16.660 / 16.853 / ESD.62J Introduction to Lean Six Sigma Methods
January (IAP) 2008

Variability Simulation

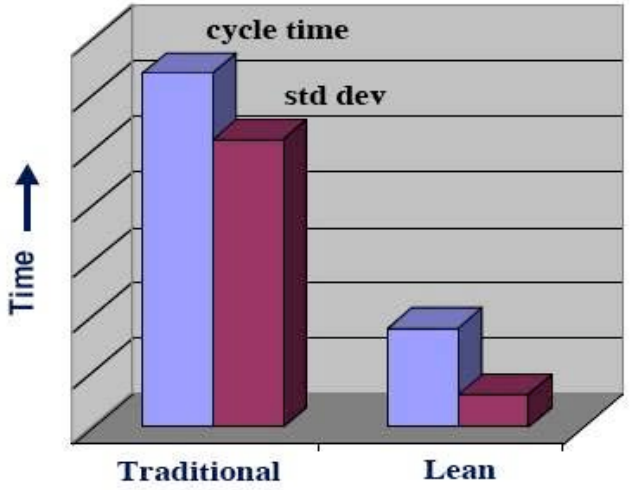
Learning Objectives

At the end of this module, you will be able to:

- **Discuss the impact that variability has on process performance**

The Curse of Variation

- Variation impacts
  - Cycle time (previous module)
  - Design for Manufacturing (Quality Module)
  - Process capability (Quality Module)
- Reducing process variation is a key step in implementing lean practices
- Reducing variation is the heart of Six Sigma (Quality module)



Pre and post lean engineering drawing release data for major aircraft program

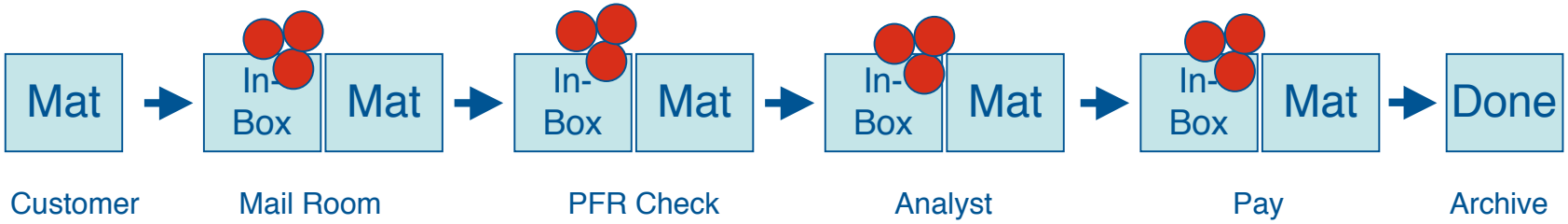
Courtesy of Lockheed Martin. Used with permission.
Source: "Lean PD Efforts for F-22", LAI Product Development Winter Workshop, January 27, 2000.

Learning About Variation

- In this module, we will gain understanding about impact of variation through two simulations
  - Dice game will give experiential encounter
  - Computer simulation will rapidly show impact of process changes
- We'll discover a useful relationship between WIP, cycle time and takt time
- The quality module will introduce tools for variation and its impact on process capability

Dice Game Setup

- 5-step system
- One die and record sheet (from packet) at each station
- 3 chips per in-box

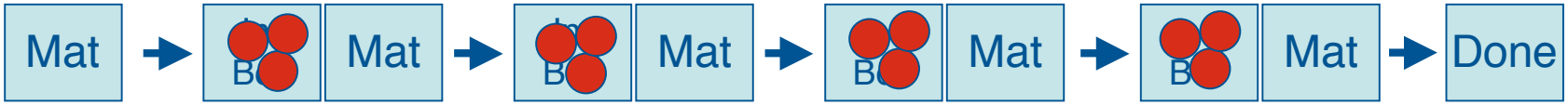


- System processes chips
  (each time period, move a quantity of chips from one person to the next)
- Roll of dice determines how many chips are moved
- CANT PASS MORE CHIPS THAN YOU HAVE IN YOUR "IN" BIN AT THE BEGINNING OF THE ROUND

- Let's work through a couple cycles

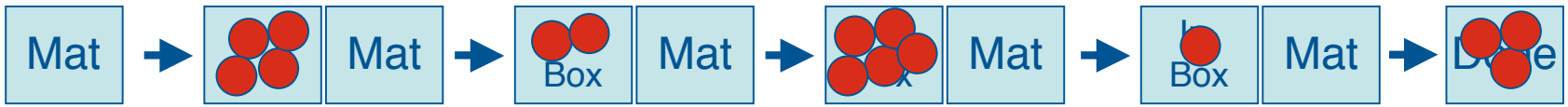
Example - Day1

Start of Day



Customer rolls a ‘3’, passes **3** chips to Mail Room
Mail Room rolls a ‘2’, passes **2** chips to PFR Check
PFR Check rolls a ‘5’, passes **3** chips to Analyst
Analyst rolls a ‘1’, passes **1** chip to Pay
Pay rolls a ‘6’, passes **3** chips to the Archive

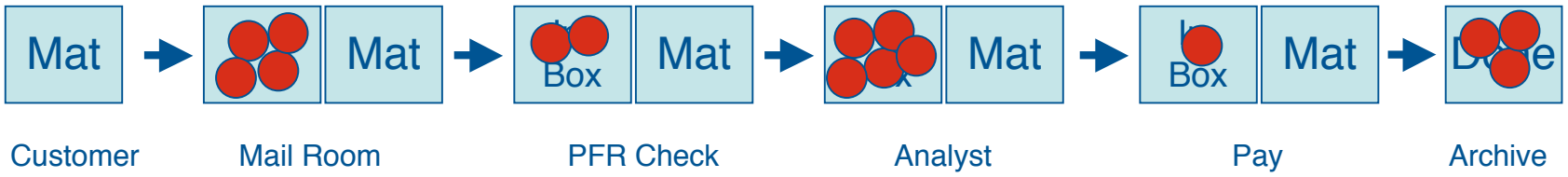
- **All these actions happen simultaneously**
- **Don’t wait for other players to pass chips before you pick up yours**



End of Day

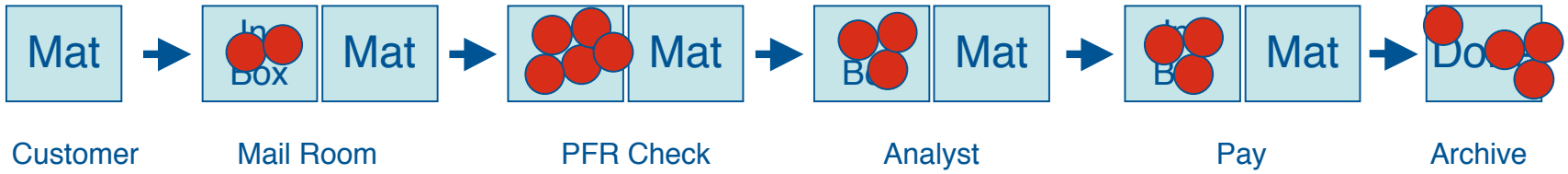
Example - Day2

Start of Day



Customer rolls a ‘2’, passes **2** chips to Mail Room
Mail Room rolls a ‘5’, passes **4** chips to PFR Check
PFR Check rolls a ‘1’, passes **1** chips to Analyst
Analyst rolls a ‘3’, passes **3** chip to Pay
Pay rolls a ‘4’, passes **1** chips to the Archive

- **All these actions happen simultaneously**
- **Don’t wait for other players to pass chips before you pick up yours**



End of Day

- Each round, record jobs you did and Work In Progress (WIP) level on your sheet
- From our example, Analyst on Day 1 had 3 WIP, completed 1, and ended up with 5
- On Day 2, Analyst completed 3 and ended up with WIP of 3

DAY	Jobs Completed	WIP
		3
1	1	5
2	3	3
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
A Total Jobs Completed		
B Jobs per day =**A**/20		
C Utilization =**B**/3.5		
D Ending WIP		
E Estimate flow time =**D**/**B**		

Customer Worksheet

- **Customer records new jobs**
- **Get Jobs Completed from Archive-Done**
- **Record total WIP by adding up all WIP or using mathematical shortcut below**

Shortcut
Total WIP (new) =
Total WIP (previous)
+ New Jobs
- Jobs Complete

DAY	New Jobs Put Into the Process	Jobs Completed (by Pay)	Total WIP
			12
1	3	3	12
2	2	1	13
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
A Total s	**A1**	**A2**	**A3**
B Jobs per day =**A2**/20			
C Utilization =**B**/3.5			
D Average WIP=**A3**/20			
E Average flow time =**D/B**			

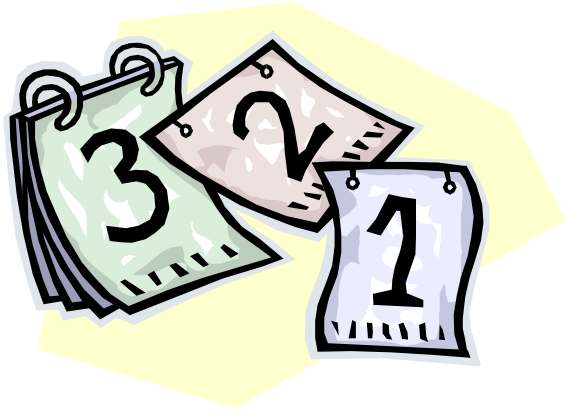
What *Should* happen?

- Consider 20 time periods, or “days”
- Each day, 3.5 chips are processed on average (the average of 1, 2, 3, 4, 5, 6)
- Intuitively, what *should* be the average throughput? Over 10 days? Over 20?
- What is the ideal flow (elapsed) time?

Let’s find out what really happens…

Ready, Set, Play!

Day 20



Accounting

- After 20 days, each person should add the appropriate columns to carry out the calculations at the bottom of their tally sheet

- The customer does slightly more complex calculations (use calculator if needed)

Let's tabulate some results

Questions

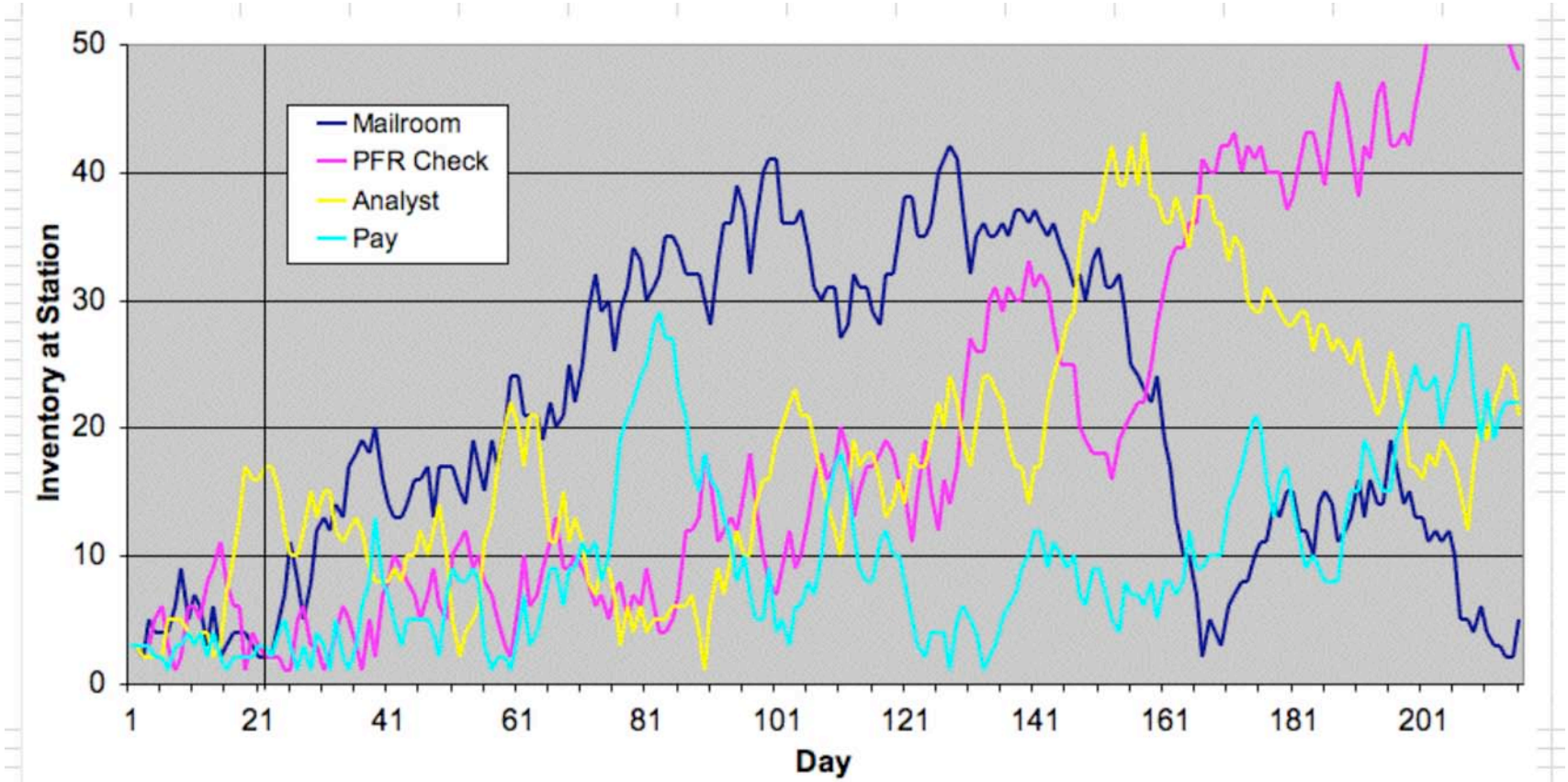
- Why are fewer jobs processed than expected? Why is flow time longer?

- How might the performance of this system be improved?

Computer Simulation

- We can more rapidly gather experimental data with a computer simulation of the dice game
- We can easily change customer input (invoice arrival) and process step variation to see the impact.
- Look at the impact of input and process variability on cycle time after 20 and 216 days
- For each simulation, write down the following data
  - Invoices/day, WIP, Cycle time
  - Then multiply (Invoices/day) x (Cycle time)

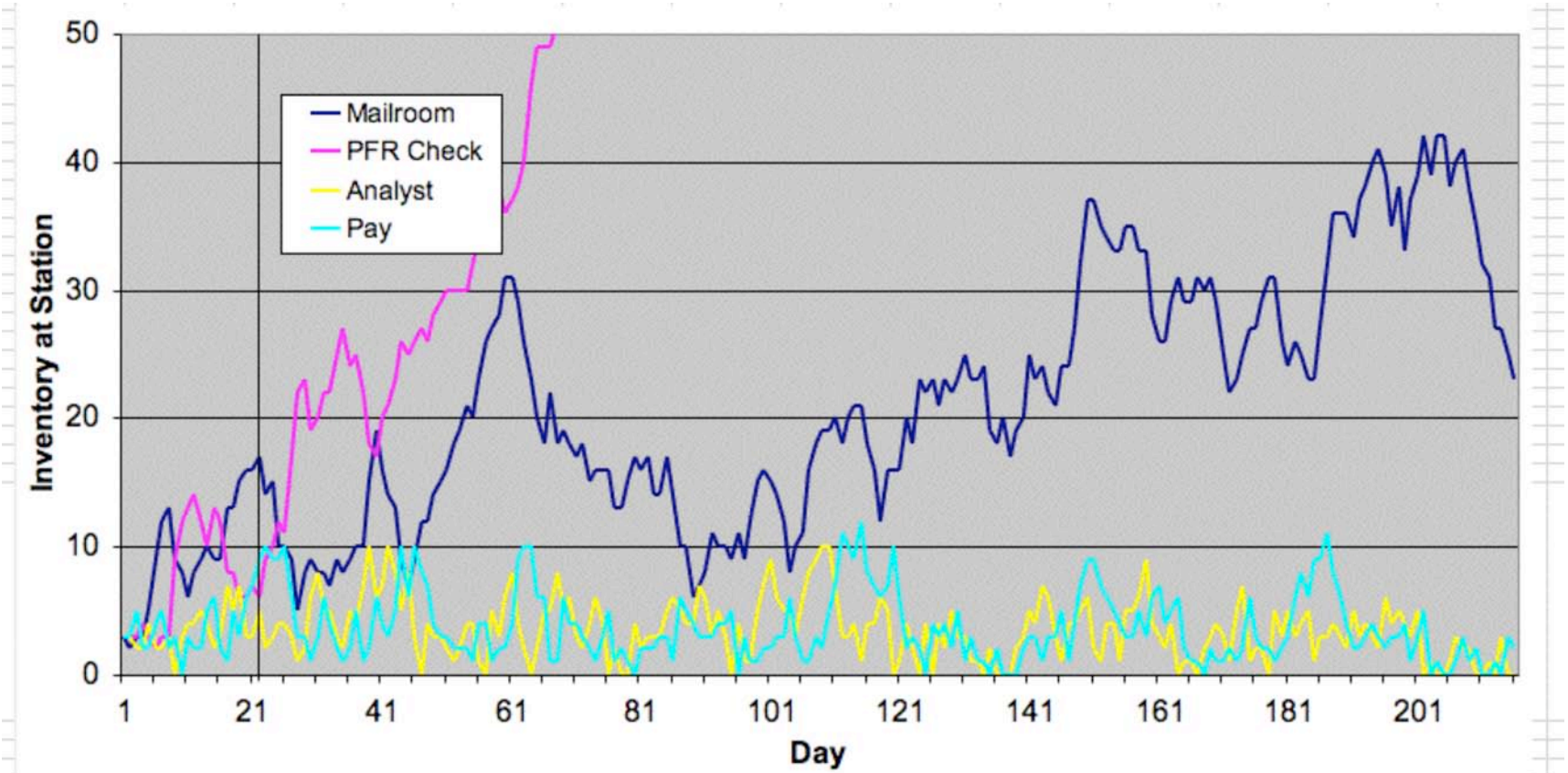
Spreadsheet Simulation



Customer	Mailroom	PFR Check	Analyst	Pay
Standard Die	Standard Die	Standard Die	Standard Die	Standard Die

Average:	Invoices/Day		WIP		Cycle Time		Luck	
Over:	20	216	20	216	20	216	20	216
	2.2	3.0	17	68	7.9	22.5	0.90	0.96

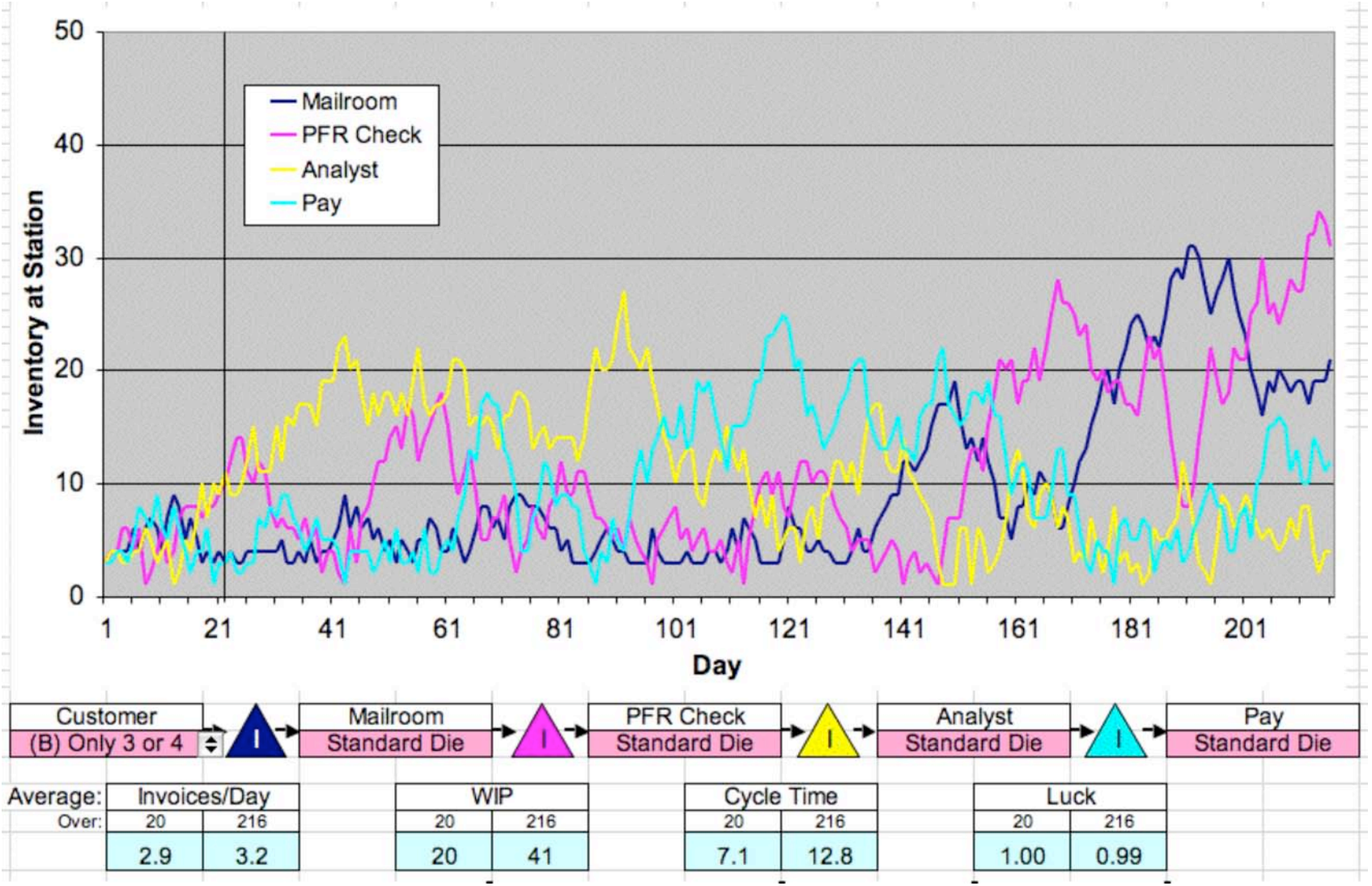
Bottleneck



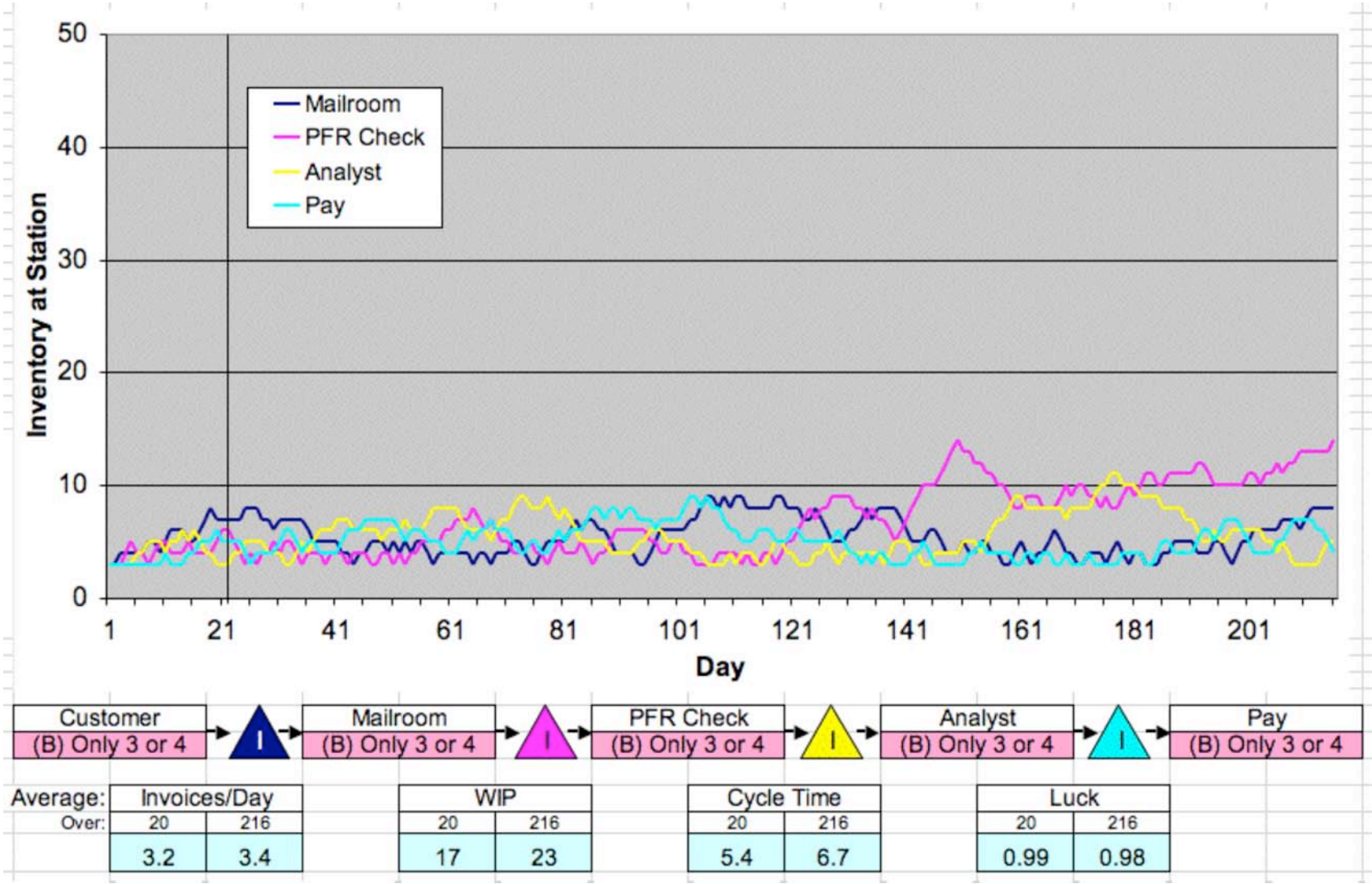
Customer	Mailroom	PFR Check	Analyst	Pay
Standard Die	Standard Die	(D) 0,1,2,3,4,5	Standard Die	Standard Die

Average:	Invoices/Day		WIP		Cycle Time		Luck	
Over:	20	216	20	216	20	216	20	216
	2.4	2.3	23	137	9.5	58.6	1.01	0.99

Reduced Input Variation (3 or 4)

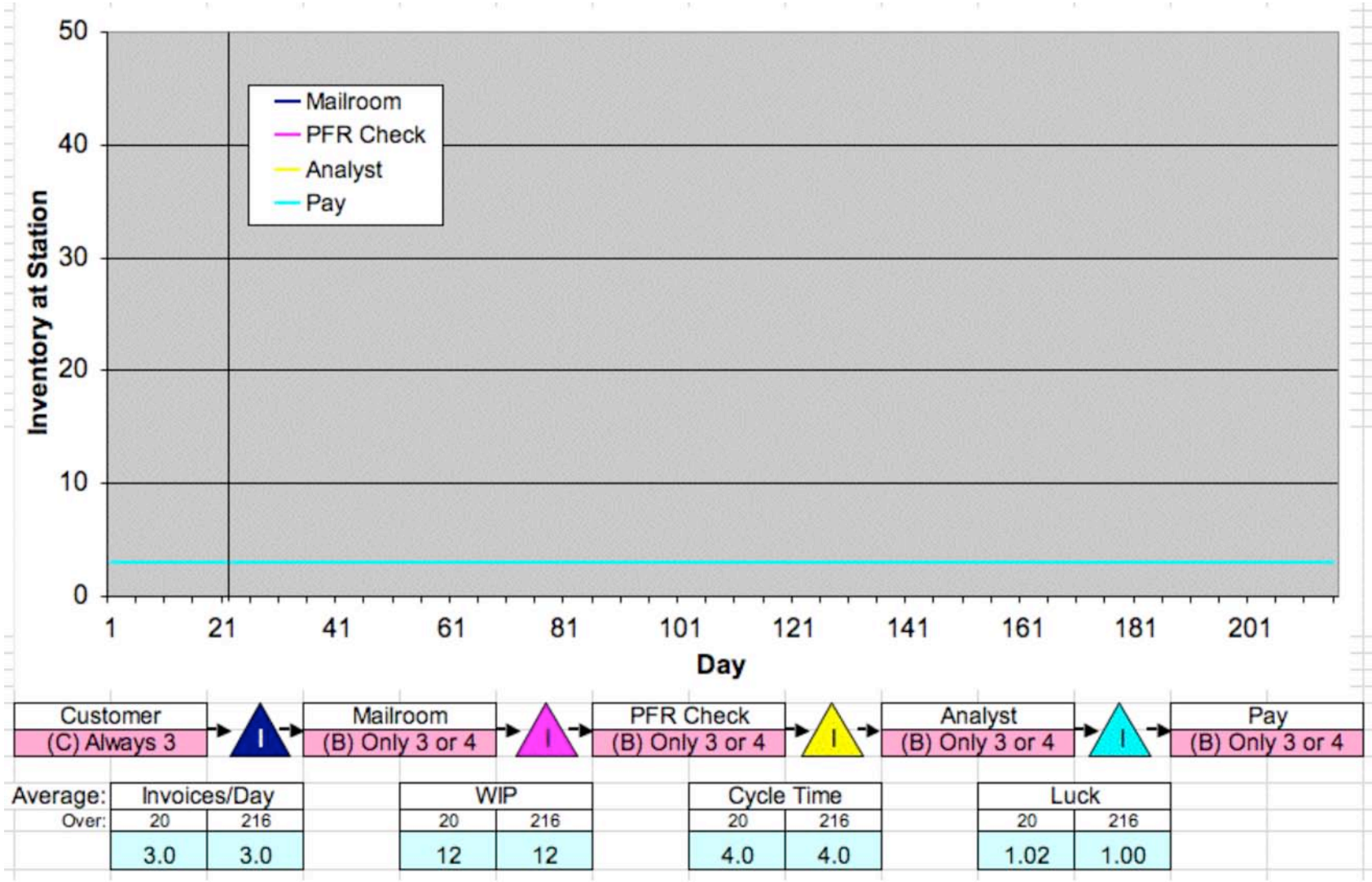


Reduced Total Variation



Average:	Invoices/Day		WIP		Cycle Time		Luck	
Over:	20	216	20	216	20	216	20	216
	3.2	3.4	17	23	5.4	6.7	0.99	0.98

Constant Demand, Low Variation



Average:	Invoices/Day		WIP		Cycle Time		Luck	
Over:	20	216	20	216	20	216	20	216
	3.0	3.0	12	12	4.0	4.0	1.02	1.00

Little's Law

$$\text{WIP} = (\text{Throughput Rate}) \times (\text{Cycle Time})$$

Or

$$\text{WIP} = \frac{\text{Cycle Time}}{\text{Takt Time}}$$

Data from 5 computer simulations

1	2	3	
Invoices/ day	WIP	Cycle Time	1 x 3
3.2	48	15	48.0
2.5	99	38.9	97.3
3.2	49	15.5	49.6
3.4	24	6.9	23.5
3	12	4	12.0

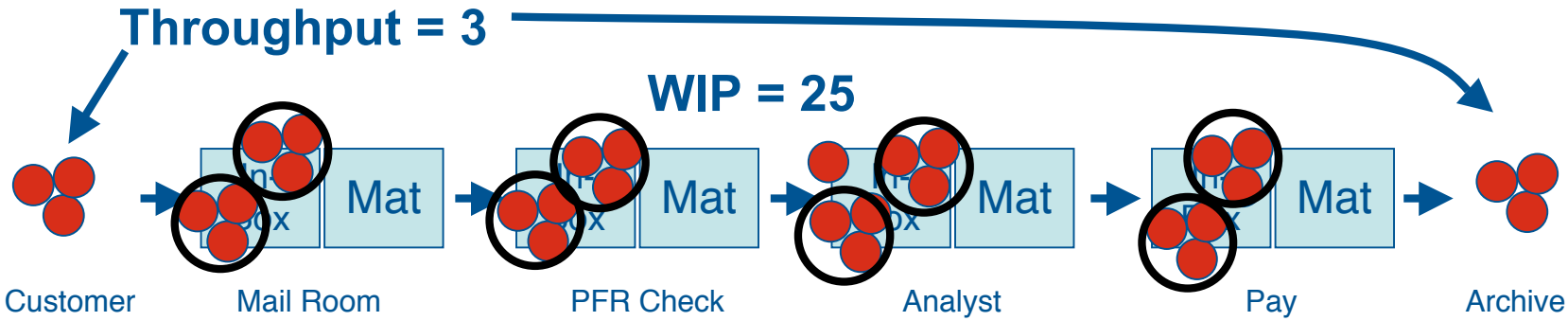
Little's Law

$$WIP = (Throughput\ Rate\ ) \times (Cycle\ Time)$$

Or

$$WIP = \frac{Cycle\ Time}{Takt\ Time}$$

Example from Sim: Throughput = 3, WIP = 25



Takes about 8 cycles to work through the system

Using Little's Law:
Cycle Time = WIP / (Throughput Rate) = 8.3

Simulation: Summary

- Simulated the system to examine behavior over a longer time period, more replications
- We made several improvements that demonstrate the power of a lean philosophy:
  - Reduced INPUT variability
  - Reduced PROCESS variability
  - Less variability and some “excess” capacity allowed response to customer need - Pull
  - Eliminating variability allowed straight-through flow to customer demand - Perfection

Take Aways

- Lean thinking and tools apply to office processes
- A structured process analysis can lead to identifying many opportunities for improvement
- Changing the theoretical process is not the only change required for successfully transforming an organization (management practices and structure determine behavior!)
- Variability reduces expected process performance

Acknowledgements

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