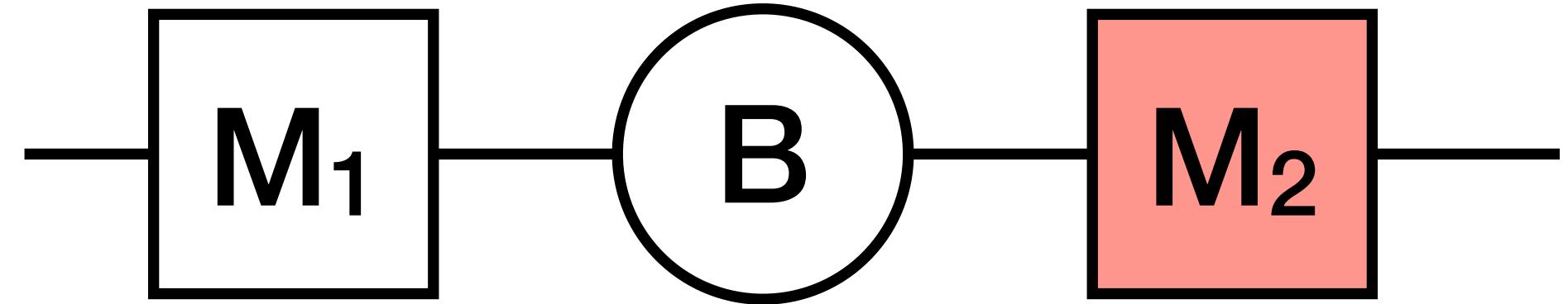


inputs:	$r_1 = 0.01$	$N = 15$	$r_2 = 0.01$
	$p_1 = 0.03$		$p_2 = 0.05$

outputs:	prodrate:	0.1247
	nbar:	9.606

⚠ remember, prodrate is always
between 0 and 1, then scale by $1/\tau$

Example 2:



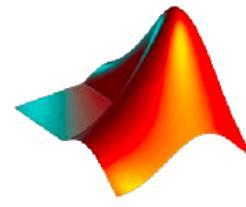
inputs:	$r_1 = 0.01$	$N = 20$	$r_2 = 0.01$
	$p_1 = 0.03$		$p_2 = 0.05$

outputs:	prodrate:	0.1285
	nbar:	12.935

Manufacturing Systems II

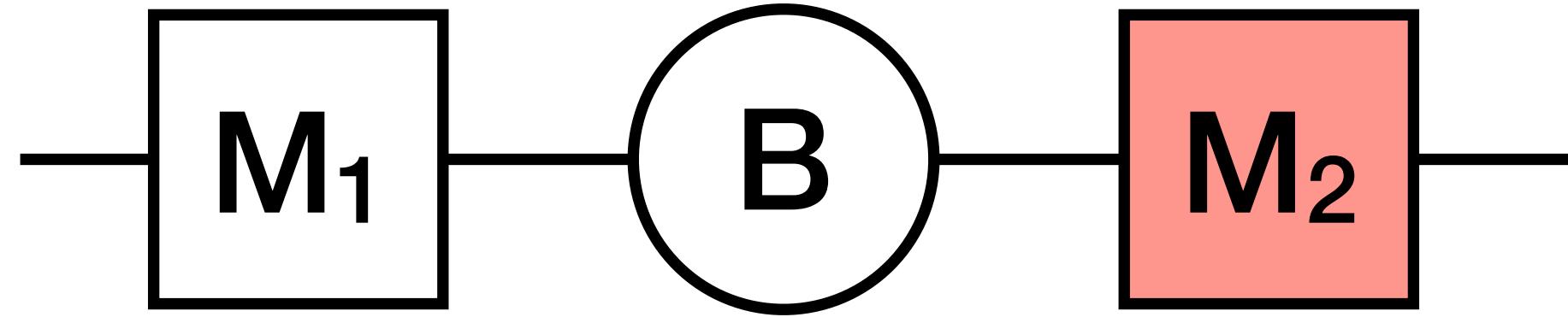
System Considerations: Layouts and Production Rates

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1. Deterministic Two-Machine Line

Example n:



inputs: $r_1 = 0.01$

$p_1 = 0.03$

$N = 4$

\downarrow
 $N = 200$

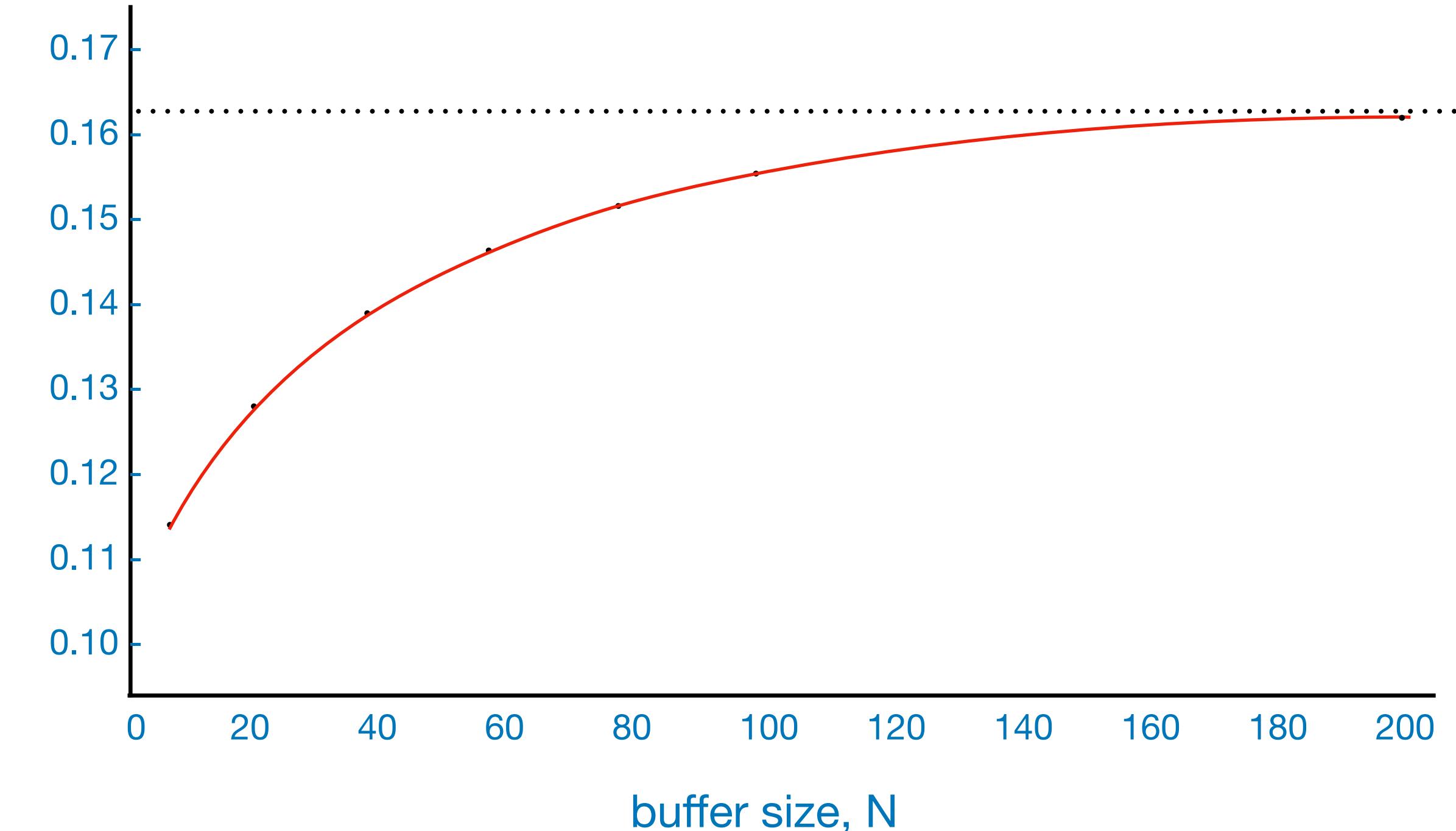
$r_2 = 0.01$

$p_2 = 0.05$

outputs: prodrate: various

nbar: various

production rate, P



Buzacott's zero buffer: 0.1111

script's $N = 4$: 0.1143

⚠ use $N = 4$ to approximate a buffer of 0

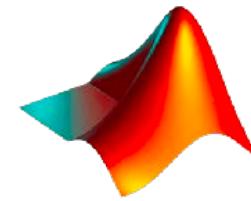
script's $N = 200$: 0.1640

script's $N = 2000$: 0.1667 $N \rightarrow \infty$

Manufacturing Systems II

System Considerations: Layouts and Production Rates

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1. Deterministic Two-Machine Line

When to use? you have revenue per part and inventory cost and you wan to see the max profit point

Cost Analysis: **uncomment lines 13, 14, and 15**

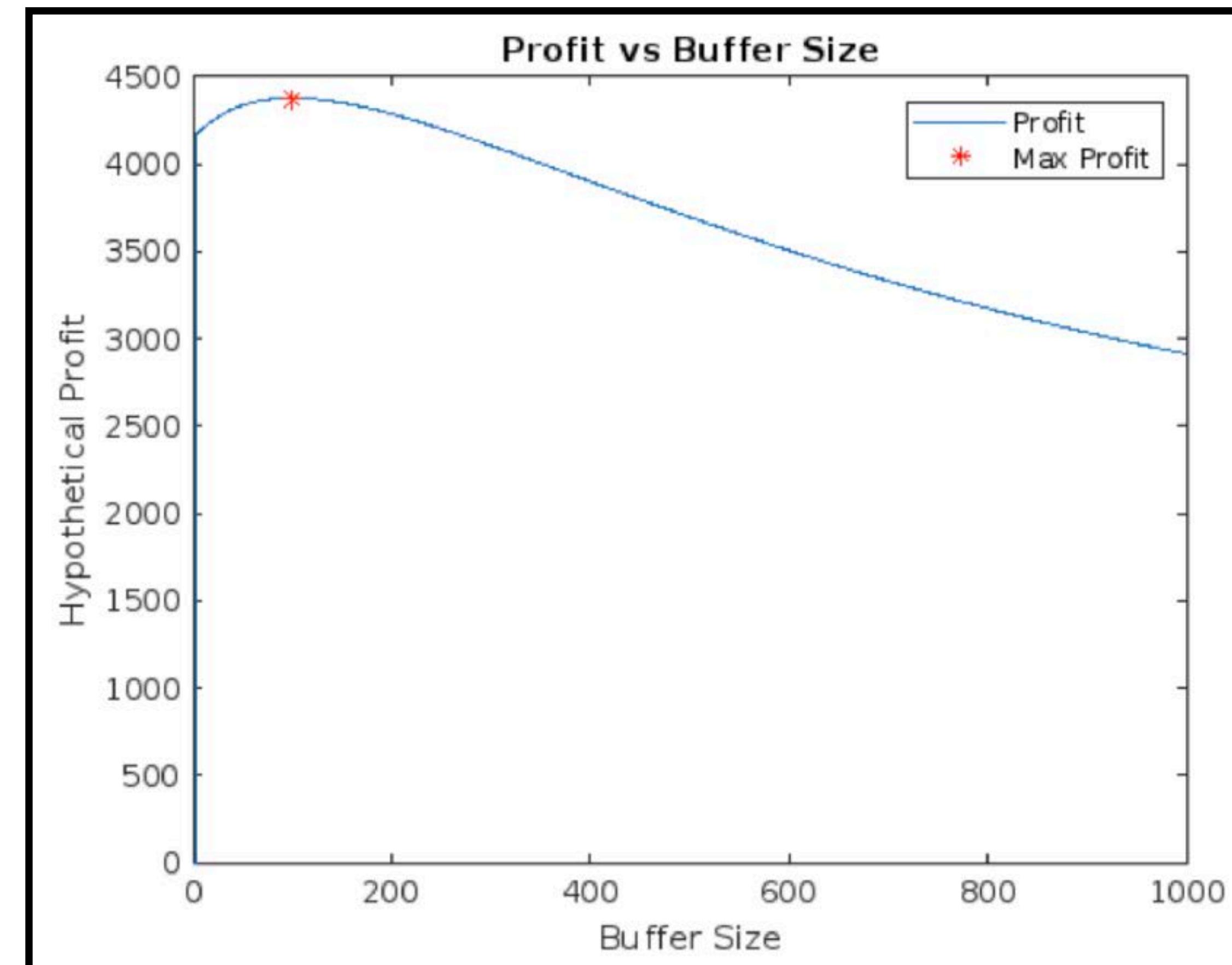
$$\text{profit} = p\text{Coeff} * \text{prodrate} - c * \text{nbar}$$

profit: \$ (per cycle)

pCoeff: revenue per part produced

c: inventory cost (per unit, per cycle)

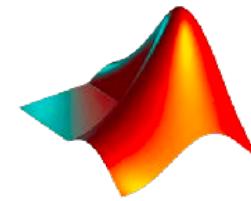
Remember that increasing buffer sizes has a diminishing return effect on production rate as well as leads to larger average buffer sizes (roughly linearly increasing)



Manufacturing Systems II

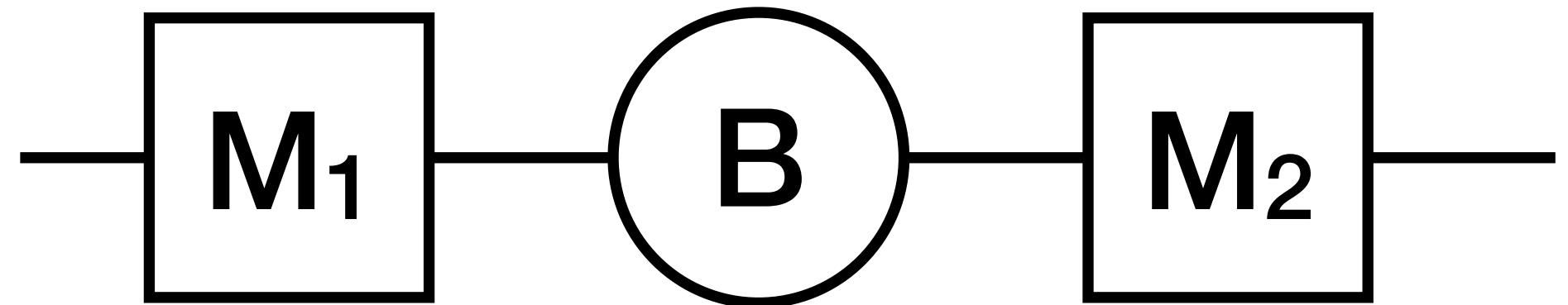
System Considerations: Layouts and Production Rates

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2. Continuous Two-Machine Line

When to use? small parts or continuous operations (chemical production)
allows for different operation rates between the two machines



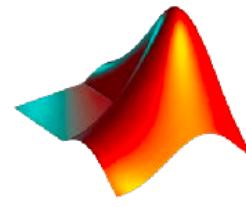
inputs:	r_1	N	r_2
	p_1		p_2
	μ_1		μ_2
outputs:	prodrate: average production rate		P
	nbar: average inventory in the buffer		\bar{N}

similar setup as Discrete Two-Machine Line,
but adds μ for each machine

Manufacturing Systems II

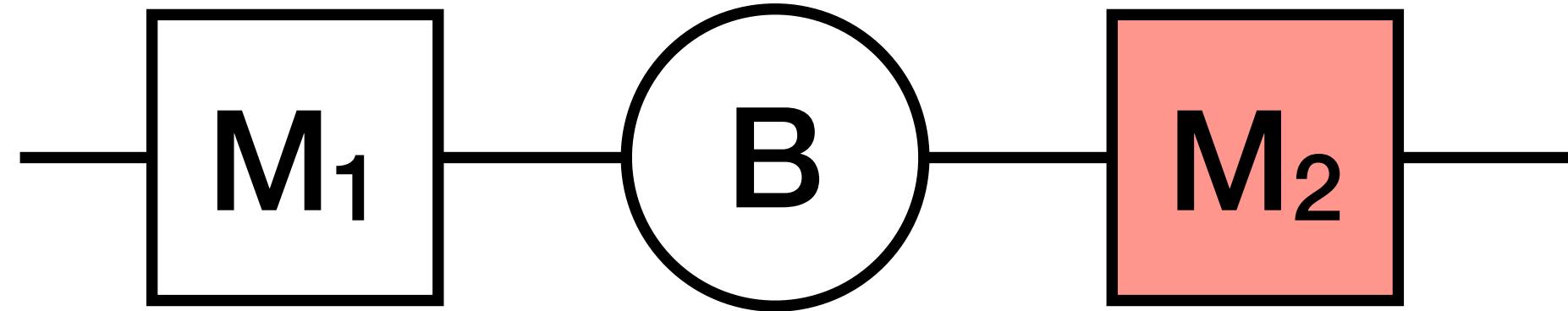
System Considerations: Layouts and Production Rates

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2. Continuous Two-Machine Line

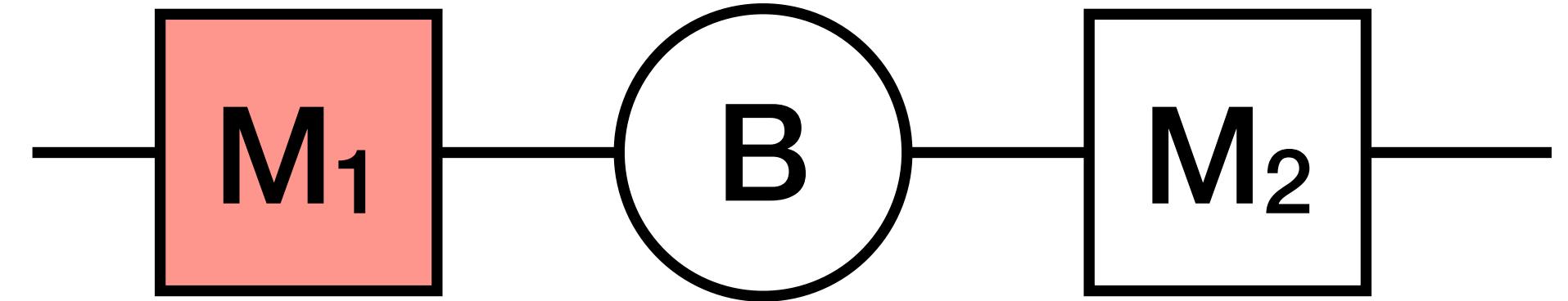
Example 1:



inputs:	$r_1 = 0.1$	$N = 8$	$r_2 = 0.1$
	$p_1 = 0.01$		$p_2 = 0.01$
	$\mu_1 = 1.5$		$\mu_2 = 1.3$

outputs:	prodrate:	1.1310
	nbar:	6.85

Example 2 (switch machines):



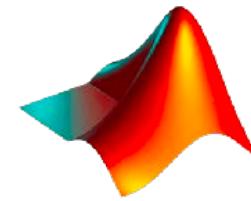
inputs:	$r_1 = 0.1$	$N = 8$	$r_2 = 0.1$
	$p_1 = 0.01$		$p_2 = 0.01$
	$\mu_1 = 1.3$		$\mu_2 = 1.5$

outputs:	prodrate:	1.1310 (same)
	nbar:	1.15 (inverse: 8 - 6.85)

Manufacturing Systems II

System Considerations: Layouts and Production Rates

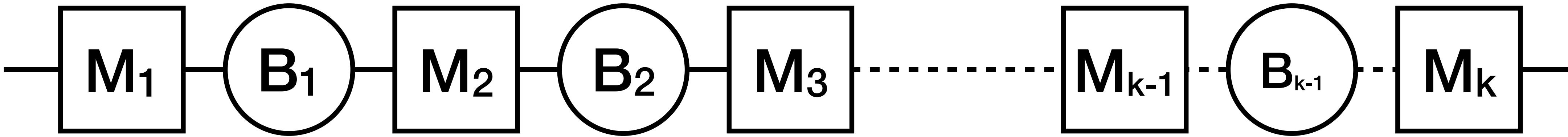
23



3. Long Line

When to use? more than 2 machines, buffers included, simplified if possible

note: effectively iterates through discrete 2-machine scenarios



⚠ input parameters are different!

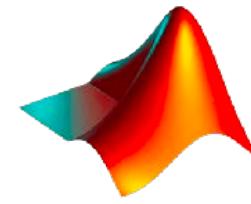
inputs:
k: scalar number of machines in the line
r: array of repair probabilities
p: array of failure probabilities
N: array of max buffer sizes

outputs:
prodrate: average production rate P
nbar: average inventory in the buffer \bar{N}

Manufacturing Systems II

System Considerations: Layouts and Production Rates

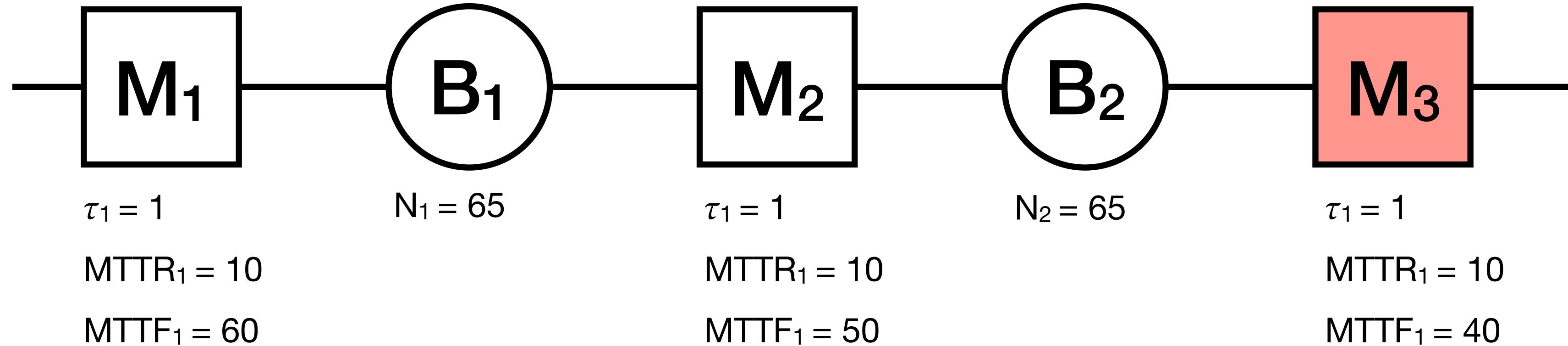
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3. Long Line

When to use? more than 2 machines, buffers included, simplified if possible
note: effectively iterates through discrete 2-machine scenarios

Example 1:



inputs:

```
k = 3
r = [0.1 0.1 0.1]
p = [0.0167 0.02 0.025]
N = [65 65]
```

outputs:

```
prodrate: 0.0782
nbar: [47.2253 38.4660]
```

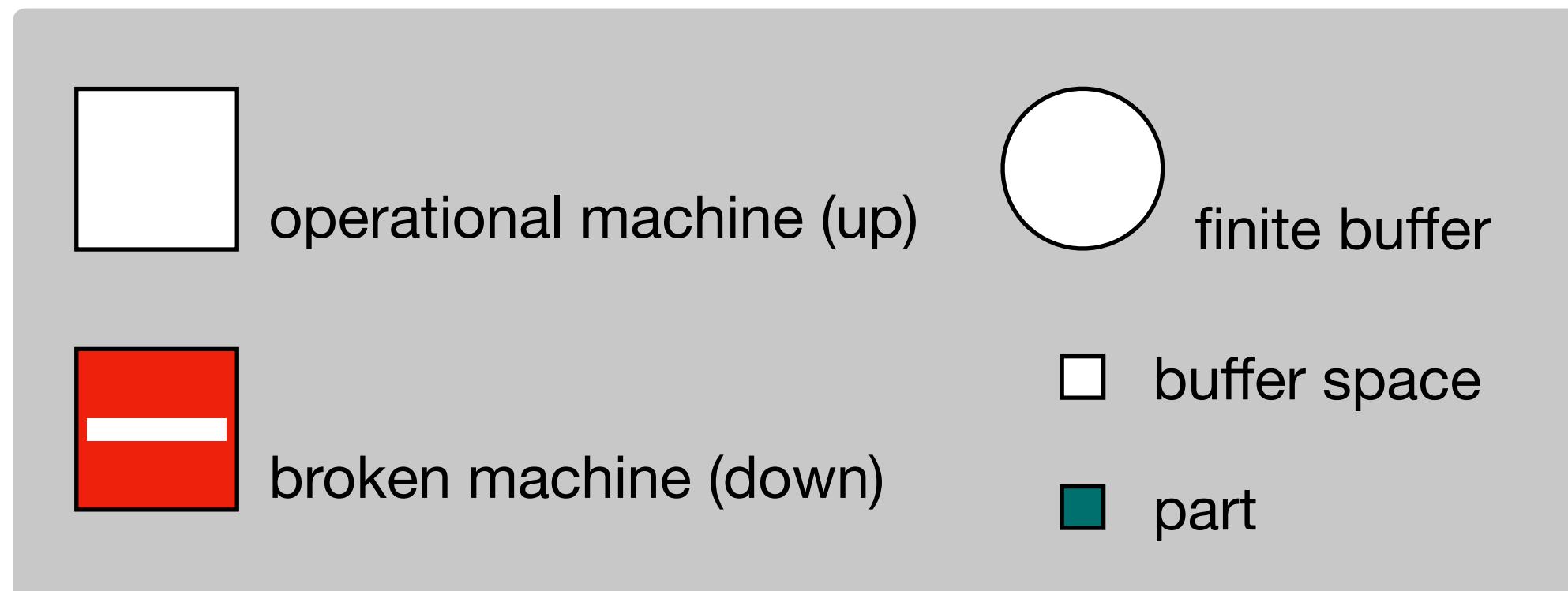
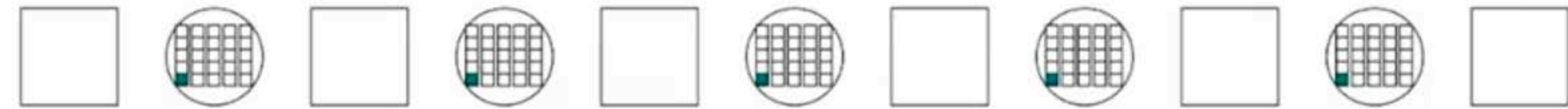
Script Note:
Zero-Buffer: $N = 4$
Infinite Buffer: $N = 10,000$

Manufacturing Systems II

System Considerations: Layouts and Production Rates

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System Intuition

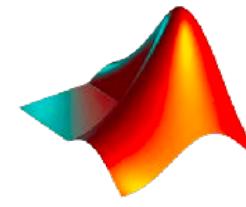


how long does it take one to get through the entire system (on average)?

Manufacturing Systems II

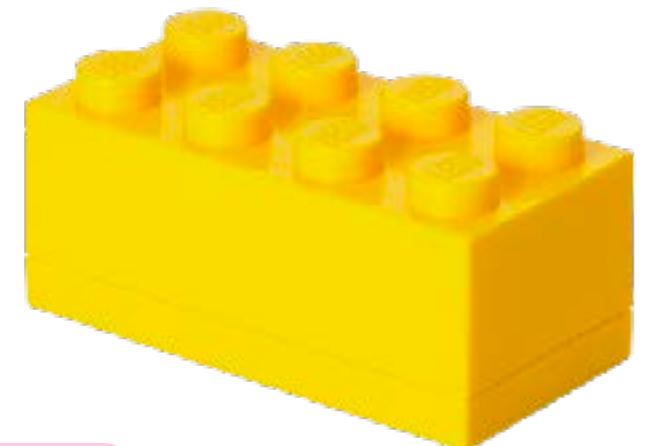
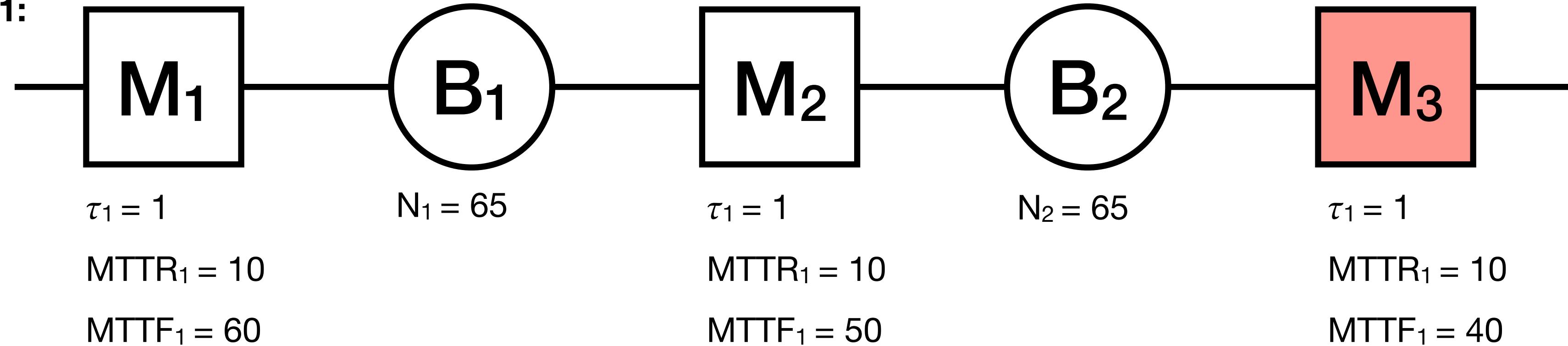
System Considerations: Layouts and Production Rates

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3. Long Line: Little's Law

Example 1:



inputs: $k = 3$
 $r = [0.1 \ 0.1 \ 0.1]$
 $p = [0.0167 \ 0.02 \ 0.025]$
 $N = [65 \ 65]$

outputs: prodrate: 0.0783
nbar: [47.2253 38.4660]

Little's Law Calculation

$$L = \lambda w \rightarrow w = \frac{L}{\lambda}$$

L: total inventory levels
 λ : system production rate
w: total waiting time (time for one part to get through the full system)

$$w = \frac{(1 + 47.2 + 1 + 38.4 + 1)}{0.0783}$$

$$w = 1132 \text{ [minutes]}$$

■ time for the square to travel through the whole system

Manufacturing Systems II

System Considerations: Layouts and Production Rates

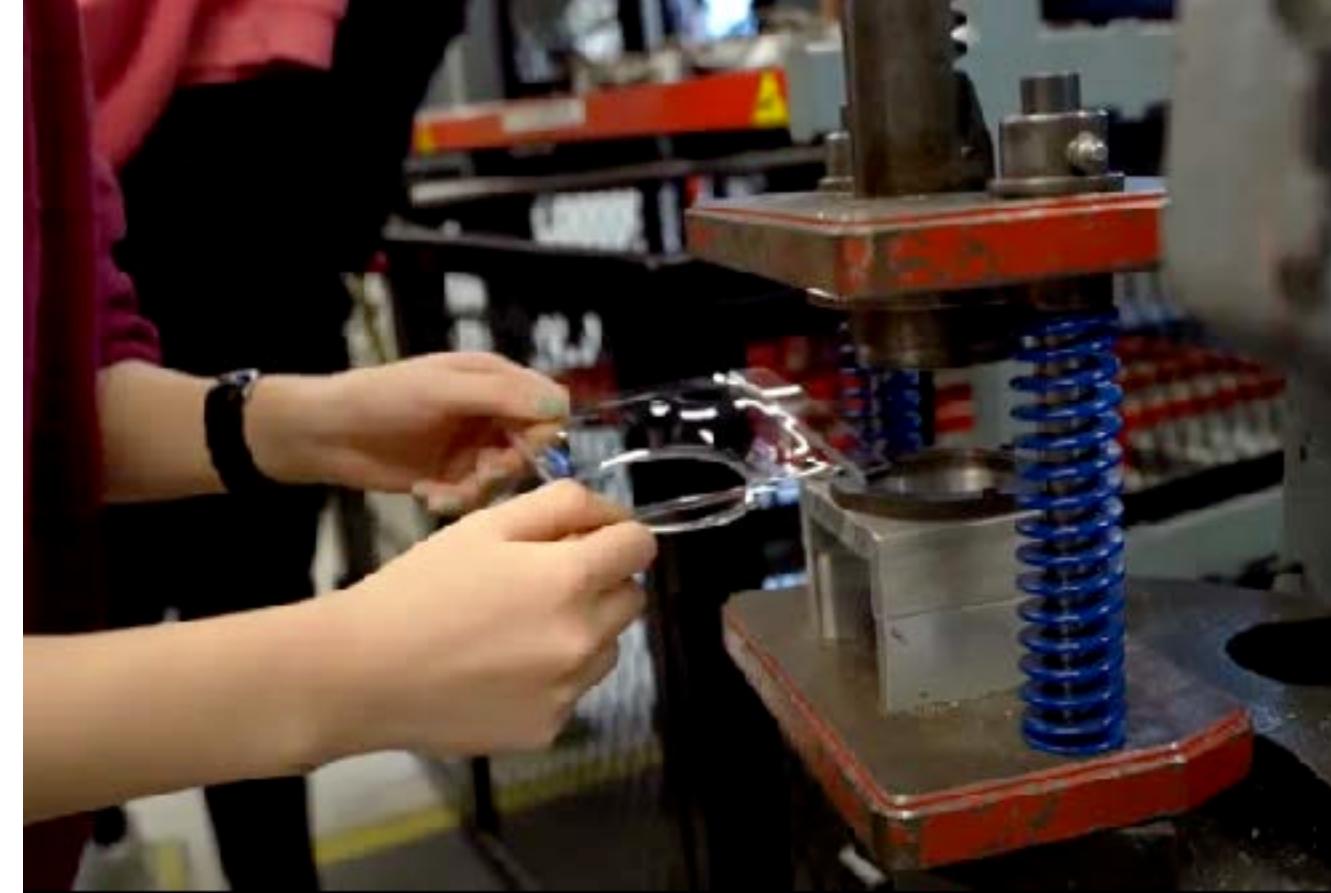
Practice Scenario How would you model a yo-yo production line?

MTTR = ?

MTTF = ?

M

$\tau = ?$



B

$N = ?$



Manufacturing Systems II

System Considerations: Layouts and Production Rates

Yo-yo Production Line

LA: Emma Higgason

A	B	C	D	E	F	G	H	I
One Time Actions:	Time (minutes)							
IM:								
change out old color	10							
add in new color	3							
install mold into MUD insert	10							
fine tune settings (right after loading in mold)	10							
Unload MUD insert	5							
Thermoforming:								
clean + set up + print 15 sheets in Mimaki	15							
set up punch + die	5							
load in mold into thermoformer	3							
fine tune laser placement	5							
General								
Clean up time!	10							
Repeat Actions:	Parts	Time (minutes)	Rate (parts/min)					
IM:								
manually IM bases w/ shoulder bolts	60	30	2					
auto IM caps	5	3	1.7					
Thermoforming:								
pull thermoforms	50	60	0.8					
punch thermoforms	2	1	2					

RULES:

- We get the Mimaki + Thermoformer 1 of the 2 days so we should put 3 people on thermoforming team since that is our bottle neck
- Assuming start time at 2:05 and end time at 4:55 SHARP for both sessions
- If someone can, get to lab early and check the IM is warmed up
- When the Mimaki is done printing, we gotta be on that STAT. So maybe we use group me/text messages to let the runner know to come grab



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Yo-yo Production Line

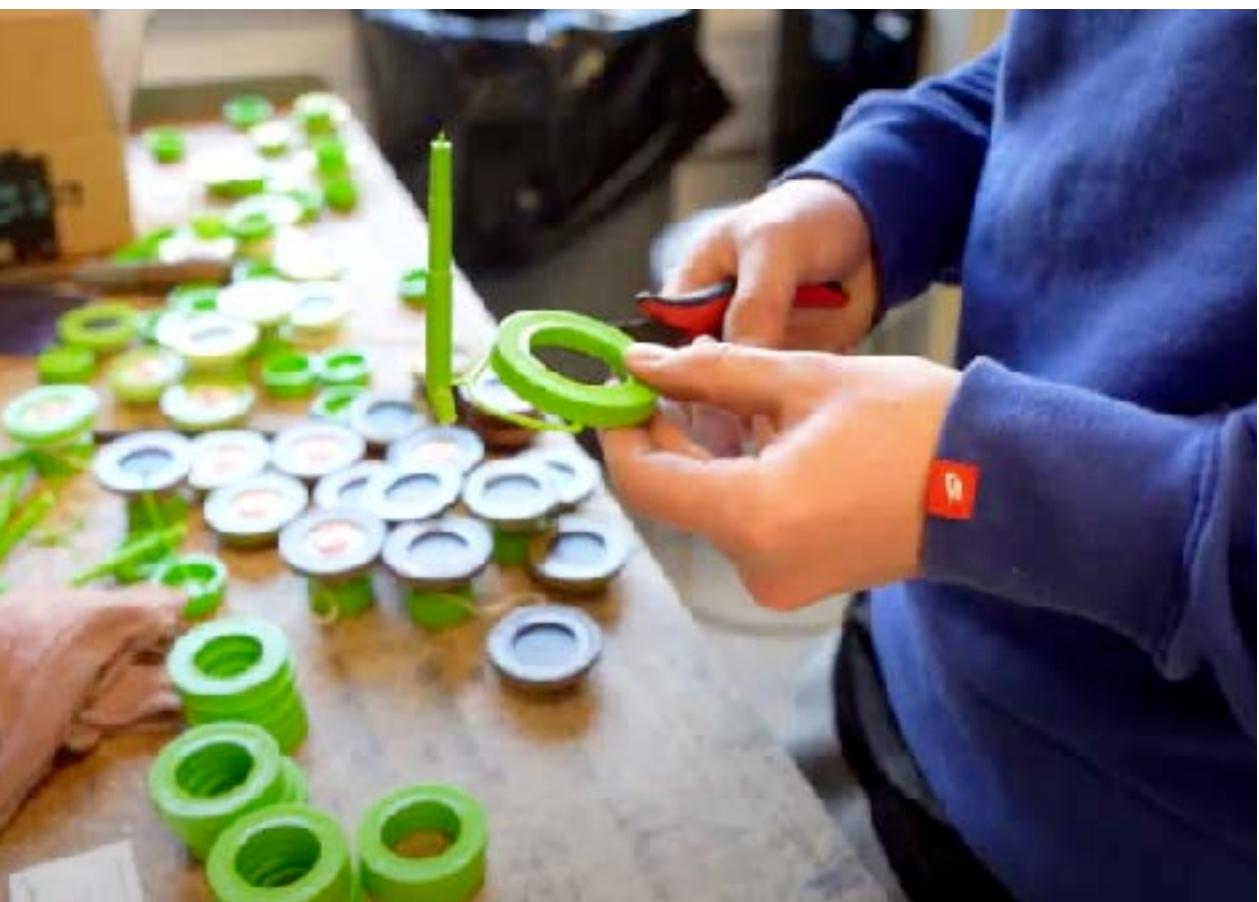
M

$$\tau = ?$$



B

$$N = ?$$



$$MTTR = ?$$

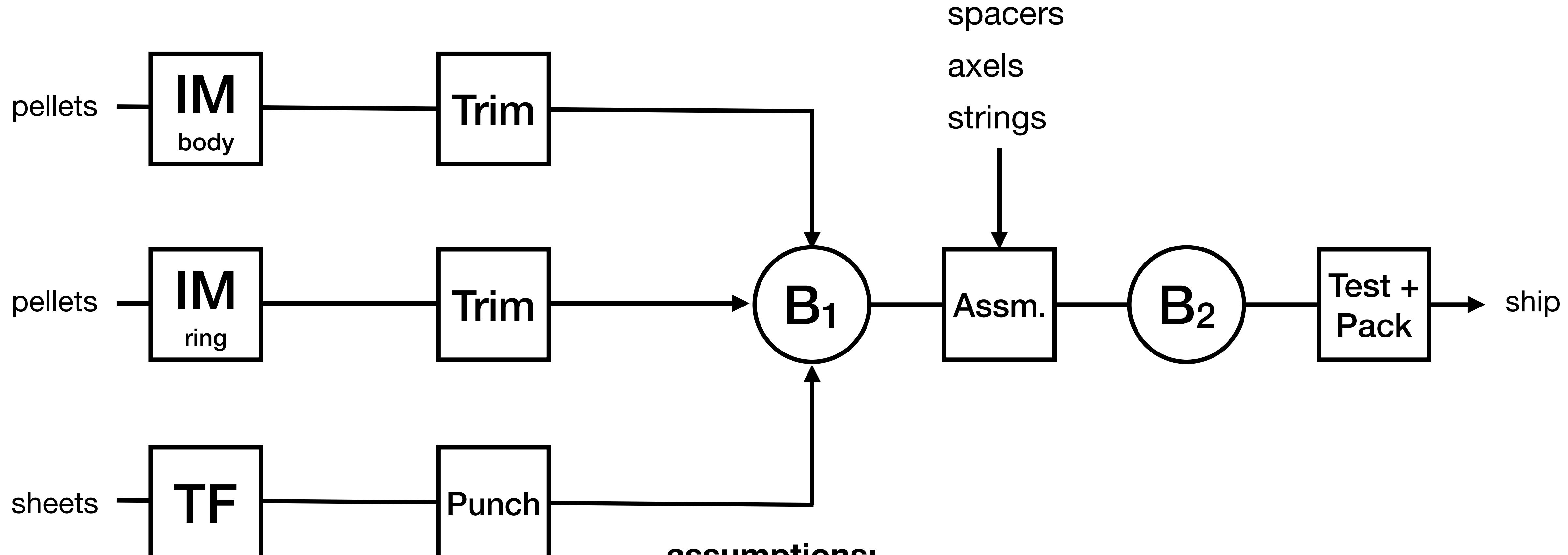
$$MTTF = ?$$

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Yo-yo Production Line



assumptions:

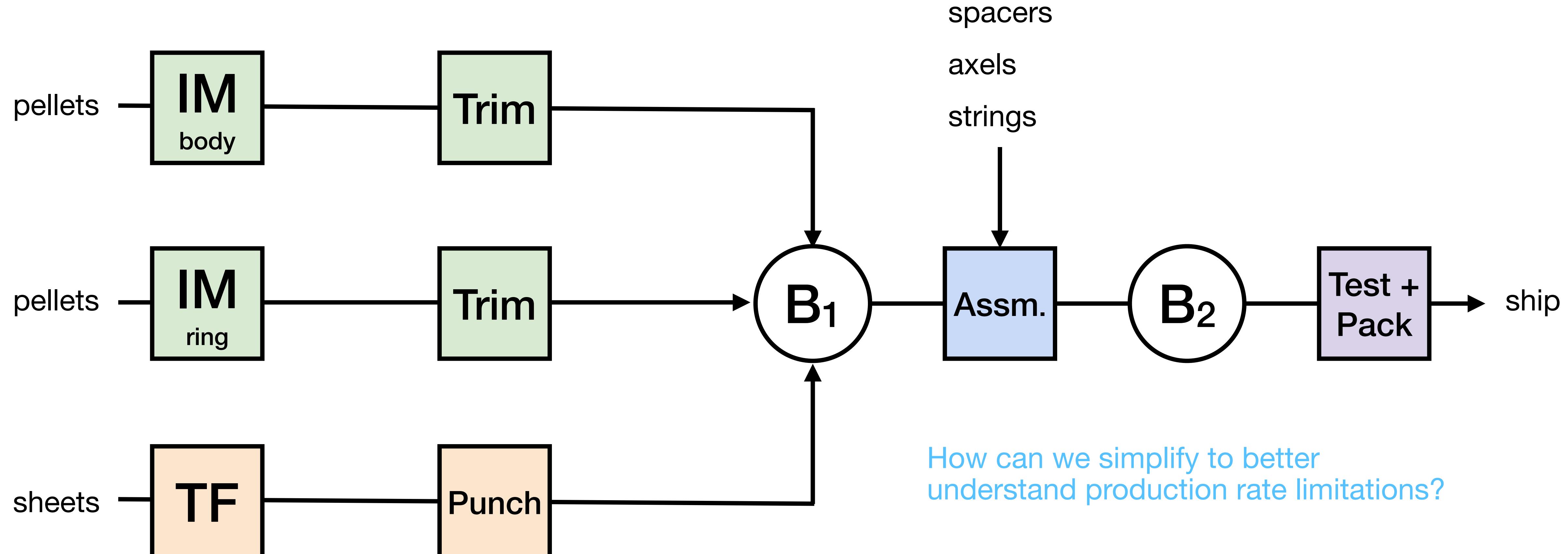
1. each IM/TF process produces 2 parts, enough for assembly

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Yo-yo Production Line

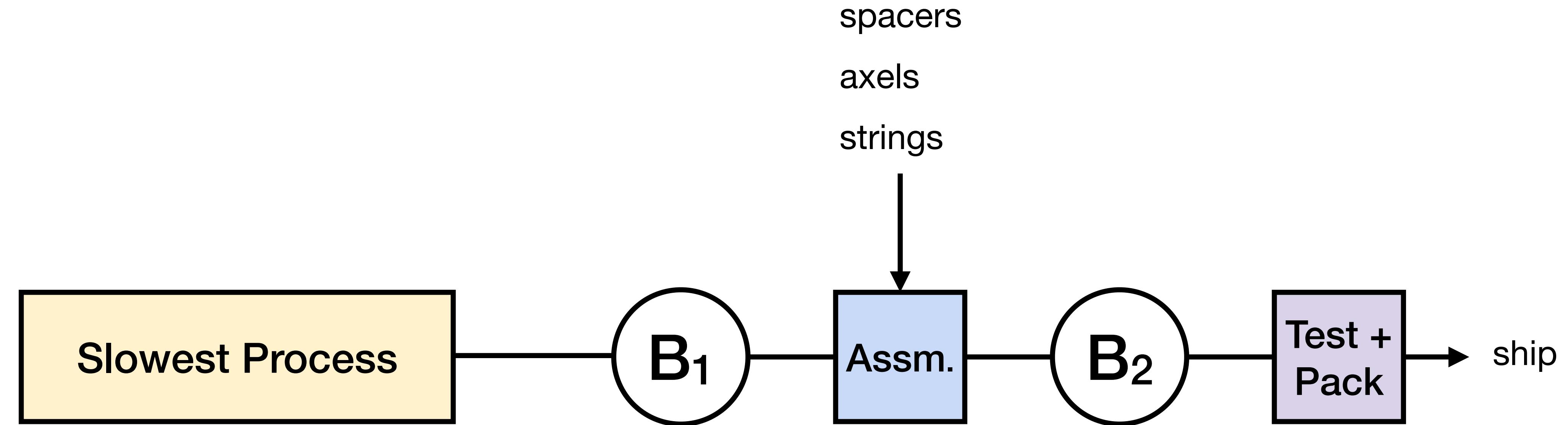


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Yo-yo Production Line



assumptions:

2. Non-slowest machines make enough mating parts
3. We can ignore the inventory from non-slowest machines

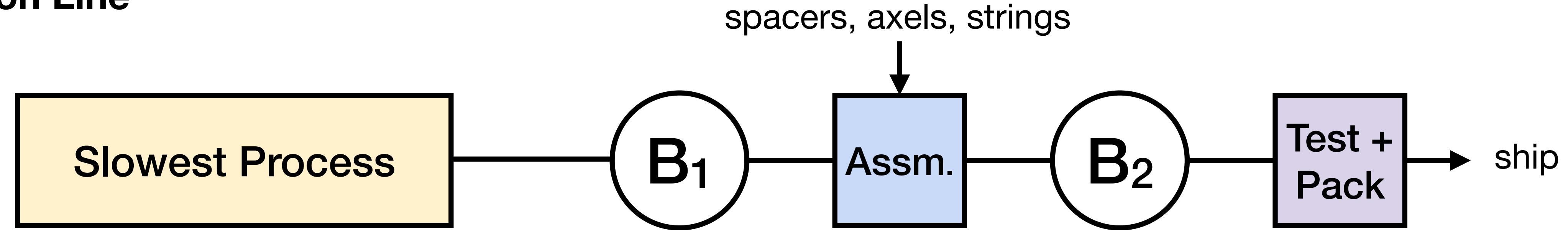
where would you place an infinite buffer, if you had one?

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Yo-yo Production Line



Questions

1. How should we simplify the production line before B1? Which of the parallel processes has the lowest average production rate?

To simplify the analysis, once you select the slowest process, you can choose to ignore the secondary step and use the reliability metrics of the slowest machine

2. For our simplified production line, what are the minimum and maximum production rates? Feel free to use the MATLAB scripts, calculations, or both.

3. What are the smallest size buffers needed in order to meet a demand of 270,000 yo-yos in a year? Assume you can operate your yo-yo factory for 16 hours a day, 7 days a week. How can you use the MATLAB script in order to help you find a solution?

4. If you could double the production rate of only one machine, which one would you choose? What is the new production rate using the buffer sizes you found in Question 3? How many yo-yos can you make in a year?

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2.008 Design and Manufacturing II
Spring 2025

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