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Variability Simulation

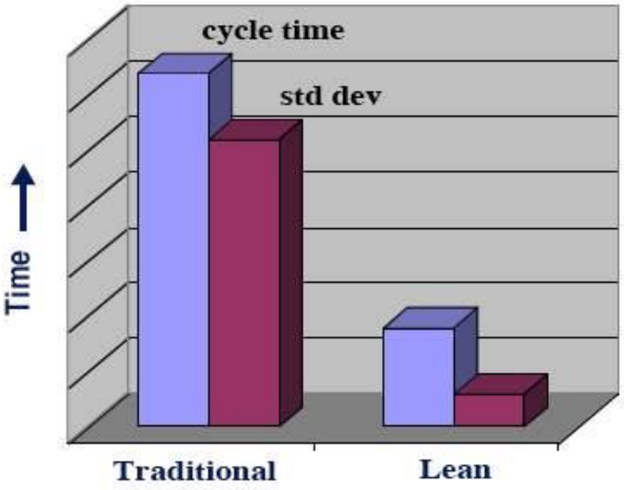
Learning Objectives

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

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

The Impact of Variation

- Variation impacts
  - Cycle time & throughput (Accounts Payable module)
  - Cost of Quality (Quality module)
  - Process capability (Six Sigma module)
- Reducing process variation is a key step in implementing lean practices



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

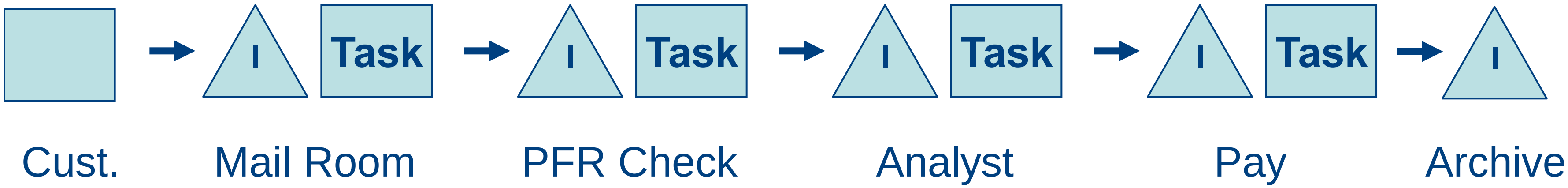
Source: Lockheed Martin Corporation

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 some important connections between variation and WIP, cycle time, throughput and utilization
- The Quality and Six Sigma Modules will introduce tools for controlling variation and its impact on process capability

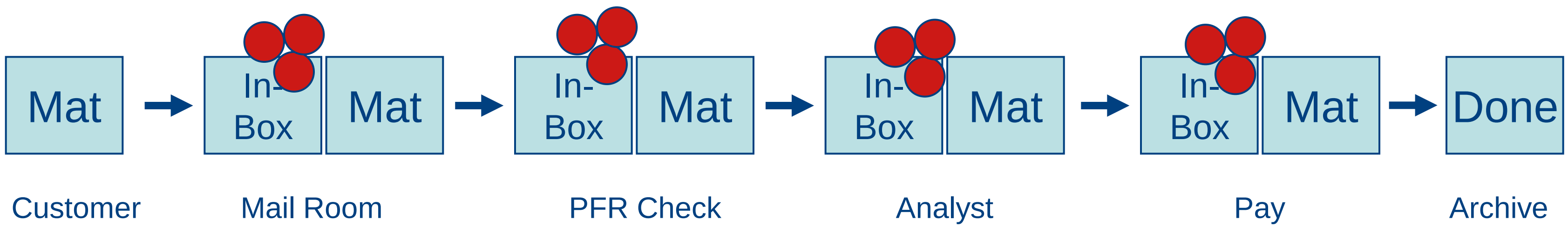
A "Perfect" System?

- Imagine a system that is perfectly balanced, has no rework, and has just enough capacity to meet customer demand
  - This module uses labels from the AP case study and/or the Clinic Lego® simulation, but this could be any system!
- The only imperfection we allow is variability in both input and process
- How will this system behave? Let's find out…



Dice Game Setup

- 5-step system
- Mat with record sheet and 6-sided die at each station
- Middle 4 stations have inbox, with 3 chips per in-box

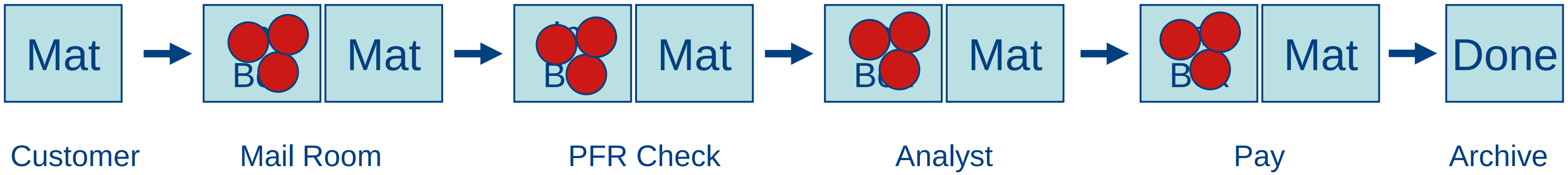


- System processes chips
  (each time period, move a quantity of chips from one person to the next)
- Roll of dice determines how many chips are moved
- CAN'T PASS MORE CHIPS THAN YOU HAVE IN YOUR "IN" BIN AT THE BEGINNING OF THE ROUND

- Let's work through one cycle

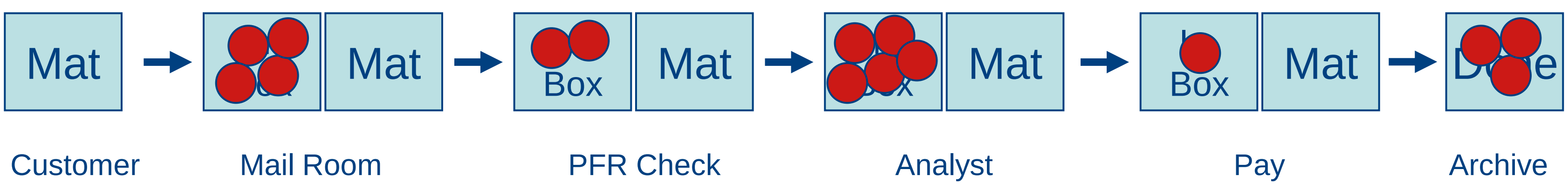
Example - Day1

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

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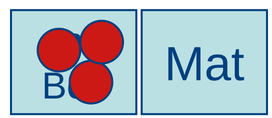
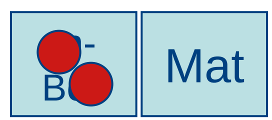
Accounting Example – Analyst

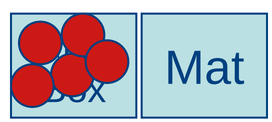
- Each round, record invoices completed and Work In Progress (WIP) level on your sheet
- From our example
  - Analyst at start of Day 1 had 3 WIP



  - Rolls a 1 and completes 1 invoice



  - Receives 3 invoices from PFR check and ends day with 5 WIP



DAY	Invoices Completed	WIP
		3
1	1	5
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		

A Total Invoices Completed	
B Invoices per day =**A**/20	
C Utilization =**B**/3.5	
D Ending WIP	
E Estimate cycle time =**D**/**B**	

Customer Worksheet

- Customer records new invoices from die roll
- Get Invoices Completed from Archive-Done
- Records total WIP by adding up all WIP or using mathematical shortcut below

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

DAY	New Invoices Put Into the Process	Invoices Completed (Archive-Done)	Total WIP
			12
1	3	3	12
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			

A Totals	**A1**	**A2**
B Invoices per day =**A1**/20		
C Utilization =**B**/3.5		
D Average WIP=**A2**/20		
E Average cycle time =**D/B**		

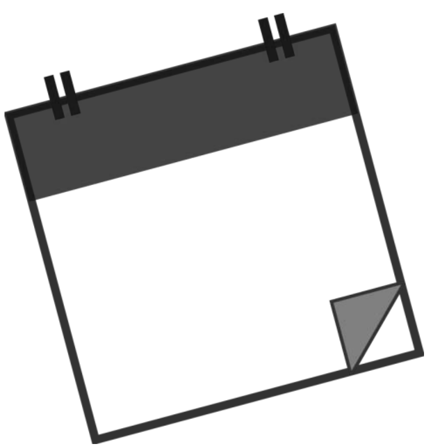
What *Should* happen?

- 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 cycle time longer?
  - Statistical fluctuations
    - Information that cannot be precisely predicted, varies from one instance to the next
  - System dependencies
    - Doing one task depends on having done another
    - Can't make up for lost capacity
- 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 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

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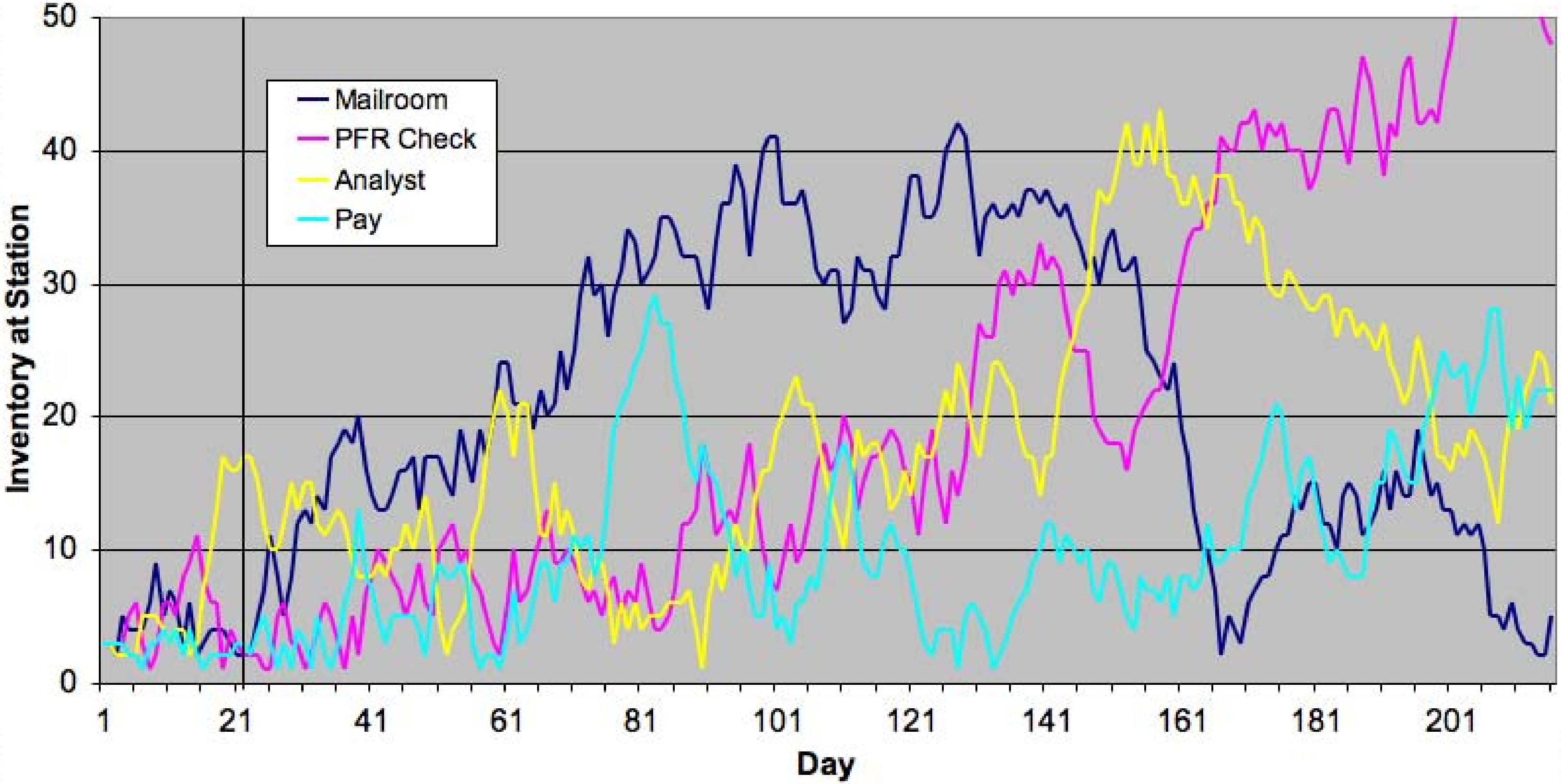
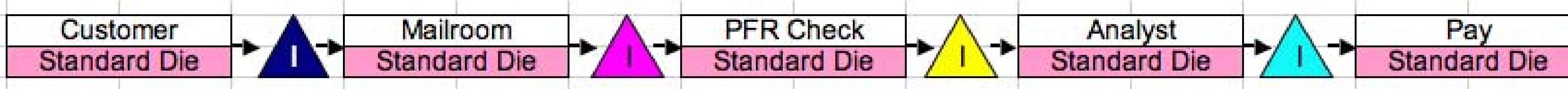
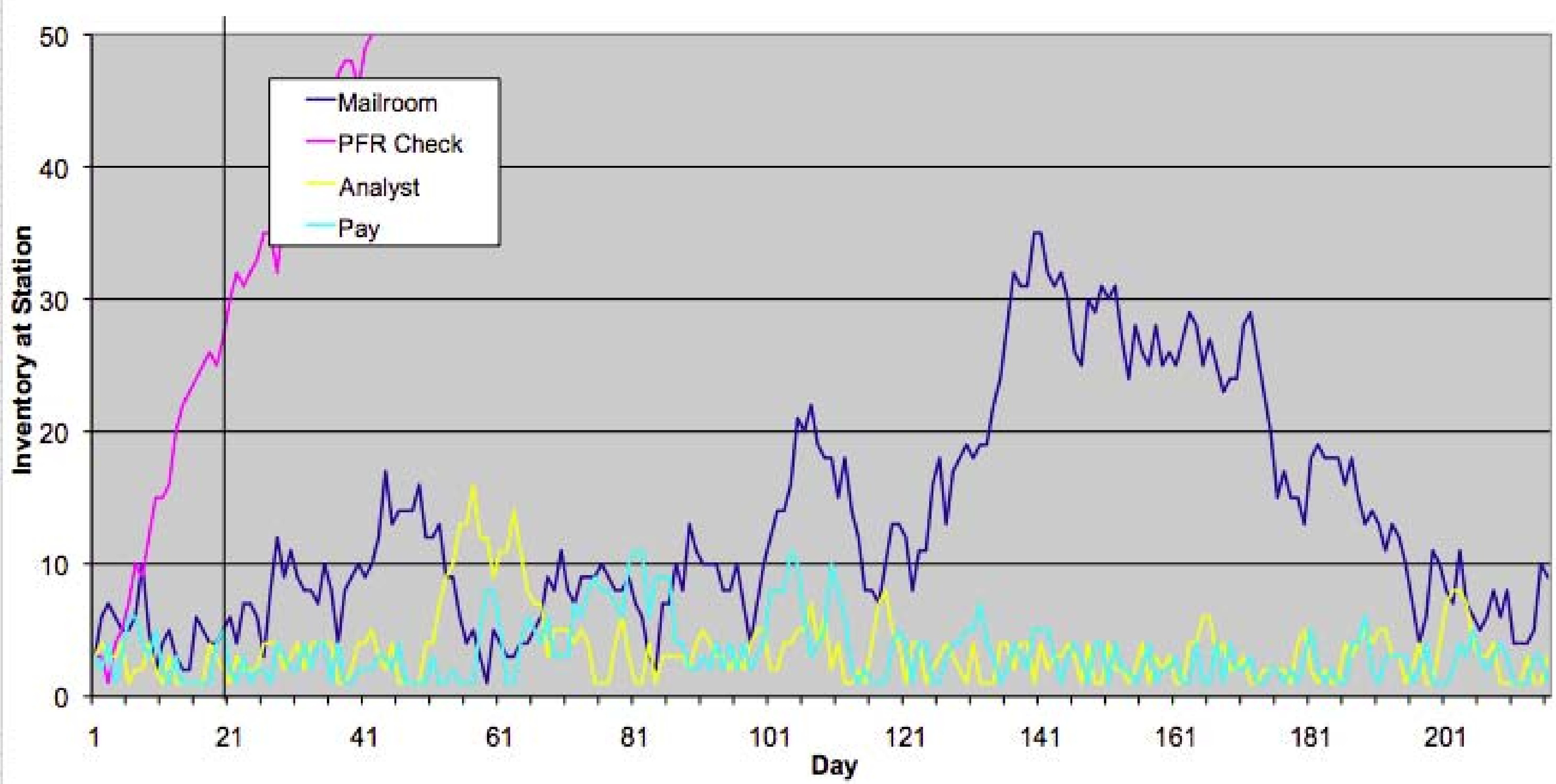
Spreadsheet Simulation





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

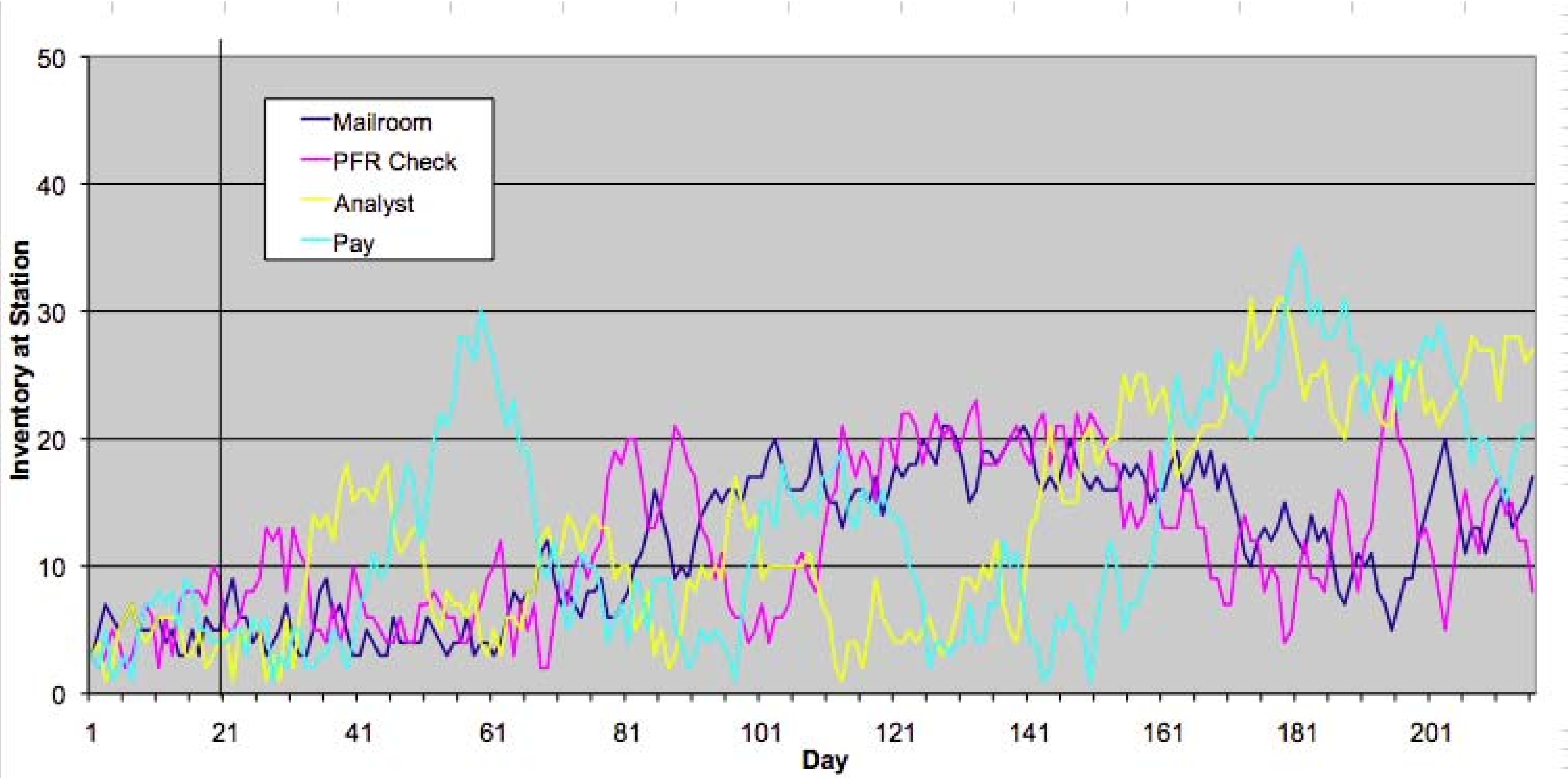
Bottleneck



Customer: Standard Die → I → Mailroom: Standard Die → I → PFR Check: Ave. reduced 30% → I → Analyst: Standard Die → I → Pay: Standard Die

Average:	Invoices/Day		WIP		Cycle Time		Luck	
Over:	20	216	20	216	20	216	20	216
	2.2	2.3	25	128	11.4	56.0	0.98	0.97

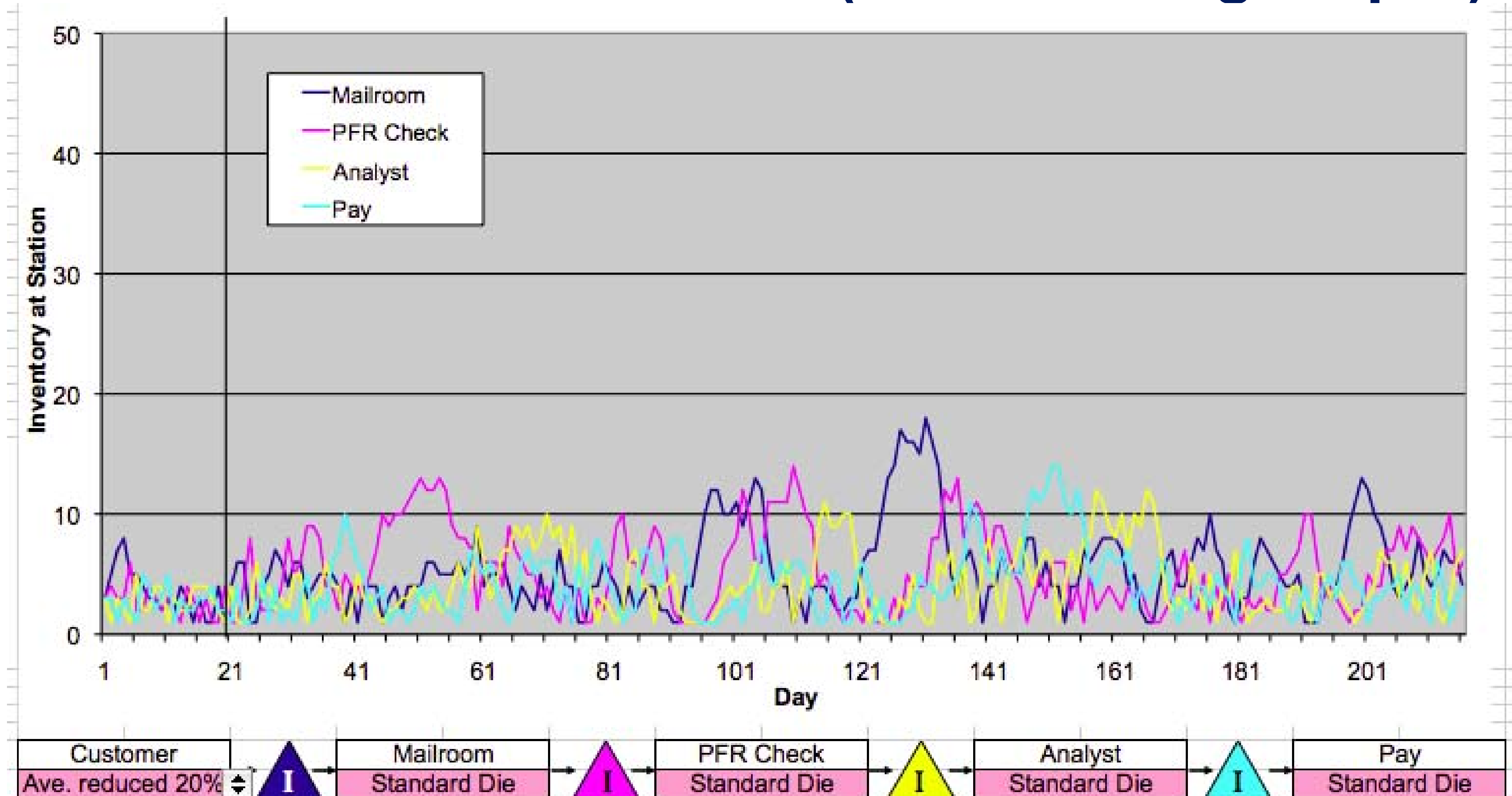
Reduced Input Variation



Customer		Mailroom		PFR Check		Analyst		Pay
Var. reduced 70%	I	Standard Die	I	Standard Die	I	Standard Die	I	Standard Die

Average:	Invoices/Day		WIP		Cycle Time		Luck	
Over:	20	216	20	216	20	216	20	216
	3.0	3.2	20	50	6.6	15.7	1.00	0.97

Reduced Demand
(lower average input)



Average:	Invoices/Day		WIP		Cycle Time		Luck	
Over:	20	216	20	216	20	216	20	216
	2.4	2.7	12	19	4.8	7.0	0.99	1.01

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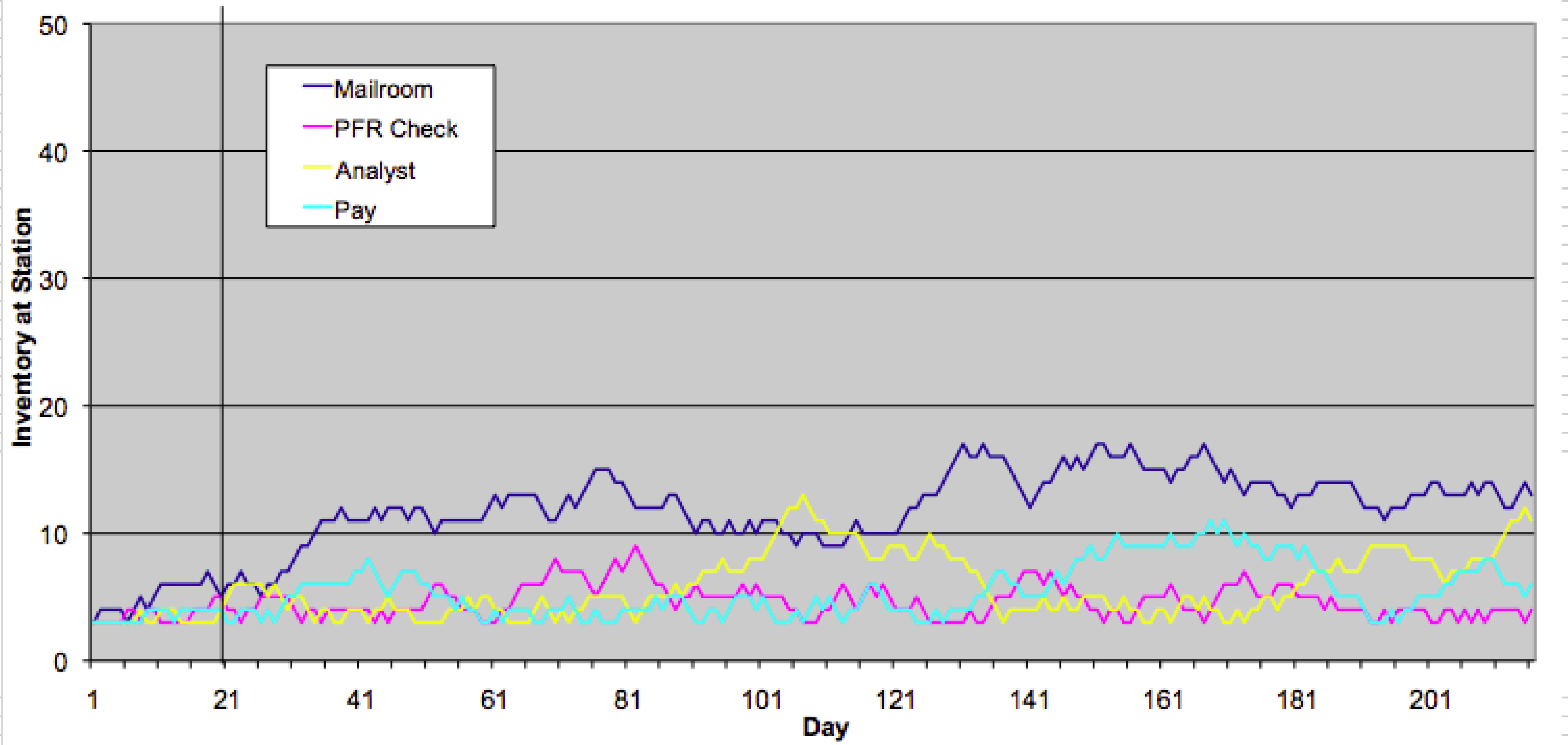
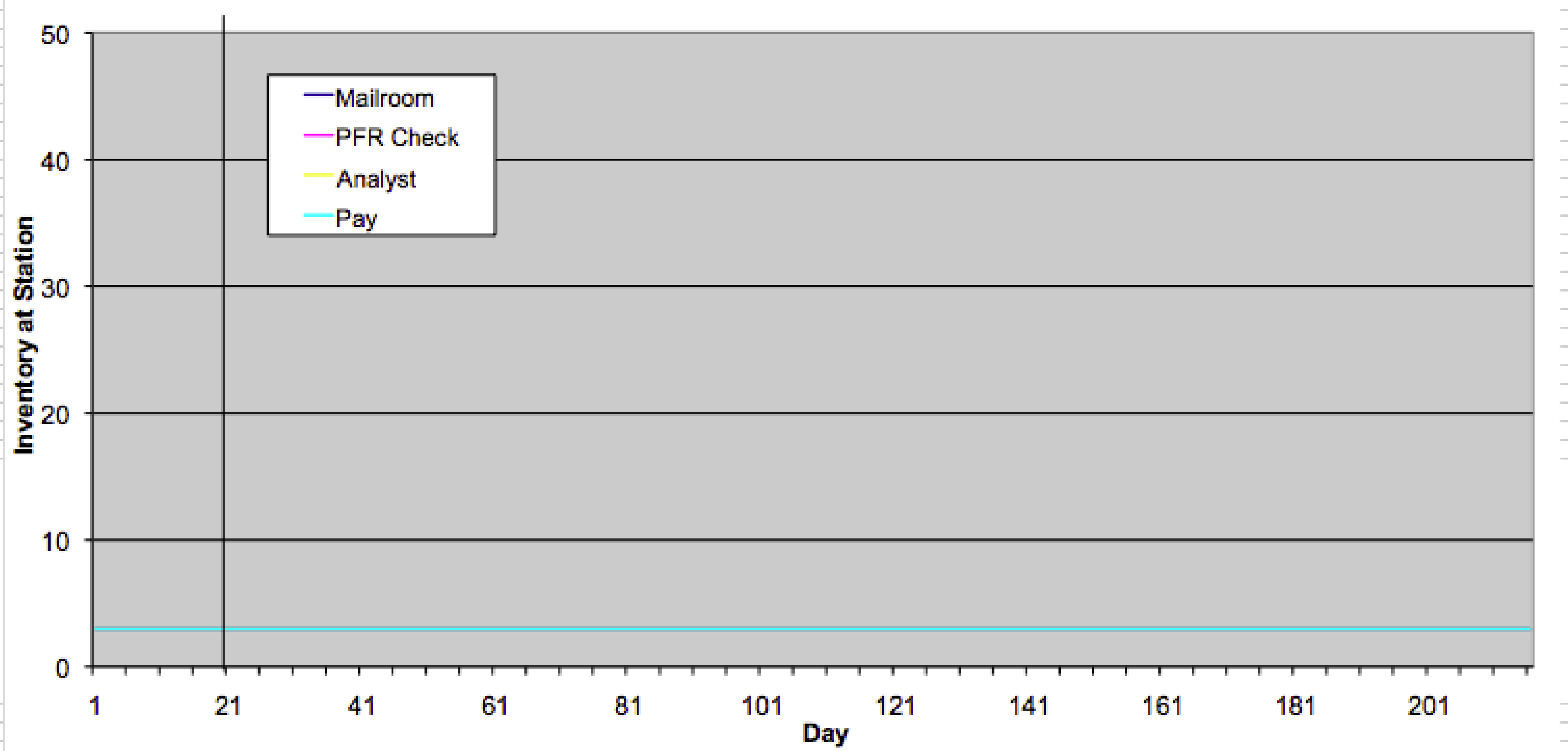
Reduced Total Variation

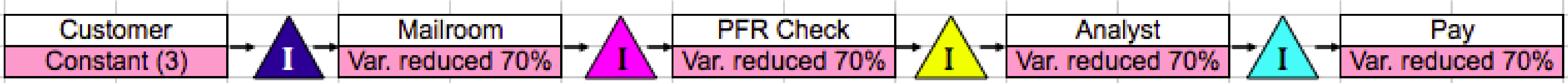


Customer	→ I →	Mailroom	→ I →	PFR Check	→ I →	Analyst	→ I →	Pay
Var. reduced 70%		Var. reduced 70%		Var. reduced 70%		Var. reduced 70%		Var. reduced 70%

Average:	Invoices/Day		WIP		Cycle Time		Luck	
Over:	20	216	20	216	20	216	20	216
	3.1	3.4	15	27	5.0	8.1	0.89	1.00

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	1.01	1.00

Queue Time

- Based on the equation for queue time,

$$Time\_in\_Queue = Activity\_Time * \left(\frac{Utilization}{1 - Utilization}\right) * \left(\frac{CV_a^2 + CV_p^2}{2}\right)$$

- CV_a is input variation
  - Which we may not control
- CV_p is process variation
  - Which we want to minimize
- Utilization is demand/capacity
  - Note to be "efficient" this should be 1…

Time_in_Queue = Wait time   Activity_Time = Processing time

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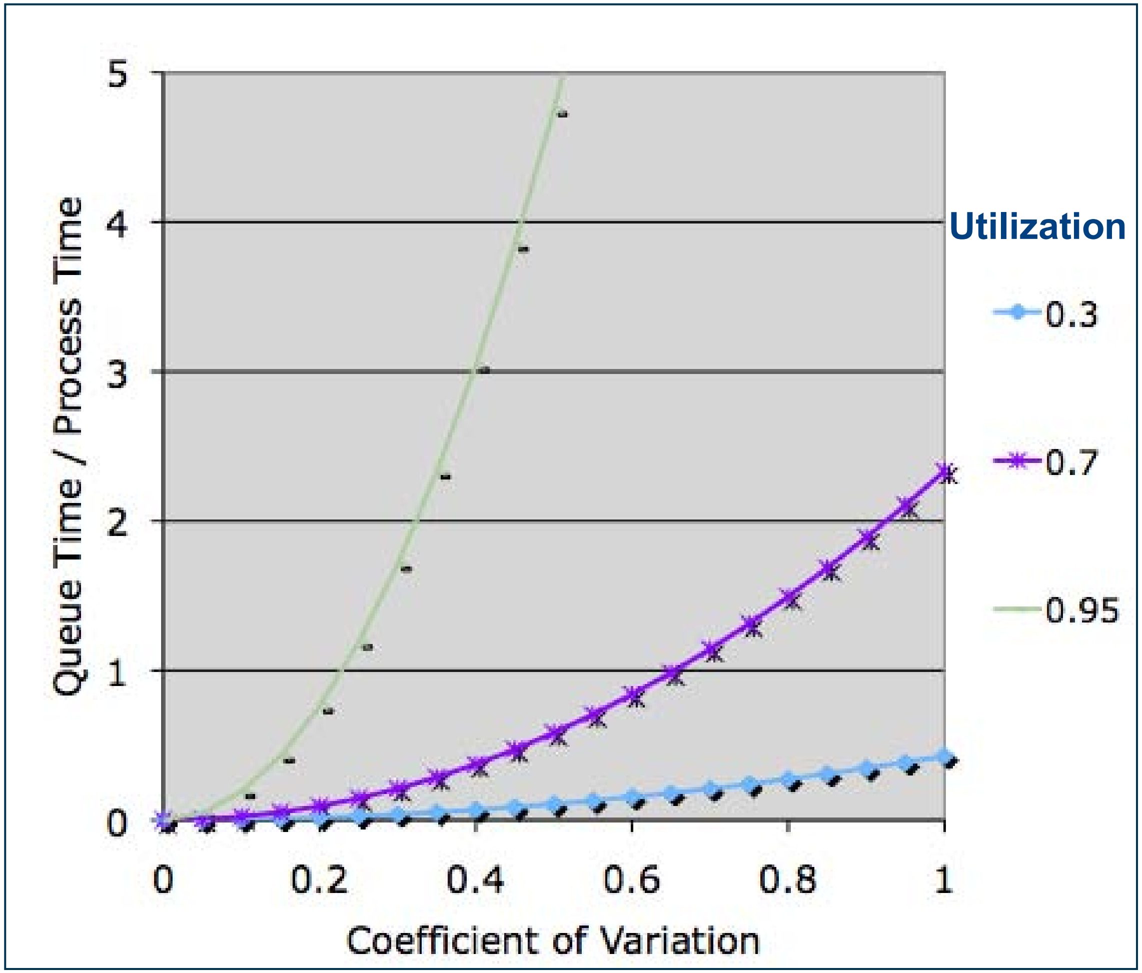
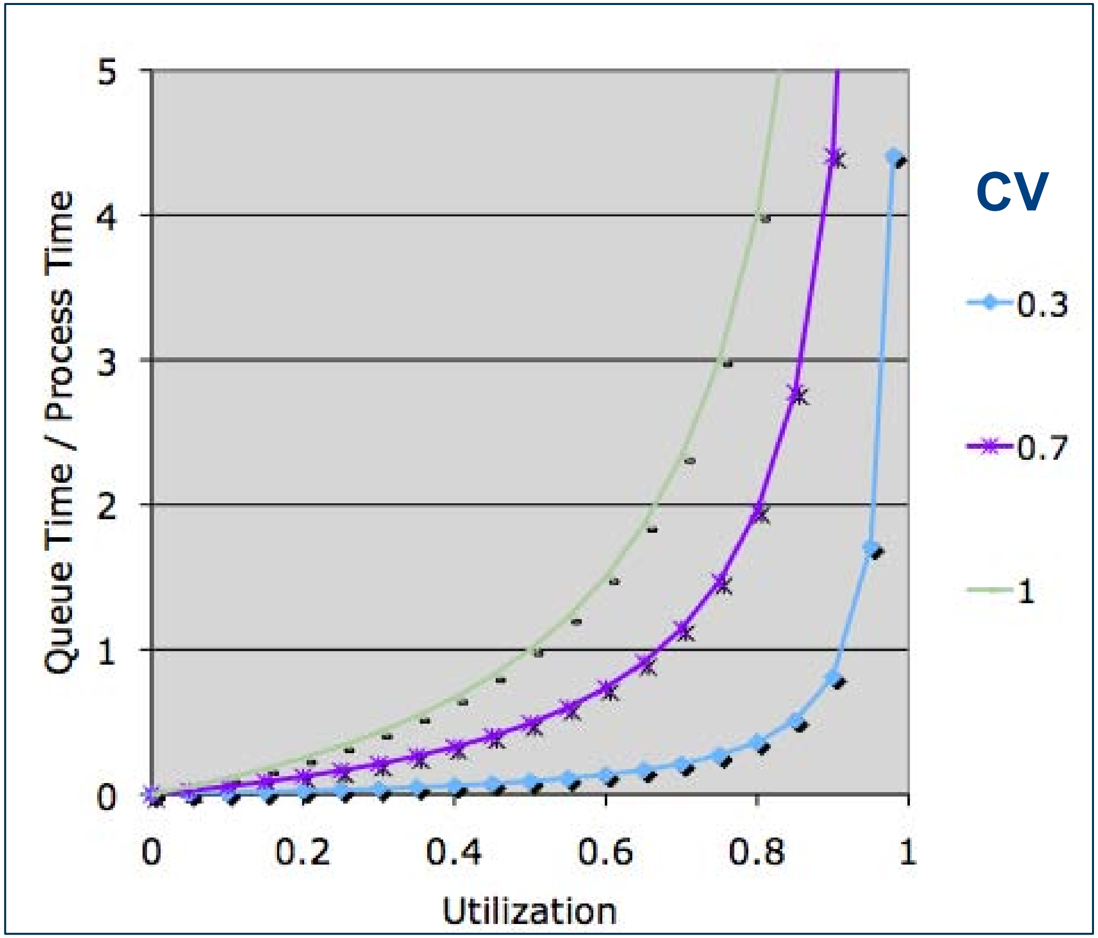
Controlling Variability

- Heroic reductions in variability required if utilization is high
- This is the motivation behind the 6-Sigma approach



Controlling Utilization (overburden)

- **For any variation level, some level of utilization makes queue time explode**
- **This is *muri* and *mura* in action**
- **Often, slight easing makes a dramatic difference**



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 and PROCESS variability
  - Reduced average utilization of system slightly
  - Less variability and some “excess” capacity allowed response to customer need - Pull
  - Eliminating variability allowed straight-through flow to customer demand - Perfection

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Take Aways

- **Variability reduces expected process performance.**
- **Variability can occur in all processes across an enterprise, from manufacturing to engineering to administrative functions to patient care.**

Acknowledgements

Contributors

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