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…

Cust. → Task → Task → Task → Task → Task
Mail Room  PFR Check  Analyst  Pay  Archive
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
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
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.

<table>
<thead>
<tr>
<th>DAY</th>
<th>Invoices Completed</th>
<th>WIP</th>
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<tbody>
<tr>
<td>1</td>
<td>1</td>
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</table>
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

<table>
<thead>
<tr>
<th>DAY</th>
<th>New Invoices Put Into the Process</th>
<th>Invoices Completed (Archive-Done)</th>
<th>Total WIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
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</table>

A Totals
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
Spreadsheet Simulation

Graph showing inventory at station over time with labels for Mailroom, PFR Check, Analyst, and Pay. Key metrics include:
- Invoices/Day: Average 2.2, Over 20; Average 3.0, Over 216
- WIP: Average 17, Over 20; Average 68, Over 216
- Cycle Time: Average 7.9, Over 20; Average 22.5, Over 216
- Luck: Average 0.90, Over 20; Average 0.96, Over 216
Bottleneck
Reduced Input Variation
Reduced Demand (lower average input)
Reduced Total Variation
Queue Time

• Based on the equation for queue time,

\[
\text{Time\_in\_Queue} = \text{Activity\_Time} \times \left( \frac{\text{Utilization}}{1-\text{Utilization}} \right) \times \left( \frac{\text{CV}_a^2 + \text{CV}_p^2}{2} \right)
\]

• \(\text{CV}_a\) is input variation
  • Which we may not control
• \(\text{CV}_p\) is process variation
  • Which we want to minimize
• Utilization is demand/capacity
  • Note to be “efficient” this should be 1...

\[
\text{Time\_in\_Queue} = \text{Wait time} \quad \text{Activity\_Time} = \text{Processing time}
\]
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
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

• Ken Gilbert - University of Tennessee at Knoxville
• Sharon Johnson - Worcester Polytechnic Institute
• Hugh McManus - LAI/Metis Design
• Earll Murman – MIT
• Barrett Thomas – University of Iowa

Collaborators

• Sue Siferd - Arizona State University
• Alexis Stanke – MIT