1 Lean Overview

1

The goal	• Provide the greatest value for customers using the fewest resources
The methods	• Principles and practices based on the Toyota Production System (TPS)
The barrier	• Culture always defeats methodology
The path forward*	• Create a culture of continuous improvement (*kaizen*) • Integrate improvement cycles into the daily work of all employees • Improve all processes, every day

*See **Toyota Kata** (2010) by Mike Rother.

1

Basic principles of Lean

2

- *Value* is defined from the customer's point of view

  → Reduce or eliminate activities that do not add customer value

- *Value stream* — all activities required to provide a specified family of products or services to the customer

  → Organize workflows by value stream, not by department

2

Customer defines value

3

Customer value adding (CVA)

- Activities that are required, from the customer's point of view, to provide the desired products and services
- What the customer is willing to pay for
- Changes the form or function of the product
- Goal: Optimize and standardize these activities

Non-value adding (NVA)

- There exists a feasible future state in which the desired products and services can be provided without these activities
- Goal: Eliminate or reduce

Non-value adding but necessary

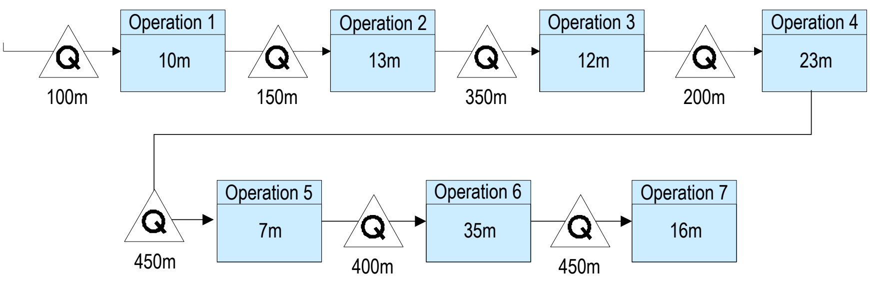
- Activities that are not CVA, but cannot feasibly be eliminated under current constraints
- Examples include audits, reporting, regulatory compliance, etc.
- Goal: Question and reduce

3

Common example of CVA and NVA

4

Typical current state value stream

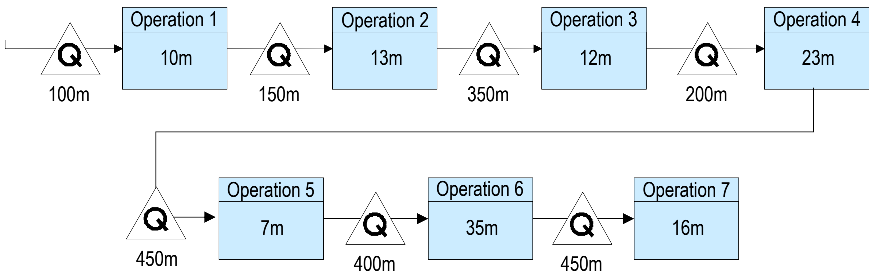


Lead time = 2,216 mins
Process time = 116 mins (5.3%)
Wait time = 2,100 mins (94.7%)

Q Queue (material or transactions waiting to be worked on) → 100% NVA

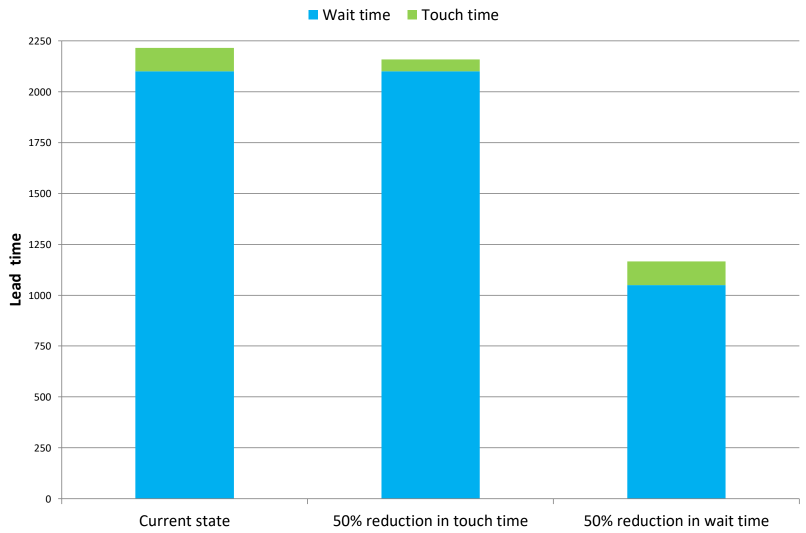
4

What is the priority: reducing CVA or reducing NVA?



	Current state	50% reduction in process time	50% reduction in wait time
Process time	116 m	58 m	116 m
Wait time	2,100 m	2,100 m	1,050 m
Lead time	2,216 m	2,158 m	1,166 m
Reduction in lead time →		**2.6%**	**47.4%**

Reduce NVA, not CVA!



Categories of NVA

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D	*Defects*: Failure to meet expected standards of quality or delivery
O	*Over production*: Making or doing more than is needed at the time
W	*Waiting*: People waiting to work, or things waiting to be worked on
N	*Not utilizing creativity*: Failure to integrate improvement cycles into the daily work of all employees
T	*Transportation*: People or things being moved from one place to another
I	*Inventory*: Storing supplies, WIP, or finished goods beyond what is needed
M	*Motion*: Excessive motion in the completion of work activities
E	*Extra processing*: Producing or delivering to a higher standard than is required

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Exercise 1.1

8

Think of processes in your organization and list examples of non-value adding (NVA) activities.
Try to identify more than one for each 'DOWNTIME' category.

D	*Defects*:
O	*Over production*:
W	*Waiting*:
N	*Not utilizing creativity*:
T	*Transportation*:
I	*Inventory*:
M	*Motion*:
E	*Extra processing*:

8

Example of organizing work by department

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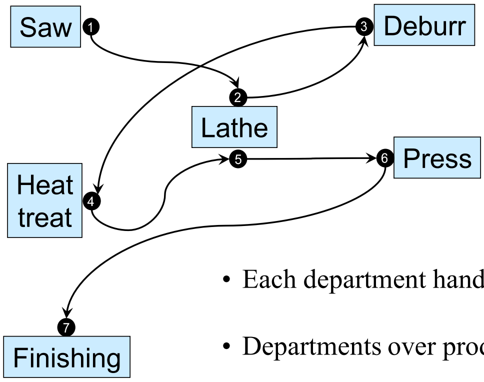

- Each department handles all products → inefficient
- Departments over produce → high levels of WIP
- WIP is valued as an asset — in reality it's a cash sink
- WIP moves between departments in large batches → long lead times, long lags before defects are discovered
- Poor layout → excessive transport

Example of organizing work by value stream

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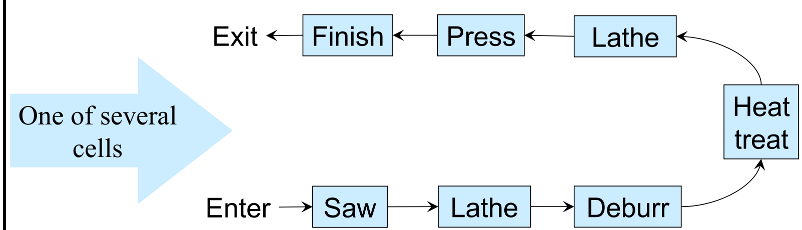

- Each cell handles particular, similar products → efficient
- Cells produce only to current customer demand → low levels of WIP, less cash tied up
- WIP moves through each cell in small batches → short lead times
- Proximity of operations → minimal transport, defects identified immediately

The kaizen culture

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- *Kaizen* — Japanese word for "continuous improvement"
- Ongoing, daily process yielding many small improvements
- Employees are *expected* to expose and solve problems instead of ignoring and working around them
- Supervisors and managers must banish *kaizen killing language*

"That's a dumb idea"

"That won't work"

"We can't do that"

"We tried that before"

"Stop complaining — just do your job"

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The spirit of kaizen

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- Open to change
- Positive attitude
- No blaming
- The only bad questions are the ones not asked
- First find the cause of the problem, then seek solutions
- One person, one vote — position doesn't matter

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Kaizen events

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- *Kaikaku* — "radical, transformational improvement"
- More commonly known as *kaizen event*
- A "concentrated dose of *kaizen*"
- Core team: pre-event preparation
- Extended team: 3-5 days of 100% dedicated involvement

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Characteristics of a typical kaizen event

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- Emphasis on "tribal knowledge" (*a.k.a.* "wisdom of the organization")
- Causes of the problem are fairly easy to identify
- Solutions are fairly easy to develop
- Bias for action
  - ✓ Develop solutions during the event
  - ✓ Reconsider previous solution ideas that were discarded
  - ✓ Implement solutions during the event if possible

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Preparation for a typical kaizen event

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- ✓ Project charter completed
- ✓ Current state process maps completed
  - Value stream
  - Flowchart
  - Spaghetti
- ✓ Data collected, metrics calculated, goals set
- ✓ Event training material prepared (if needed)
- ✓ Event logistics arranged
  - Command Center
  - Materials
  - Food
- ✓ Team members, process owners, and resources notified
- ✓ Impacted workers met with and challenges identified

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Essential component: the “command center”

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Walking the *gemba* (“the actual place”)

17

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Possible pitfalls of kaizen events

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- Time constraint drives selection and scoping of projects

  “We tend to choose easy projects that can be completed in 3-5 days.”

  ✓ Mitigating strategy – Choose larger projects and develop a solution during kaizen event. Use 30-day homework plan for implementation.

  “We tend to choose projects with very narrow scope — it is not uncommon for us to make improvements in one area only to cause problems in another.”

  ✓ Mitigating strategy – Include team members from other potentially impacted areas. Discuss negative side-effects and develop solution that will prevent unintended consequences.

- Gains not sustained after the event

  “The results disappear as soon as the team does. We have a lot of do-overs.”

  ✓ Mitigating strategy – Update all necessary documentation, develop a training plan, and create supporting management materials for the new standards.

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Possible pitfalls (cont'd)

19

- Failure to foster *kaizen* culture in the organization

"We only do kaizen events — there is very little culture building."

✓ Mitigating strategy – Culture change takes time. Be patient. Develop problem identification and solving into daily work cycles for all people.

"We have done many kaizen events, but the fundamental behaviors and processes of top management haven't changed."

✓ Mitigating strategy - Include top management in LSS training and improvement events. Change in managerial expectation should come from upper management.

"Decisions and changes are driven by 'outside experts' rather than the people doing the work."

✓ Mitigating strategy – The role of outside lean experts is to provide knowledge on the lean process and tools, and to guide the process. Solutions should come from process experts.

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Notes

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2 Six Sigma Overview

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- Process spread
- Pursuit of perfect quality
- Pragmatic business initiative

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Process spread

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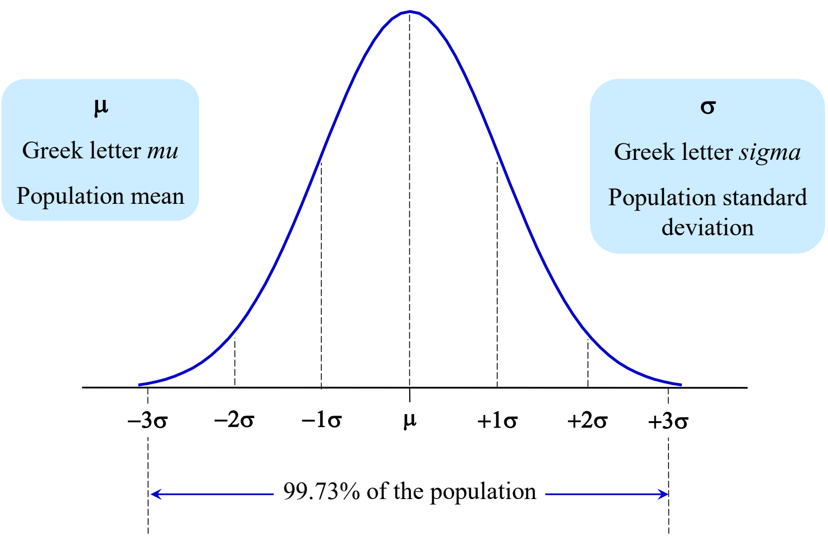
Normal distribution (*bell curve*)



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Process capability

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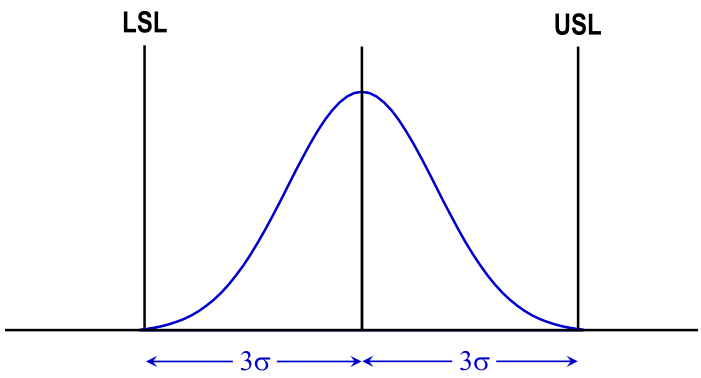

0.27% defective (first pass)

Process capability (cont'd)

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USL stands for *Upper Specification Limit*, LSL stands for *Lower Specification Limit*. Specification limits represent the Voice of the Customer in regard to measureable characteristics of products or services.

For the Normal distribution shown in the previous slide, the mean (μ) is equal to the midpoint of the specification range, and the process spread (6σ) is exactly equal to the width of the specification range (USL minus LSL).

This fact means that 99.73% of product or service outcomes produced by this process satisfy the spec limits. Equivalently, 0.27% of outcomes lead to scrap, rework, do-overs, or other costly measures to prevent or respond to customer dissatisfaction.

Pursuit of perfect quality

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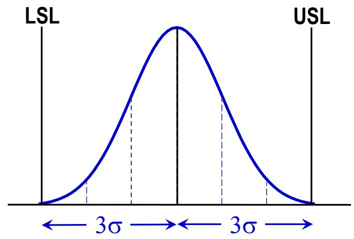
In the 1980s, Motorola questioned the adequacy of 0.27% defective as an improvement objective



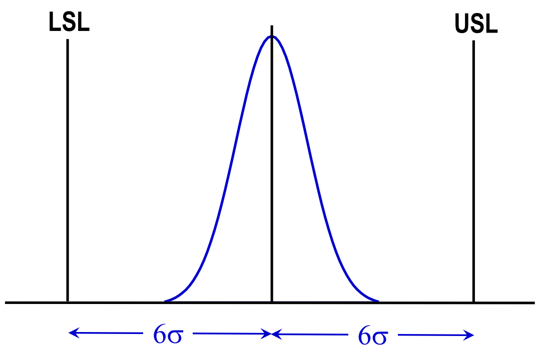
2,700 defective parts per million
2,000 pieces of mail lost each hour
20,000 wrong prescriptions per year
15,000 newborn babies dropped per year
No electricity or water 8.6 hours per month
500 incorrect surgical procedures each week

25

Pursuit of perfect quality (cont'd)

26

Motorola proposed a more aggressive objective



2 defective parts per *billion*

26

Allowing the mean to wander

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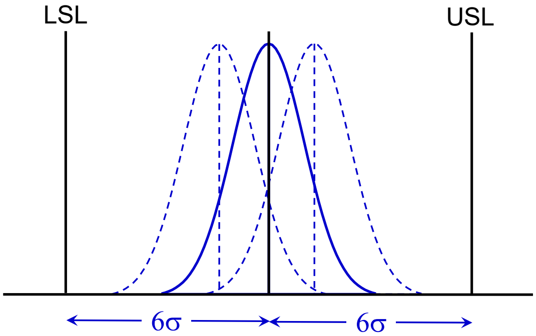

At most 3.4 defective parts per million (DPPM)

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Wandering mean (cont'd)

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- Motorola backed away from 2 defective parts per billion as the stretch goal
- They allowed that the process mean might wander as much as 1.5σ away from the spec midpoint
- At these extremes, the process would produce 3.4 defective parts per million (DPPM*)
- The ± 1.5σ offset was somewhat arbitrary, but 3.4 DPPM became the definition of "Six Sigma quality"

*For very low defect counts, instead of multiplying by 100 for a percentage (defects per 100), we multiply by 1 million to get DPPM (defects per 1,000,000)

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Doesn't have to be a Normal distribution . . .

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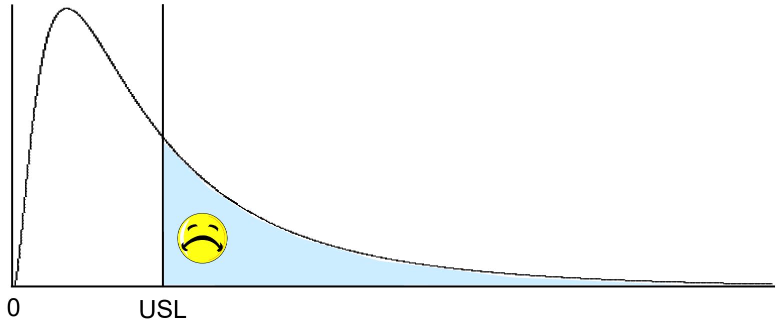
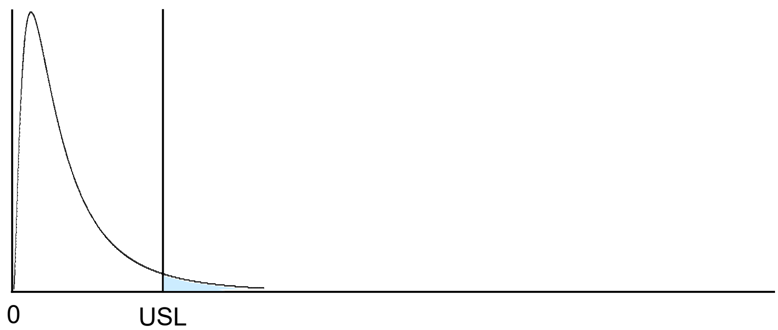
Before improvement project



. . . in fact, often it isn't

30

After improvement project



Why set the quality bar so high?

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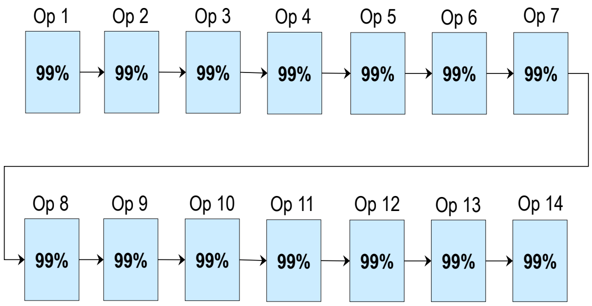
Suppose we have 10,000 DPPM (99% yield) for each operation



Area manager: "Our overall yield is 99%"

Is this true?

We can't repeal the laws of probability!

32

Overall yield* $=$ Probability of no defect in 14 operations

$$= 0.99 \times 0.99 \times \cdots \times 0.99 \text{ (14 times)}$$

$$= (0.99)^{14}$$

$$= 0.868746$$

Defect probability $= (1 - 0.868746) = 0.131254$

It's typical to report these probabilities as percentages:

$0.868746 \times 100 = 86.9\%$

$0.131254 \times 100 = 13.1\%$

Converted to DPPM: $0.131254 \times 1{,}000{,}000 = \boxed{131{,}254 \text{ DPPM}}$

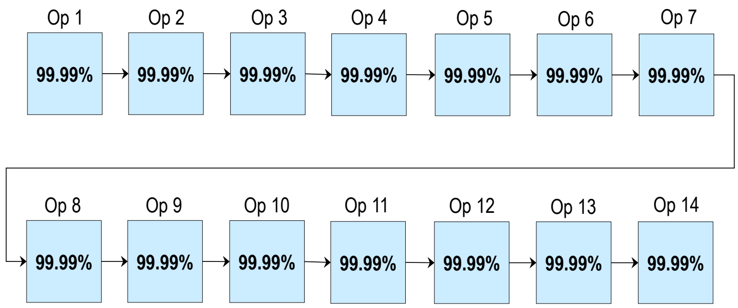
(compare to the Six Sigma quality level of 3.4 DPPM!)

*Also known as **cumulative yield**, **end-to-end yield**, and **rolled throughput yield**

Setting the quality bar (cont'd)

33

100 DPPM (99.99% yield) in each operation



Overall yield $= (0.9999)^{14} = 0.998601 \rightarrow 99.86\%$

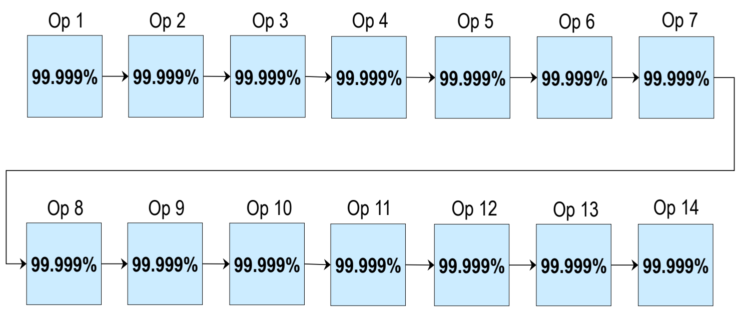
1399 DPPM

33

Setting the quality bar (cont'd)

34

10 DPPM (99.999% yield) in each operation



Overall yield $= (0.99999)^{14} = 0.999860 \rightarrow 99.986\%$

140 DPPM

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Exercise 2.1

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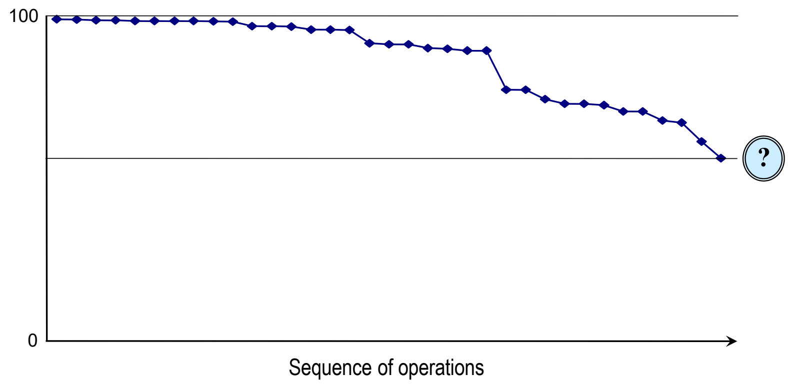
The average yield for 35 operations in an assembly process is 98.4%. Calculate the overall yield under the simplifying assumption that the yield for each operation is exactly equal to 98.4%. (The real answer would be the product of the actual operation yields.)



35

Exercise 2.1 (cont'd)

36

The area manager reported 98.4% as the overall yield of the operation. His reaction to the correct analysis followed the classic grief cycle:

Denial	*"This can't be right. There must be a mistake in your calculation."*
Anger	*"This is ridiculous. You're wasting my time."*
Bargaining	*"Isn't my method just as valid as your method?"*
Depression	*'This is really bad. What am I going to tell everyone?"*
Acceptance	*"I guess you can't solve a problem if you don't know you have it."*

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Pragmatic business initiative

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- In the 1990s, GE shifted the emphasis from the Six Sigma quality goal to *Six Sigma projects* — the way to pursue the goal
- Leaders and Champions define *key performance indicators* (KPIs) — a "balanced scorecard" including but not limited to $$ measures
- KPIs drive a prioritization process
- Prioritization tells us which project(s) should be first in line
- "Black Belts" or "Green Belts" lead the project teams
- "Champions" provide resources and remove barriers for the teams

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Champions

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- ✓ Management team members
- ✓ Identify and prioritize projects
- ✓ Assign project teams
- ✓ Provide teams with resources as needed
- ✓ Remove organizational barriers to project completion
- ✓ Provide project management support
- ✓ Communicate project results to the organization

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Comparison of Green and Black Belts

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Prerequisites and roles	Green	Black
• Experience in process improvement	✓	✓
• Strong teamwork, leadership, and people skills	✓	✓
• Basic Excel skills • Ability to acquire intermediate Excel skills	✓	✓
• Receive training in basic statistical concepts and methods	✓	✓
• Lead project teams	✓	✓
• Provide technical support to project teams	✓	✓
• Prior experience with statistical methods		✓
• Able to learn and use statistical software		✓
• Receive training in advanced statistical concepts and methods		✓
• Assist Champions in project identification and prioritization		✓

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Examples of projects

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Project	Annual $$ benefit
Reduce alpha case on large titanium castings	20,800,000
Reduce cost and lead time to develop extrusion tooling	2,000,000
Reduce wasted medication in hospital central pharmacy	1,100,000
Reduce roll stock inventory in box plant	768,000
Reduce cost of belt grinding in casting finishing	500,000
Improve the court collections process in city government	400,000
Reduce DOA replacement parts in field service	216,000
Reduce DPMO and amount of testing of circuit boards	192,000
Reduce electricity consumption in manufacture of airline storage bins	65,000
Reduce quoting turnaround time (not counting increased Purchase Order award rate)	34,000

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3 Why Combine Lean and Six Sigma?

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- They require the same *kaizen* culture
- They employ common strategies
- They focus on complementary problem areas
- They employ complementary methods
- They emphasize fact over opinion and use data to inform decisions
- One improvement infrastructure is better than two

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The need for kaizen

42

- Without *kaizen*, both Lean and Six Sigma fall into "top down, command & control, outside experts" mode
- Culture always beats methodology — benefits will be limited
- Improvement cycles must be integral to the daily work of all employees
- Teamwork across departments must be "business as usual"
- Open discussion of problems must be *safe* — emotionally and professionally
- "It's not a witch hunt — it's a *treasure* hunt"

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Common strategies

- Driven by Voice of the Customer
- Focus on eliminating waste
- Focus on processes and process improvement
- Improve processes via team projects
- Keep the improvement cycles going

Complementary problem focus and methods

Lean	Six Sigma
Lead and Cycle time WIP Other visible waste	Defects “Invisible” waste
Defects caused by chaos and confusion	Defects caused by materials and equipment
Root causes easier to determine. (Processes directly observable.)	Root causes harder to determine. (Processes often not observable.)
Value stream mapping Geographic mapping	Basic process mapping Cross functional process mapping
Defines and standardizes the “Wisdom of the organization”	Data collection and analysis to discover a new solution
Common Lean solutions can be adapted to many circumstances	Project roadmap provides a method for finding solutions

A single improvement infrastructure

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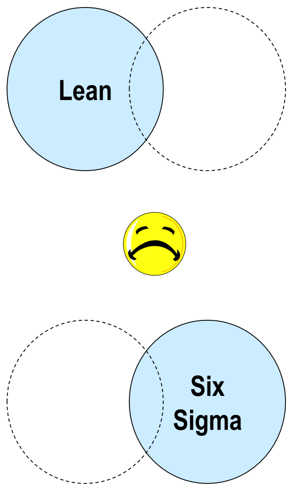

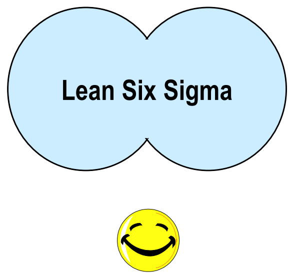

- Eliminates redundancy
- Eliminates wasteful competition for resources
- Provides a universal roadmap for improvement projects

Lean Six Sigma

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Originally, the Toyota Production System (TPS) included virtually all the tools of what we now call Lean Six Sigma (LSS). When TPS came to the USA, the Lean tools were adopted right away, but the Six Sigma tools were not. This made sense because there was plenty of "low hanging fruit" that could be harvested by Lean without undertaking the difficult task of teaching people statistical concepts and methods.

For many organizations, it still makes sense to embrace Lean concepts and methods first. The LSS project roadmap is an excellent vehicle for this. Eventually, organizations will need to tackle more difficult problems that cannot be solved with Lean concepts and methods. When this time comes, the LSS project roadmap provides the Six Sigma concepts and methods needed to solve the more difficult problems.

Thus, in the USA at least, we might think of Lean and Six Sigma as fraternal siblings separated at birth, reunited at last by LSS.

4 Relation of LSS to Other Initiatives

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- Strategic planning
- ISO 9001
- Voice of the customer
- Supply chain management
- Balanced scorecard

Strategic planning

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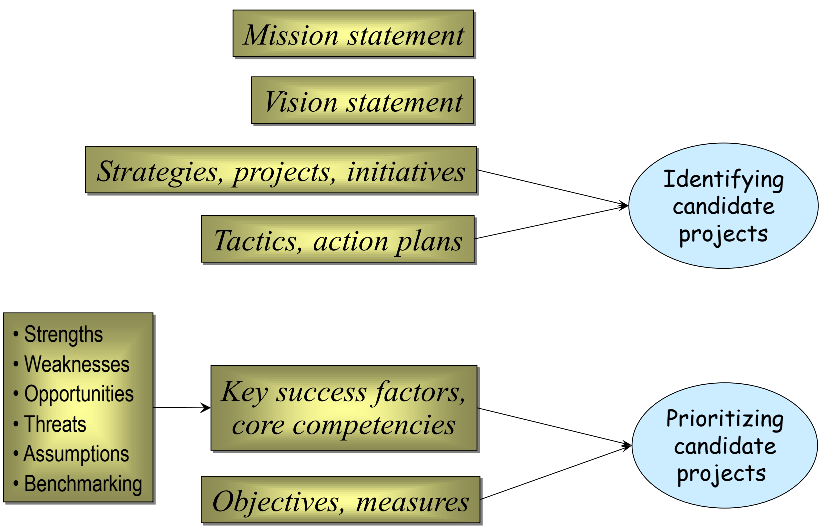

ISO 9001

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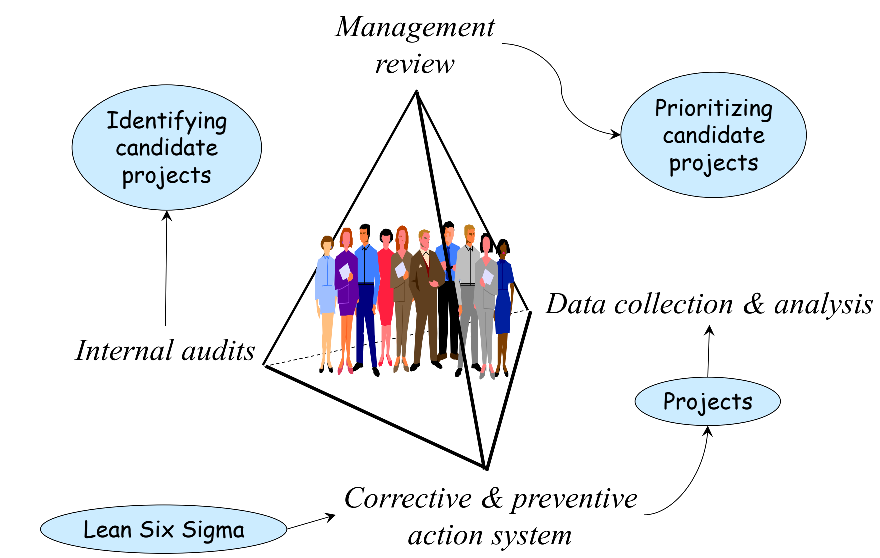
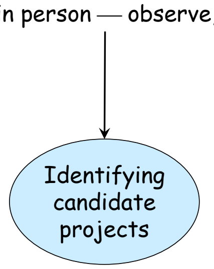


Voice of the customer

50

- Resolving complaints does not increase customer satisfaction
- Suppliers must *proactively* discover what customers really want
  - ✓ Collect and analyze data on customer feedback, complaints, returns, . . .
  - ✓ Visit customers in person — observe, listen, learn



Supply chain management

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- Finding the right suppliers
- Building partnerships, not just writing contracts
- Knowing and communicating your needs and expectations
- Listening to the “Voice of the Supplier”
- Monitoring your supplier’s performance
- Giving clear and useful feedback

Joint projects

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Balanced scorecard

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Financial

Revenue
Profit
Costs
⋮

Customer

Customer satisfaction
Quality
Delivery
Employee satisfaction
Safety
⋮

KPIs
Project prioritization

Internal process

Defects
Lead time
Supply chain performance
⋮

Learning & growth

New business
Effectiveness of training
Cumulative benefit of projects
⋮

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5 Deploying LSS Projects

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- Roles and responsibilities
- Limiting projects in process
- The continuous improvement cycle
- LSS and the Fire model

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Roles and responsibilities

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	Define KPIs	Identify candidate projects	Prioritize candidate projects	Champion projects	Lead projects
Top Mgmt	✓ Corporate level	✓	✓		
Champions	✓	✓	✓	✓	
Black Belts		✓	✓		✓
Green Belts	✓ LSS Project	✓	✓		✓

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Must limit projects in process

55

- Suppose we have two “belts”, each leading four projects
- They are spread too thin
- It takes a long time to get the projects done
- It takes a long time to accrue the benefits

55

Limit projects in process (cont’d)

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- Much better to give each of them one project at a time
- Now they have a manageable workload
- Project lead time is dramatically reduced
- Accrual of benefits is accelerated

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Continuous improvement cycles

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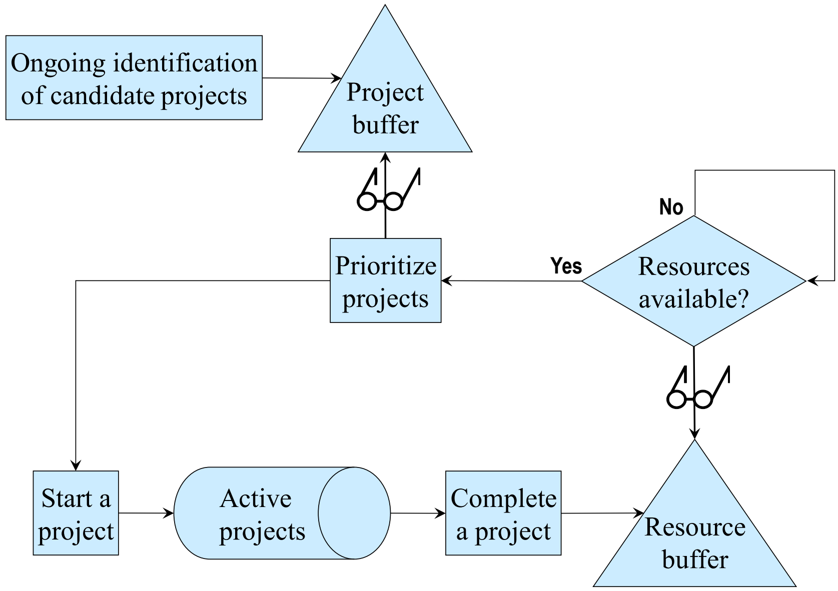

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LSS and the Fire model

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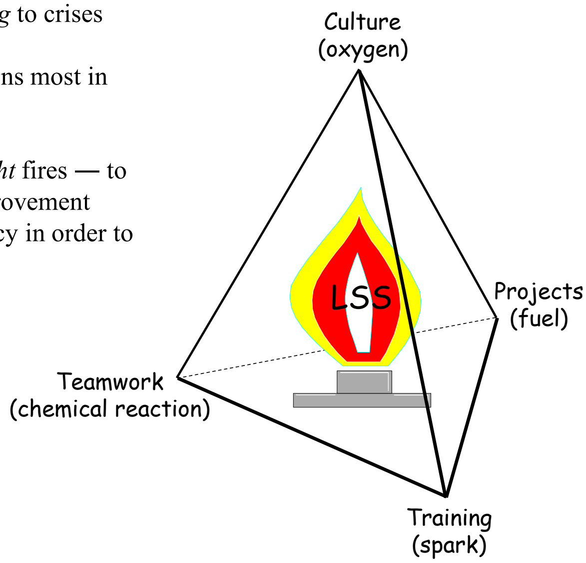
- Many organizations are stuck in fire-fighting mode — *reacting* to crises
- These are the organizations most in need of LSS
- The goal of LSS is to *light* fires — to pursue high priority improvement opportunities with urgency in order to *prevent* crises



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6 LSS Project Roadmap

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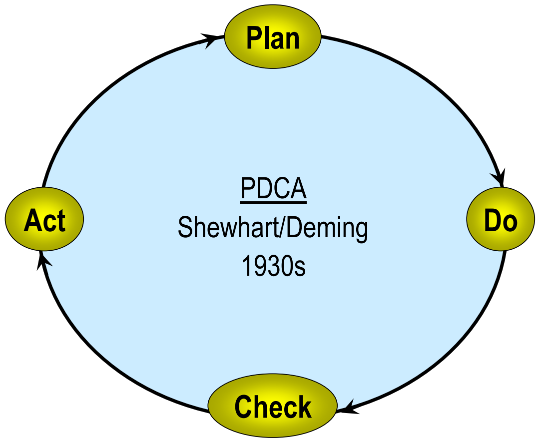

The scientific method applied to business problems

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PDCA (cont'd)

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Plan	Define the problem to be solved, collect and analyze data on the current state, identify possible causes of the problem.
Do	Identify possible solutions, select the most likely solution, pilot the solution.
Check	Analyze the results to see if the problem is solved.
Act	If the solution is successful, implement it. If the solution is not successful, repeat the cycle.

- PDCA is the oldest improvement cycle for manufacturing, business, and service processes
- It has been around for more than 80 years, it has served us well, and it is still in use

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DMAIC

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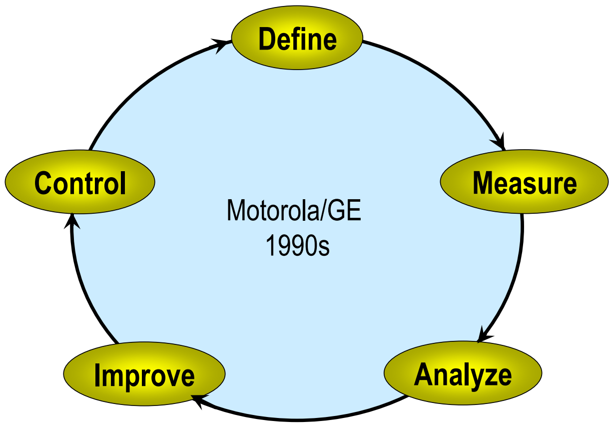

A high level description of today's most widely used improvement project roadmap

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DMAIC has more "teeth" than PDCA

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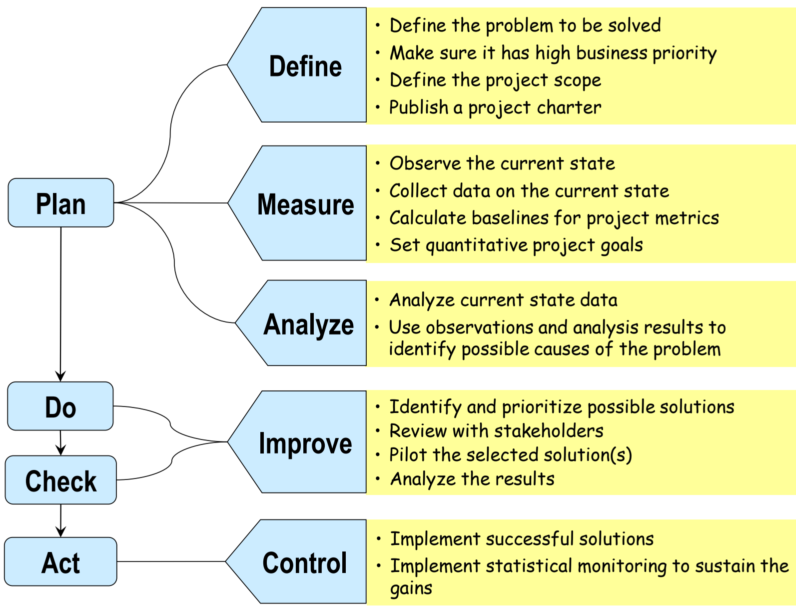

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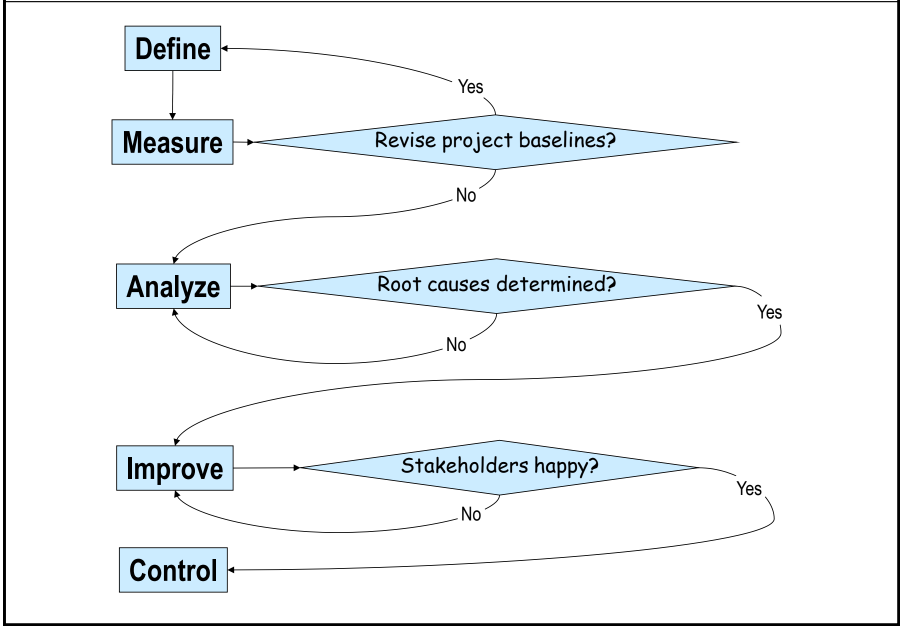
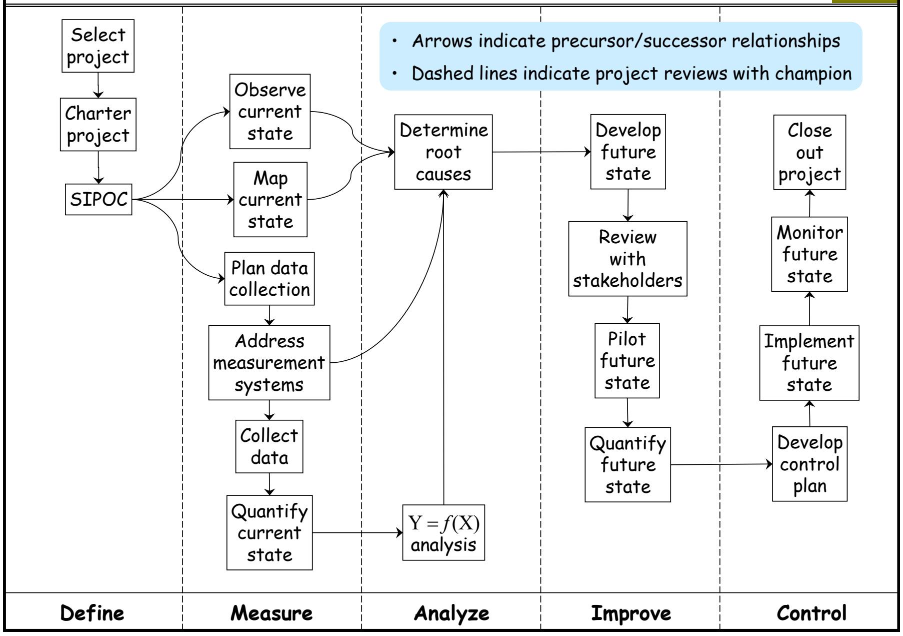
Common DMAIC complications



63

The LSS project roadmap (detailed version of DMAIC)



64

Strengths of LSS projects

65

- Aligned with business priorities
- Clearly defined scope and boundaries
- Combination of process observation and data analysis
- Solve problems by understanding them
- Conclusions supported by statistical standards of evidence
- Improvements verified quantitatively
- Statistical monitoring used to sustain gains

65

Characteristics of LSS projects

66

- We want to improve a process (the way we do something) or product (a way for customers to do something)
- The current process or product falls measurably short of what is needed or desired
- The cause of the problem is not known, or there is lack of consensus as to what it is
- Process observation and data collection/analysis are required
- Root cause analysis is required
- Lean solutions may or may not be applicable

66

Examples of LSS projects

67

	Probability that Lean solutions will apply
• Reduce injection molding defects	Low
• Reduce injection molding setup time	High
• Reduce oxidation layer on titanium castings	Low
• Reduce unplanned downtime	Medium
• Reduce Request For Quote (RFQ) turnaround time	High
• Reduce repair shop turnaround time	High
• Reduce the cost of belt grinding	Low

Other types of projects (non-LSS)

68

- We know what needs to be done, and we want to do it
- It may be simple, quick, and cheap (a "just do it" project)
- It may be complex, time consuming, and/or expensive (a "project management" project)
- All of the above involve *implementing known solutions*
- These projects could be action items *resulting* from a LSS project, but they are not in themselves LSS projects

Examples of non-LSS projects

69

Automate a task that is currently done manually

Upgrade software to the latest revision

Revise outdated work instructions

Install a new piece of equipment

Obtain environmental permits

Replace outdated computers

Install a bar coding system

Build a plant in China

69

Exercise 6.1

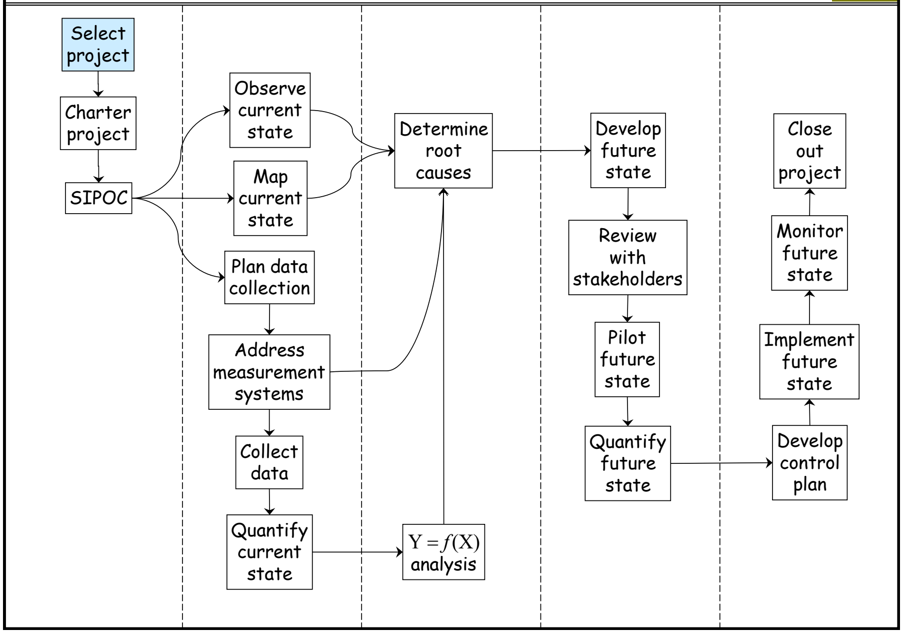
70

Classify these projects	LSS	Other
Implement the new ERP system we have decided to use		
Reduce errors in processing purchase requisitions		
Reduce wave solder defects		
Open a new branch office in the next town		
Reduce billing lead time		
Install a web-based ordering system		
Reduce non-manufacturing time from order to sell		
Reduce scrap in the coiling department		
Eliminate cracking of molded housings		
Reduce installation & warranty costs		
Increase the percentage of quotes that produce a PO		

70

7 Identifying Candidate Projects

71



Where do candidate projects come from?

72

- Benchmarking
  - ✓ If they can do it, why can't we?
- Vision of the future
- Demand expected to exceed current capacity
  - ✓ Seems to require capital expenditure
  - ✓ Better to reduce defects and lead times
- Voice of the customer (VOC)
  - ✓ Quality
  - ✓ Delivery
  - ✓ Cost
  - ✓ Service
- Cost of waste analysis
  - ✓ Follow the money

We will focus on these two

Capturing VOC data

73

Increasing effectiveness

- Direct observation of the customer's process
  - ✓ Engage customers in conversation around their work
  - ✓ Not specific to product features
  - ✓ Capture their words — clues to unspoken needs
- Interviews
  - ✓ One on one, team on team, focus groups . . .
- Surveys
  - ✓ Telephone, mail, email, website . . .

73

VOC survey method

74

Ask two questions for each customer requirement

What is the importance of this requirement to you?

H. How important is it to you that we deliver our products within one day of your requested delivery date?

__X__ 5. Most important
_____ 4. Very important
_____ 3. Moderately important
_____ 2. Slightly important
_____ 1. Not important at all

What is your level of satisfaction with our performance relative to this requirement?

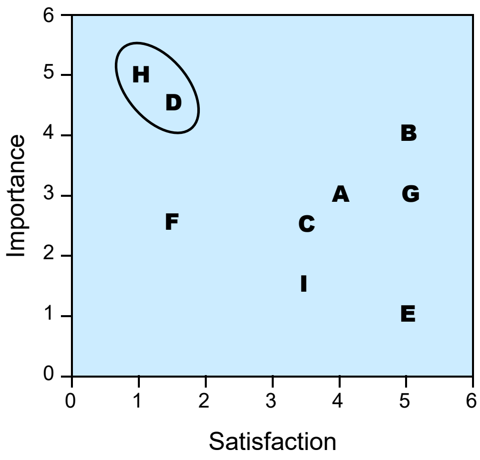
H. What is your level of satisfaction with our delivery performance relative to your requested delivery date?

_____ 5. Completely satisfied
_____ 4. Very satisfied
_____ 3. Moderately satisfied
_____ 2. Slightly satisfied
__X__ 1. Not satisfied at all

74

"Perceptual map" based on VOC data

75



- Average importance vs. average satisfaction for requirements A thru I
- Need improvement projects directed at requirements H and D
- The averages could represent multiple customers (smaller companies)
- They could also represent multiple individuals with different roles within a single customer (larger company)

75

Exercise 7.1

76

Discuss the following questions:

(a) What types of Voice of the Customer (VOC) information does your organization monitor and analyze?

(b) How is this VOC information obtained? That is, who gathers it and what methods are used to do so? These methods may be both formal and informal.

(c) How might you use VOC information to identify potential LSS projects for your area of the organization? Consider both internal and external customers.

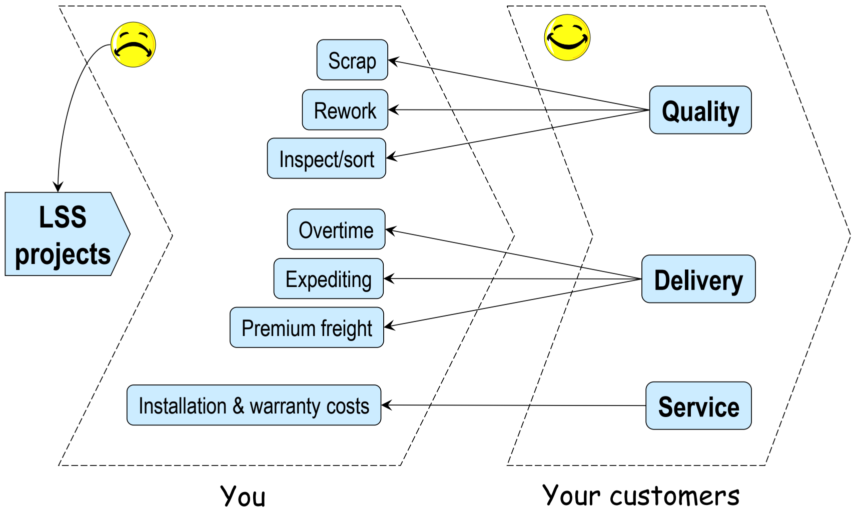
(d) What are some past examples of decisions, actions, or improvement projects based on VOC information?

76

Often your customers are happy . . .

77

. . . but you're killing yourself to make it so



77

Cost-of-waste analysis

78

- Includes, but not limited to, cost of poor quality
- Assists in project selection and scoping
- Needed to establish project baselines
- Assists in defining project goals
- Needed to determine project benefits
- Money speaks loudest in many organizations

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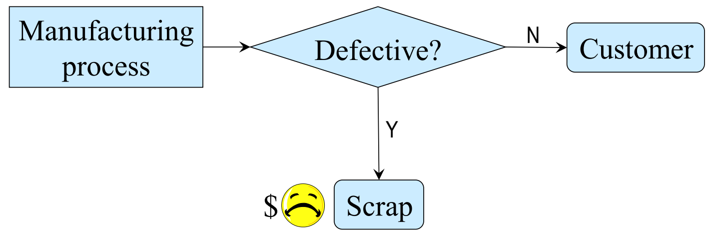
Apparent cost of poor quality

79



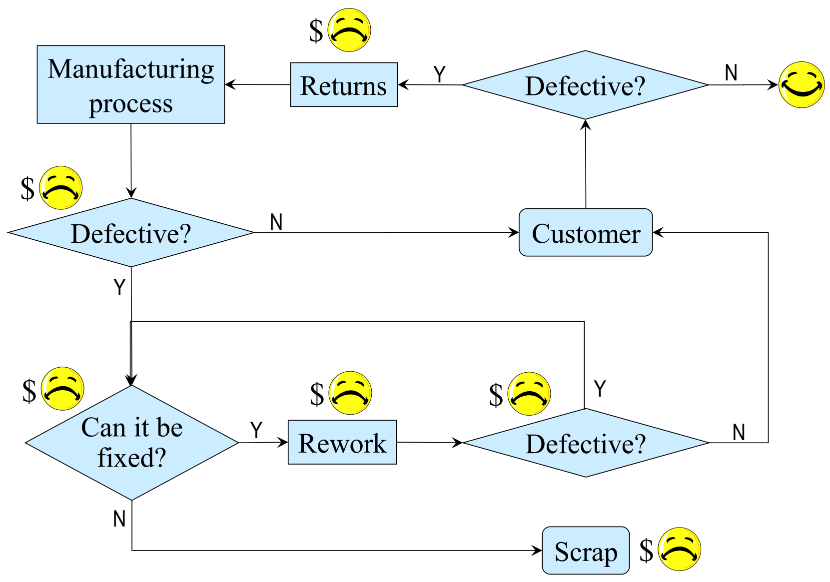
79

What is the real cost of poor quality?

80

80

The "hidden factory"



81

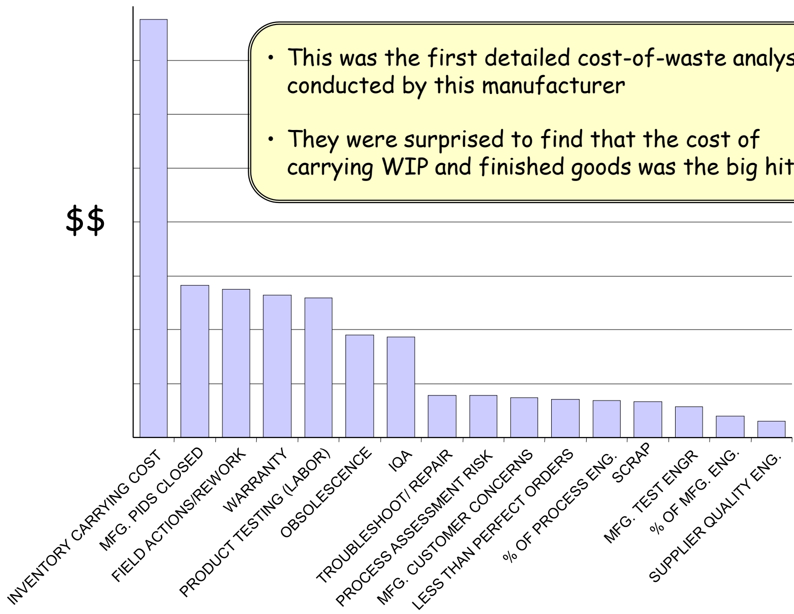
Hidden factory (cont'd)

- Inspections to sort good parts from bad
- Efforts to determine causes of defects
- Inflating material orders and time/cost standards
- Returned goods
- Service activity under warranty
- Trips to placate unhappy customers
- Loss of business due to unhappy customers
- Reworking or scrapping defective parts
- Complicated inventory management
- Specialized training for rework processes
- Specialized rework equipment
- Capacity allocated to rework
- Special rework qualification processes

82

Example: cost-of-waste analysis

83



- This was the first detailed cost-of-waste analysis conducted by this manufacturer
- They were surprised to find that the cost of carrying WIP and finished goods was the big hitter

83

Costs of poor transactional quality

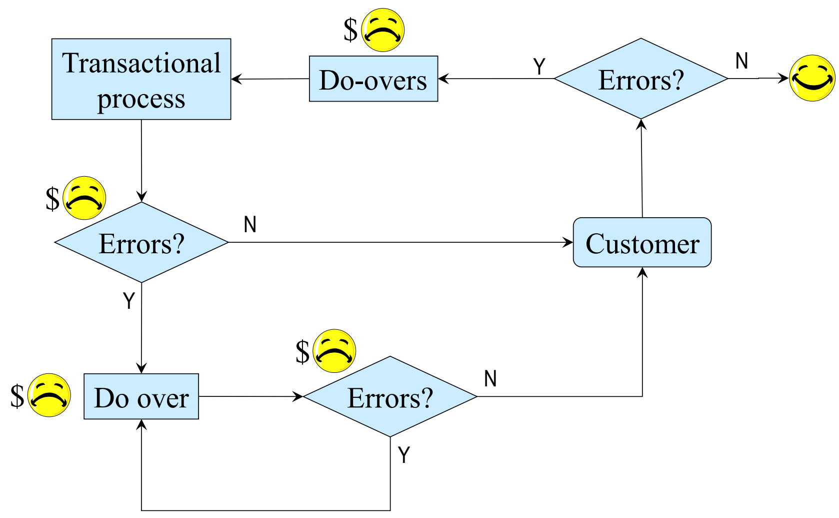
84

- Waste is harder to see in transactional processes
- The only quantifiable cost factor is the time people spend on NVA activities
- Even if this time is reduced, there will be no actual cost reduction (unless people are laid off)
- The real benefits are
  - ✓Reducing lead time,
  - ✓Increasing customer satisfaction, and
  - ✓Increasing capacity without additional resources

84

The “hidden office”

85



85

Hidden office (cont’d)

86

- Doing things over again due to errors or omissions
- Inspections to find errors and omissions
- Workarounds necessitated by root causes not being addressed
- Efforts to determine causes of errors and omissions
- Loss of business due to unhappy customers

86

Other costs of waste (from the Lean playbook)

87

D	Failure to meet expected standards of quality or delivery
O	Making or doing more than is needed at the time
W	People waiting to work, or things waiting to be worked on
N	Failure to integrate improvement cycles into the daily work of all employees
T	People or things being moved from one place to another
I	Supplies, WIP, or finished goods beyond what it is needed
M	Excessive motion in the completion of work activities
E	Producing or delivering to a higher standard than is required

Exercise 7.2

88

a) The current practice of a central pharmacy in a hospital is to prepare all IV piggybacks and syringes for each day at 7:00 am. Every day, some of this medication is wasted because patients are discharged, transferred, or have their medication orders changed. The anecdotal estimate of the annual cost of this waste is $100,000. Open *Data Sets* → *hospital central pharmacy* to use the “hidden factory” data given below and in the spreadsheet to get a better estimate of the annual cost of waste. (Assume 52 working weeks per year.)

Weekly averages	
Number of doses wasted	657
Staff hours spent retrieving wasted doses	21
Staff hours spent disposing of wasted doses	10

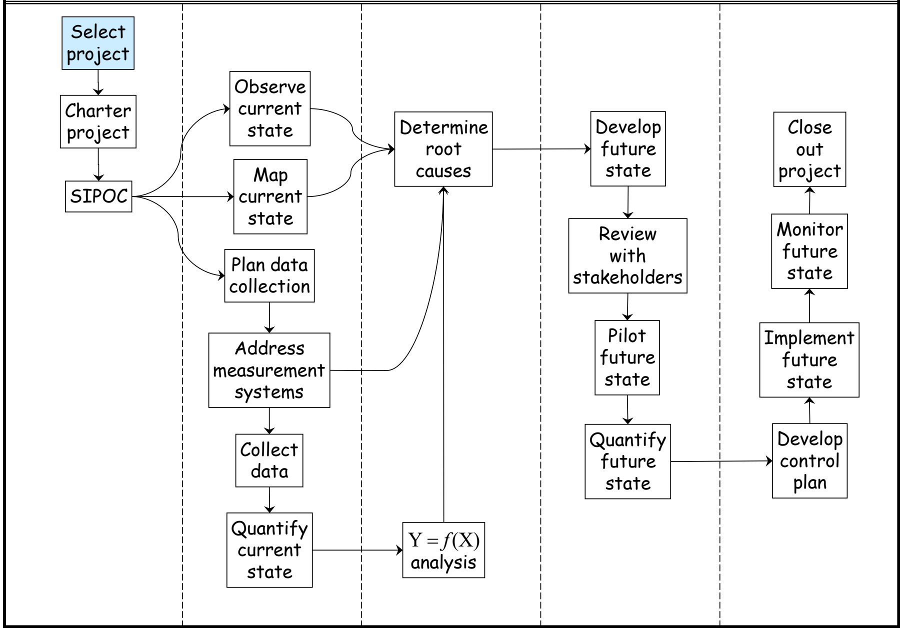
Average rates	
Product cost per dose	$14
Disposal fee per dose	$42
Labor cost per hour	$23

b) Suggest a way to reduce the cost of waste in this example.

c) What other costs or impacts can you think of that might be occurring due to this practice?

8 Prioritizing Candidate Projects

89



89

Qualitative description of a good improvement project

90

Clearly defined problem, scope, and boundaries	**S**pecific
Clearly defined project metrics with baselines and goals	**M**easurable
Resources available, good chance of success, rapid benefits	**A**chievable
Aligned with business priorities	**R**elevant
Can complete in a reasonable amount of time	**T**ime-bounded

How do we quantify these attributes?

90

Examples of project feasibility metrics

- ✓ High likelihood of solving the problem
- ✓ Rapid completion of project
- ✓ Rapid realization of benefits
- ✓ Availability of required resources
- ✓ Availability of data
- ✓ Process is easy to change
- ✓ . . .

Feasibility metrics (cont'd)

Sometimes people want to use *cost of implementation* or *ease of implementation* as feasibility metrics. The *cost* metric doesn't make sense for LSS projects, because we don't know what the solution is going to be. The same can be said for the *ease* metric, if it refers to a solution.

If, on the other hand, the *ease* metric refers to the changeability of the in–scope workflow, then it is valid.

Measures of project impact: KPIs

93

- ✓ Customer satisfaction — quality, delivery, service . . .
- ✓ Revenue, cash flow, cost of waste . . .
- ✓ Growth in existing markets
- ✓ New market penetration
- ✓ Lack of adverse safety impact
- ✓ Lack of adverse environmental impact
- ✓ . . .

93

KPIs (cont'd)

94

An organization should use its *key performance indicators* (KPIs) to measure the probable impact of proposed improvement projects. KPIs are often established during a strategic planning process.

If your organization has a balanced scorecard, it has already taken a step towards understanding what its KPIs are. If a KPI in a balanced scorecard is defined too broadly, it will need to be broken down further to be useful in project prioritization. An example would be breaking "customer satisfaction" into separate KPIs for quality, delivery, and service.

KPIs should be defined *before* they are used to prioritize projects. This helps people distinguish between the KPIs and the projects themselves, which in turn helps in scoping projects appropriately. For example, "reduce scrap and rework" is too broad for a project scope. A better project scope would be something like "reduce scrap and rework for product XYZ."

KPIs are supposed to reflect the priorities of the organization. As such, they should change when these priorities change, and only then.

94

Instructions for prioritizing projects

95

1. Open *Student Files* → *blank C&E matrix – impact & feasibility*.
2. In the *Metrics* sheet, change *Impact metrics* to *KPIs*. (Already done)
3. List your KPIs and relative weights.
4. List your feasibility metrics and relative weights.
5. Go to the *Impact ratings* sheet, change *Items to be ranked* to *Projects*.
6. List the candidate projects you wish to rank.
7. Rate each project for degree of positive impact on each KPI (by H, M, L).

Prioritizing projects (cont'd)

96

8. Go to the *Feasibility ratings* sheet, rate each project for each feasibility metric (by H, M, L).
9. Go to the sheet *Impact–feasibility plot* to evaluate the results.

Student Files \ prioritizing projects – example 1

97

Metrics tab

KPIs	Relative weights		Feasibility metrics	Relative weights
Reduce cost of waste	1		Short time frame	1
Customer satisfaction - quality	2		Low complexity	1
Customer satisfaction - delivery	2		Skill set available	2
No adverse safety impact	1		Process is easy to change	1

97

Metrics (cont'd)

98

- Enter your KPIs in the *Metrics* sheet
- State KPIs in "higher is better" form — for example, use "reduce cost of waste" instead of "cost of waste"
- Enter relative weights (importance) for the KPIs. Here is a process for doing this:
    1. If the KPIs are equally important, weight them all as 1.
    2. If some KPIs are more important than others, split them into a more important group and a less important group.
    3. If some KPIs in a group are more important than others, split them into a more important subgroup and a less important subgroup.
    4. If necessary, split subgroups into sub-subgroups.
    5. If you end up with two homogeneous groups, use weights 1 and 2. If you end up with three homogeneous groups, use weights 1, 2, and 3. And so on.
- Everything said here applies as well to your feasibility metrics.

98

Impact ratings

99

KPIs	Reduce cost of waste	Customer satisfaction - quality	Customer satisfaction - delivery	No adverse safety impact	0	0	0
Relative weights	**1**	**2**	**2**	**1**	**0**	**0**	**0**
Reduce manufacturing downtime	M	L	H	H			
Reduce NCR turn time	M	L	L	H			
Reduce out-of-box failures	M	H	L	H			
Reduce redundant inspections	M	L	M	H			
MS II source manufacturing	L	H	M	H			
Improve automatic tester capability	H	M	M	H			
Reduce in-line defects	H	M	M	H			

99

Comments on impact and feasibility ratings

100

The previous slide shows the *Impact ratings* sheet with some project titles entered. Our job is to rate each project as having high (H), medium (M), low (L), or no impact (blank) on each KPI. The numerical codings for H, M, and L are specified in the sheet *Impact calculations*.

Ideally, the team should assign the ratings one KPI at a time, working vertically, because our goal is to prioritize the projects, not the KPIs. If you would rather assign the ratings one project at a time, just make sure to check that the resulting project rankings for each KPI make sense.

The next slide shows the *Feasibility ratings* sheet. Here we rate each project as high (H), medium (M), or low (L) for each feasibility metric. The numerical codings are specified in the *Feasibility calculations* sheet. A blank Feasibility ranking should not occur. Why?

As for the impact ratings, it is best if the team assigns feasibility ratings one metric at a time. If you would rather assign the ratings one project at a time, just make sure to check that the resulting project rankings for each feasibility metric make sense.

100

Feasibility ratings

101

Feasibility metrics	Short time frame	Low complexity	Skill set available	Process is easy to change	0	0	
Relative weights	**1**	**1**	**2**	**1**	**0**	**0**	**0**
Reduce manufacturing downtime	M	M	H	H			
Reduce NCR turn time	H	M	H	M			
Reduce out-of-box failures	L	M	H	M			
Reduce redundant inspections	M	M	H	M			
MS II source manufacturing	L	L	L	L			
Improve automatic tester capability	H	M	H	H			
Reduce in-line defects	L	L	L	L			
0							
0							
0							

Impact-feasibility plot

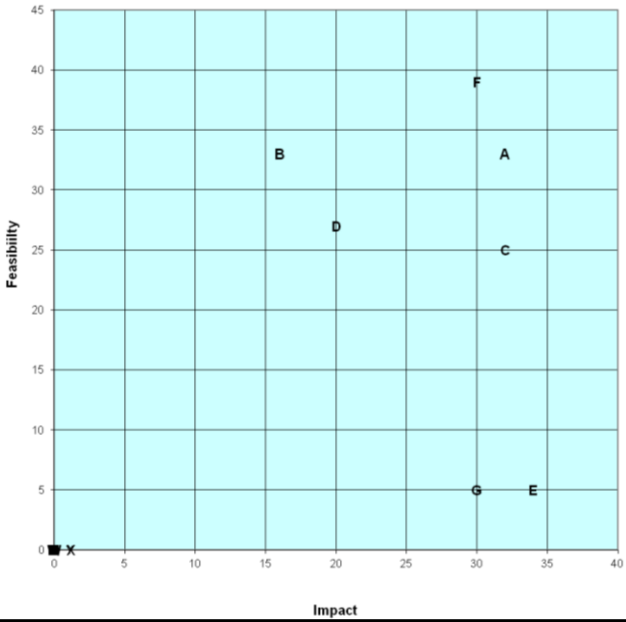
102

Projects	Tag	Impact	Feasibility
Reduce manufacturing downtime	A	32	33
Reduce NCR turn time	B	16	33
Reduce out-of-box failures	C	32	25
Reduce redundant inspections	D	20	27
MS II source manufacturing	E	34	5
Improve automatic tester capability	F	30	39
Reduce in-line defects	G	30	5
0	H	0	0
0	I	0	0
0	J	0	0

- Project names and impact ratings are carried forward from the *Impact ratings* sheet
- Feasibility ratings are carried forward from the *Feasibility ratings* sheet

Impact-feasibility plot (cont'd)

103



103

Impact-feasibility plot (cont'd)

104

This is a scatterplot of the overall impact and feasibility scores for the projects. The upper right hand corner is the "sweet spot." Projects that score highly for both impact and feasibility should be your first priority.

Based on the plot, projects A and F both have high priority based on the plot. Assuming you have resources for only one project, how should you choose between them?

The answer to this question can be found by considering the maturity of your organization with respect to continuous improvement. If your organization is solidly committed to continuous improvement, and has been at it long enough to dispel any skepticism in the workforce, you should go with A (greater impact). On the other hand, if your organization has just started its continuous improvement journey, and you want a high probability success to win over the skeptics, you should go with F (greater feasibility).

104

Student Files \ prioritizing projects - example 2

105

Worksheet: "Metrics"

KPIs	Relative weights		Project feasibility metrics	Relative weights
Improve cust. satis. w/delivery	2		Process is easy to change	3
Improve cust. satis. w/quality	2		Rapid completion of project	2
Improve cash flow	1		Needed resources available	2
Improve P, Y, E	1		Highly likely to solve the problem	1
Lack of compliance/safety impact	1			
Lack of environmental impact	1			
Reduce other cost	1			
Reduce scrap or rework	1			

Impact and feasibility scores

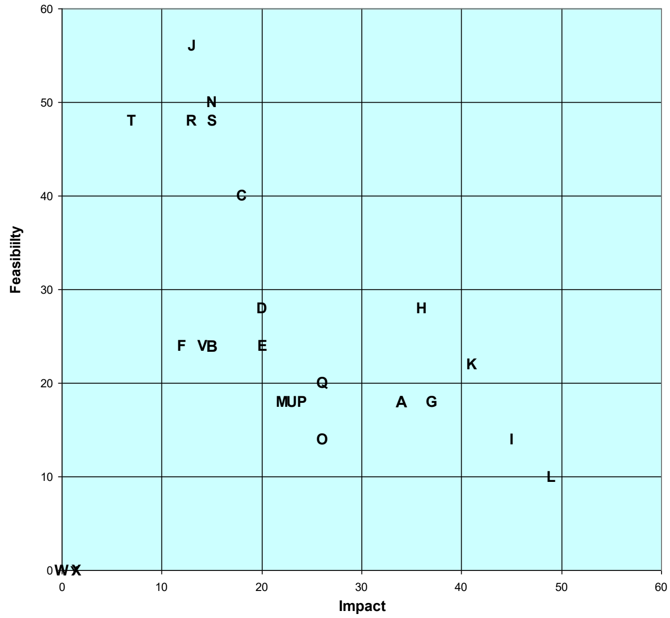
106

22 projects!

Projects	Tag	Impact	Feasibility
Improve first pass yield of sonic welding	A	34	18
Reduce injection molding start-up scrap	B	15	24
Reduce final assembly cycle time for exterior SAE compliant lamps	C	18	40
Improve first pass yield of manual solder	D	20	28
Improve first pass yield of wave soldered parts	E	20	24
Reduce internal scrap due to material handling	F	12	24
Reduce scrap in painting	G	37	18
Reduce scrap in metallization	H	36	28
Reduce scrap in doming	I	45	14
Reduce scrap in epoxy mixing	J	13	56
Reduce internal fog lamp process	K	41	22
Improved first pass yield of name plates thru painting and doming	L	49	10
Reduced plant power consumption	M	22	18
Reduce product development testing cost	N	15	50
Reduce product development time	O	26	14
Improve % of products that meet requirements 6mos after PPAP	P	24	18
Reduce number of design changes post design freeze prior to SOP	Q	26	20
Reduce payables processing time	R	13	48
Improve reporting accuracy of end of life service only product cost	S	15	48
Reduce period end closing time	T	7	48
Reduce working capital as a % of sales	U	23	18
Reduce warranty returns of lamps with water ingress	V	14	24

Impact-feasibility plot

107



107

Impact-feasibility plot (cont'd)

108

- Nothing in the "sweet spot"
- Instead, an "efficient frontier" running from project J down to project L
- This company had been at it for a while, so they chose project L

108

Exercise 8.1

109

Open *Student Files → prioritizing projects – exercise*. Use your knowledge and experience to do the following tasks.

a) Choose three (3) of the given KPIs to use in the exercise. Feel free to modify the weights for the impact and feasibility metrics as desired.

b) Rate the projects with respect to impact for the 3 KPIs you chose.

c) Rate the projects with respect to feasibility, using the given metrics.

d) Use the impact–feasibility plot to determine which of these projects your team would give top priority.

Exercise 8.2

110

This is "homework" to be done as a group activity involving Black Belt candidates and individuals likely to serve as Champions. It could also include other stakeholders. Do (a) and (b) first. Do (c) and (d) later in a separate session.

(a) Identify KPIs likely to be used by your organization to prioritize improvement projects.

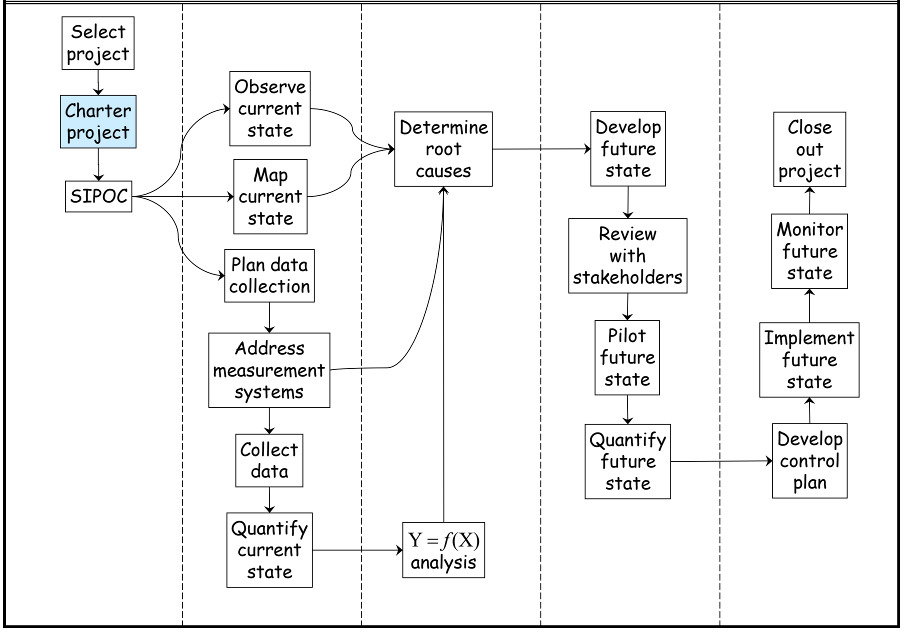
(b) Identify feasibility metrics likely to be used by your organization to prioritize improvement projects.

(c) Compile a list of candidate improvement projects.

(d) Use the project prioritizer to rank these projects.

9 Chartering LSS Projects

111



Elements of a project charter, *Student Files → blank charter*

112

Project Charter elements marked with an asterisk (*) are mandatory

*Project title

*Problem statement

Goal statement (qualitative)

*Value stream and Workflow scopes; Out of scope items, processes, depts, etc.

Constraints, concerns, assumptions

*Primary project metrics, baseline values & goals, KPIs affected

Secondary ("do no harm") metrics, baseline values

*Team members and roles/responsibilities

*Resources and roles

*Stakeholders and their connection to the project

*Milestones with planned and actual review dates for project start and DMAIC phase reviews

Approvals

Purpose of the charter

113

- Make the business case for the project
- Define the project scope and process boundaries
- Define the project metrics, give baselines and goals
- Identify the project team
- Identify resources for the team
- Identify stakeholders affected by the project outcome
- Provide a starting point for managing the project
- Create buy-in and excitement

113

The charter must evolve with the project

114

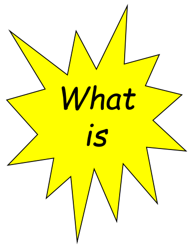
- Baselines for benefit metrics may not be known initially — update the charter when these are determined
- Project scope may be modified as new information comes to light
- Stakeholders may change if the project scope is modified
- Additional resources may be needed to overcome unanticipated barriers
- Anticipated completion dates for project reviews may have to be pushed out

114

Problem statement

115

- Describes the current situation in objective terms
- Does not suggest or imply causes &/or solutions
- Locates the problem in time
- Can include baseline values of project metrics
- Gives enough information that people outside the team can understand what the project is about



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Problem statement guidelines

116

State the effect
Say who and what are affected, and how they are affected. Say what is wrong, not why it is wrong. Avoid "due to" or "because of" statements — they imply solutions.

Be specific
Avoid general terms like "morale," "productivity," "communication" and "training" — they tend to have a different meaning in each person's mind. Use specific, operationally defined terms to narrow the focus to the problem at hand.

Use positive statements
Avoid "lack of" statements (e.g., not enough, we need, we should). Negative statements imply solutions. Do not state a problem as a question — this implies that the answer to the question is the solution.

Quantify the problem
Say how much, how often, when, where. Use project metrics.

Focus on the "gaps"
Compare the current levels of the project metrics to previous levels, expected levels, or desired levels. These will also be presented in the *Project metrics* section.

116

Example: Critiquing a problem statement

117

In 2024 there were 15 industrial accidents site wide. Previously, the annual average was 2.5 with at most 7 in a given year. This new level represents a significant decline in employee safety. If it continues, we will see a $200,000 increase in annual costs, and substantially decreased productivity.

117

Example: Checklist for critiquing a problem statement

118

- ❑ What is happening? (No causes or solutions)
- ❑ Who is affected by the problem?
- ❑What are the "gaps"?
- ❑ What are the consequences of not solving the problem?
- ❑ Where does the problem occur?
- ❑ When does the problem occur?
- ❑ When did the problem start?

118

Exercise 9.1

Critique this problem statement using the checklist on the next slide. Check the boxes for questions that are answered. The purpose of this process is to note which questions are *not* answered.

Customers are dissatisfied with telephone support wait times for calls handled through our call center in Uzbekistan. Our records show an average wait time of 8 minutes. 10% of wait times exceed 20 minutes.

Checklist for critiquing a problem statement

- ❑ What is happening? (No causes &/or solutions)
- ❑ Who is affected by the problem?
- ❑ What are the "gaps"?
- ❑ What are the consequences of not solving the problem?
- ❑ Where does the problem occur?
- ❑ When does the problem occur?
- ❑ When did the problem start?

Evolution of problem statements

121

☹	😐	☺
We are unhappy with our customers because they don't pay our invoices on time.	15% invoices submitted to customers are paid more than 60 days late.	20% of invoices submitted to Customer X last year were paid more than 60 days late. This compares to 5% for our other customers.
Due to lack of training in the ED (Emergency Dept.), patients are waiting too long.	The average wait time for ED patients has increased from 1 hour to 2 hours.	In the last 6 months, the average wait time for ED patients during peak hours has increased from 2 hours to 4 hours.

121

Evolution of problem statements (cont'd)

122

☹	😐	☺
Regional account managers submit RFQs (Requests for Quotes) to business units on behalf of customers. The account managers say our customers are voicing dissatisfaction with our long quotation turnaround times (TATs). The business units don't really think there is a problem. If there is a problem, it is most likely caused by the account managers.	Regional account managers submit RFQs to business units on behalf of customers. The expectation is to turn quotes within 3 days. According to the account managers, this expectation is not being met in many cases. This is causing customer dissatisfaction and lost orders.	Regional account managers submit RFQs to business units on behalf of customers. The expectation is to turn quotes in 3 days. Over the past 17 months, 27% have exceeded 3 days. The TATs have ranged from 1 to 29 days, with an average of 2.8 days. We suspect that long TATs are at least partially responsible for lost orders. (*Student Files \ Case Studies \ quotation process \ quotation process charter*)

122

Example Problem statement: *Student Files \ Case Studies \ tool development \ tool development charter*

123

As our business has grown over the years, our tool development process has become a major problem. The primary customer complaint is that our order-to-sell time is too long. This is caused primarily by large numbers of tool rework cycles. Over the past year, the number of reworks per tool ranged from 0 to 18. The order-to-sell time ranged from 3 to 57 days. The rework cost per tool ranged from 0 to $32,400. We cannot compete on price with our Chinese competitors, so our only hope is to compete on quality and lead time.

A secondary problem is that many of the tools released to manufacturing from the current testing process require slow line speeds and high material weight.

123

Example Problem statement: *Student Files \ Case Studies \ Ti casting \ Ti casting charter*

124

"Alpha case" is an oxidation layer commonly found on titanium castings in the as-cast condition. It must be removed by chemical milling. Alpha case is measured by chemical analysis of coupons taken from the castings. The upper specification limit for O_2 is 200 PPM. Over the past six months, post-milling O_2 levels on large titanium castings have gradually trended upward. It has become common practice to send castings back for one or more extra chemical mills to bring the O_2 below 200. Each extra cycle reduces our profit margin by $TBD and adds TBD days to the lead time.

In the past two months, repeated chemical milling has failed to solve the O_2 problem for increasing numbers of castings. Instead, these castings are scrapped for dimensional nonconformance. This has resulted in scrap costs of about $400,000 per week, and has severely hindered our ability to meet delivery schedules.

124

Exercise 9.2

125

(a) Write a problem statement for the project you and your team currently have in mind. Leave blanks for metrics, as needed.

(b) Share your problem statement with another team. Take appropriate precautions for any proprietary information.

(c) Write a critique of the problem statement you receive from another team.

(d) Share your critique with the other team and the class. (Start by saying something positive.)

(e) Revise your problem statement in light of the other team's comments.

125

Exercise 9.2 (cont'd) Problem Statement Outline/Critique Checklist

126

- ❑ What is happening? (No causes &/or solutions)
- ❑ Who is affected by the problem?
- ❑ What are the "gaps"?
- ❑ What are the consequences of not solving the problem?
- ❑ Where does the problem occur?
- ❑ When does the problem occur?
- ❑ When did the problem start?

Problem Statement Guidelines

- State the effect
- Be specific
- Use positive statements
- Quantify the problem
- Focus on the "gaps"

126

Examples of goal statements

127

- Reduce the number of reworks per tool by 50%.
- Meet the 3-day turnaround time (TAT) expectation 95% of the time.
- Achieve O_2 level of 200 PPM or less for all castings after first chemical milling.
- Complete all first project reviews within the 10-day expectation.

127

Project scope: the two dimensions

128

Value stream scope

- Which customers?
- Which products?
- Which services?
- Which locations?
- Which suppliers?
- Which materials?

Workflow scope

- Starts with an RFQ (request for quote) from the customer, ends with an approved quote or a request to modify the RFQ.
- Starts with receipt of a CAD drawing from the customer, ends with an approved tool and run conditions released to Manufacturing.
- Starts with ceramic slurry make up, ends with a finished casting.
- Billing, payment, adjustment, and collection.
- Order processing, fulfillment, and costing.

128

Examples of project constraints and concerns

129

Constraints	Concerns
• Deadlines for project completion • Types of solution excluded • Limitations on availability of resources • Limitations on availability of data • . . .	• Several previous attempts to solve this problem were unsuccessful • The low average TAT has created the impression there is no problem • None of the process participants want to be on the team • Our yield is currently 0%, so we must move quickly to solve this problem • . . .

129

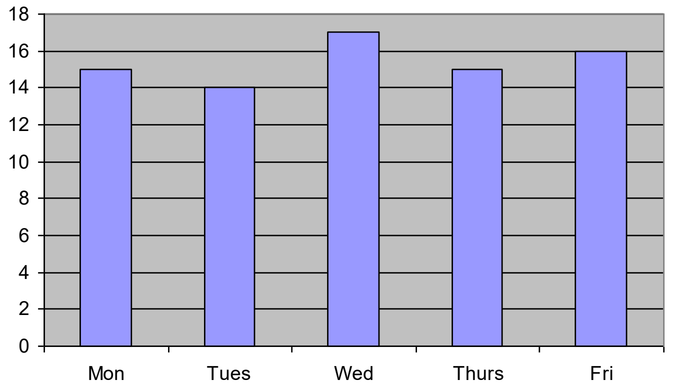
Examples of project assumptions

130

- How often the team will meet
- How long the meetings will be
- Time to be spent on the project by each team member
- Roles and responsibilities of the team members
- In scope solutions will apply to out of scope areas
- We will be able to get some process participants on the team
- We will engage stakeholders and convince them to support the project
- . . .

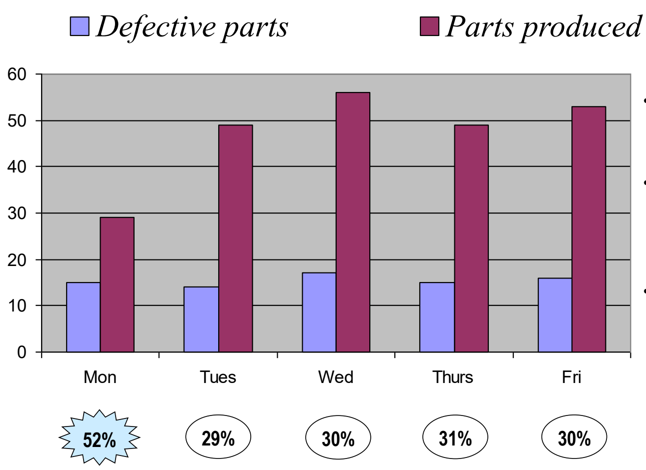
130

Project metrics



- Total number of defective parts last month, by day of week
- Can we conclude that Tuesdays are best and Wednesdays are worst?

Project metrics must be normalized!



- Part volume was lower on Mondays
- % Defective is much higher on Mondays
- The problem is worse on Mondays than on other days

Categories of Project Metrics

133

The three main categories of project metrics are quality, delivery and cost.

- It is recommended that your primary metric be a Quality or Delivery metric, in order to keep your project focused on the process.
- With process improvement, cost will follow.

If your primary metric is:	**Secondary metrics to consider are:**
Quality (defects, scrap, rework, etc.)	Delivery and Cost
Delivery (time to complete, on-time delivery, etc.)	Quality and Cost
Cost	Quality and Delivery

Examples of project metrics

134

a) Statistics calculated from current state data (must be *normalized*)

Statistic	Data needed to calculate statistic
Avg. number of reworks	Numbers of reworks for N tools
Avg. time order to sell	Order to sell times for N tools
PO hit rate %	PO (yes or no) for N quotes
% TAT > 3	TAT > 3 (yes or no) for N quotes
Avg. TAT	Turnaround times for N quotes
% O_2 > 200	O_2 > 200 (yes or no) for N castings after first chem. mill
Avg. O_2	O_2 levels for N castings after first chem. mill

↑

Do you see a pattern here?

TAT = Turnaround Time

We can count ***defects*** instead of ***defective parts***

135

- Each potential defect on a part, or potential error in a transaction, is called an *opportunity*
- We can use DPMO (defects per million opportunities) instead of DPPM (defective parts per million)
- DPPM is more *customer* focused

  The fact that **anything** is wrong is primary — the **number of things** wrong is secondary

- DPMO is more *process* focused

  DPMO is a finer measure than **DPPM** — it responds more rapidly to process changes

- Requirements for using DPMO
  - ✓ A finite number of identifiable opportunities per part or transaction
  - ✓ Statistical independence of defect occurrence at different opportunities

135

DPPM vs DPMO

136

Definition of "defect"	Fraction defective	Formulated for reporting as	Focus
Each part	$\frac{\text{Defective parts}}{\text{Total parts}}$	% Defective or DPPM	Customer
Each possible defect on a part	$\frac{\text{Defects}}{\text{(Total parts)} \times \text{(finite number of identifiable defects per part)}}$	DPMO (Defects per million opportunities)	Process
Each transaction	$\frac{\text{Defective transactions}}{\text{Total transactions}}$	% Defective or DPPM	Customer
Each possible error in a transaction	$\frac{\text{Errors}}{\text{(Total transactions)} \times \text{(finite number of identifiable errors per transaction)}}$	DPMO (Defects per million opportunities)	Process

136

Project metrics (cont'd)

137

b) Validated financial calculations are needed to ensure your baseline costs (and benefits achieved) align with the financial methods used by your organization

- Cost of product rework
- Cost of product scrap
- Cost of tool rework
- Cost of lost orders
- Cash flow
- Revenue
- . . .

Normalized →

- Total $$ for a specified time period
- Annualized $$
- $$ as percent of COGS
- $$ as percent of sales
- . . .

COGS = Cost of Goods Sold

Project metrics must be linked to KPIs

138

- ✓ Customer satisfaction — quality, delivery, service . . .
- ✓ Revenue, cash flow, cost of waste . . .
- ✓ Growth in existing markets
- ✓ New market penetration
- ✓ Lack of adverse safety impact
- ✓ Lack of adverse environmental impact
- ✓ . . .

Exercise 9.3

139

Define the primary metric for the project you currently have in mind. Describe the data that will be needed to calculate it and give the formula by which it will be calculated.

Exercise 9.4

140

Define secondary metrics for the project you currently have in mind. Describe the data that will be needed to calculate them, and give the formula by which it will be calculated.

Baselines for project metrics

141

- Should be calculated from data representative of the current state
- Use a long enough timeframe to get an adequate sample size
- Don't go back so far that you lose relevance to the current state

141

Setting goals for project metrics

142

- From benchmarking
- From established business goals
- Performance prior to onset of the problem
- A percentage of the current state value (once this has been established)
- 50% reduction is a common goal*

*In many cases this is feasible and will have substantial business impact

142

LSS projects must be team projects

143

- They need to solve difficult problems
- They need expertise in diverse areas
- They require resources controlled by different parts of the organization
- They need internal customer/supplier participation
- They have to consider unintended consequences of proposed solutions
- They must create stakeholder support for proposed solutions

143

Iteration between team and individual work

144

Team work

- ✓ Developing shared purpose
- ✓ Sharing information
- ✓ Combining, enhancing, improving, refining ideas

Individual work

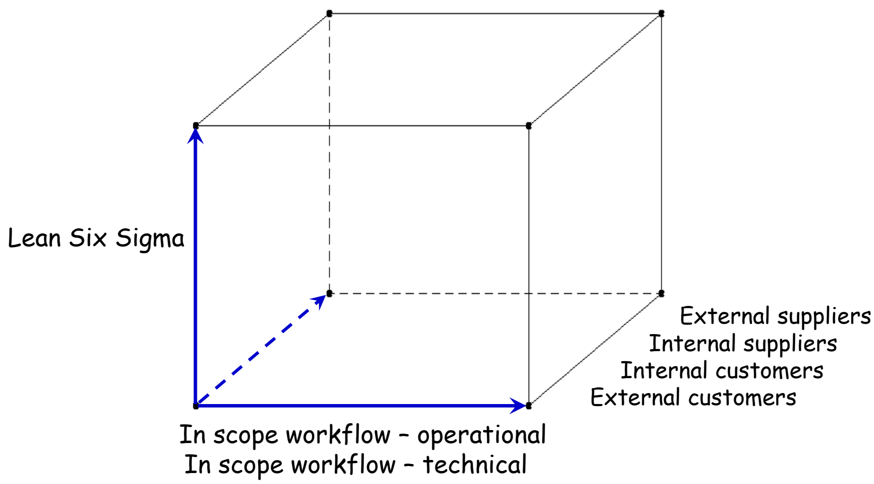
- ✓ Following up on action items
- ✓ Gathering information
- ✓ Creating new ideas

144

Team member knowledge and experience

145

Multiple dimensions must be represented



Knowledge and experience (cont'd)

146

It might seem that the ideal project team would consist entirely of people who possess substantial knowledge in all of the dimensions mentioned in the previous slide. One problem is that such people may not exist. In any case, the ideal team should be *well balanced* with respect to these dimensions. Here are some reasons:

- All relevant perspectives on the in–scope workflow must be represented within the team: process participants, customers, suppliers, and other stakeholders.
- Team members with little prior knowledge of the in–scope workflow can provide the team with "outside eyes" and "out of the box" thinking.
- The team must include members with knowledge and experience in Lean Six Sigma.
- Team members with little prior knowledge of Lean Six Sigma receive valuable hands–on training by participating in the project.

Team member strengths and weaknesses

147

Code	Strengths	Weaknesses
CIU	Creative, imaginative, unorthodox. Can solve difficult problems.	Ignores details. Too preoccupied to communicate effectively.
EEC	Extrovert, enthusiastic, communicative. Explores opportunities, develops contacts.	Overly optimistic. Loses interest once initial enthusiasm has passed.
MCL	Mature, confident, good leader. Clarifies goals, promotes decision making, delegates well.	Can be seen as manipulative. Delegates personal work.
CDP	Challenging, dynamic, good under pressure. Has the drive and courage to overcome obstacles.	Can provoke others. Hurts people's feelings.
SSD	Sober, strategic, discerning. Sees all options, judges accurately.	Lacks drive and ability to inspire others. Overly critical.
CMPD	Cooperative, mild, perceptive, diplomatic. Listens, builds consensus, averts conflict.	Indecisive in crunch situations, easily influenced.
DRCE	Disciplined, reliable, conservative, efficient. Turns ideas into practical action.	Can be inflexible, slow to respond to new possibilities.
PC	Painstaking, conscientious. Searches out errors and omissions, delivers on time.	Inclined to worry unduly. Reluctant to delegate. Can be a nit-picker.
SAD	Analytical, detail oriented, specialist. Provides knowledge and skills in rare supply.	Contributes only on a narrow front. Dwells on technicalities. Can't see the "big picture."

147

Strengths and weaknesses (cont'd)

148

Optimal team composition has been researched from a personality point of view. The table shown is adapted from the book *Team Roles at Work* by Meredith Belbin and is just one of many examples available for understanding character traits. It can be helpful for team members to use an assessment tool to better understand their own and other members' styles for communication, learning, confrontation, etc.

Successful teams need members with a variety of different strengths such as those described in the previous slide. The strengths that a member brings to the team usually come with corresponding weaknesses. Team members make their greatest contributions when they are aware of their strengths and weaknesses. Team leaders are most successful when they are aware of the strengths and weaknesses of every team member.

The pairings of strengths and weaknesses shown in the previous slide are based on statistical correlations. They do not apply to all individuals. However, most people can find themselves somewhere on each list.

Which strengths do you possess? Which weaknesses?

148

Resources

149

People who provide the team with things they need:

Master Black Belt

Project champion

Process owner

Facilities

Finance

HR

IT

.
.
.

It's recommended to designate these people during project chartering.

149

Stakeholders

150

People with a vested interest in the project or its outcome who provide the team with their point of view on the project and its potential impacts

- May control critical resources
- May have concerns with proposed changes
- May have approval authority over proposed changes
- May own the in-scope process
- Team must engage stakeholders to get support for the project

150

Stakeholder analysis

151

It is in the best interest of the team to determine the current levels of stakeholder support or resistance, and the levels of support needed for the project to succeed. The more strongly a stakeholder is affected by the project and its outcome, and the greater the influence they have on the project and its outcome, the stronger their support must be.

For each stakeholder, gather information (tactfully) and evaluate their level of support or resistance. Use this information to rate them with respect to the three criteria given in the next slide.

A stakeholder analysis contains sensitive information and should remain confidential to the core team and champion.

Example: Stakeholder analysis – criteria

152

Student Files → stakeholder analysis example - Criteria

	1	2	3	4	5
Position with respect to the project	Strong support	Support	Indifference	Resistance	Strong resistance
Degree of Influence on the project or its outcome	Very low	Low	Medium	High	Very high
Degree affected by the project or its outcome	Very low	Low	Medium	High	Very high

Stakeholder analysis – rating

153

Student Files → stakeholder analysis example – Stakeholders

Stakeholders	Criteria →					Total rating
A	2	2	1	5	2	**20**
B	3	2	2	4	2	**48**
C	3	2	2	3	2	**36**
D	4	2	3	4	3	**144**
E	2	2	1	2	3	**12**
F	3	2	2	3	4	**72**
G	3	3	1	2	3	**18**
H	3	2	2	1	3	**18**
I	1	1	1	1	1	**1**
J	1	1	1	1	1	**1**

153

Stakeholder analysis – rating (cont'd)

154

A form of risk analysis is used to identify the stakeholders most in need of gentle persuasion. Your ratings should be entered into the white cells of the sheet shown in the previous slide. The column *gap between current needed* is computed as (*current position – needed position + 1)*. For example, if the *current* and *needed* scores are the same, the *gap* is 1 — the lowest (best) possible value. If the *current* score is 5 and the *needed* score is 1, the *gap* is 5 — the largest (worst) possible value.

The total rating is the product of all columns, excluding the *needed position* column. The *needed position* is used only to compute the *gap*, the degree of increase in support required.

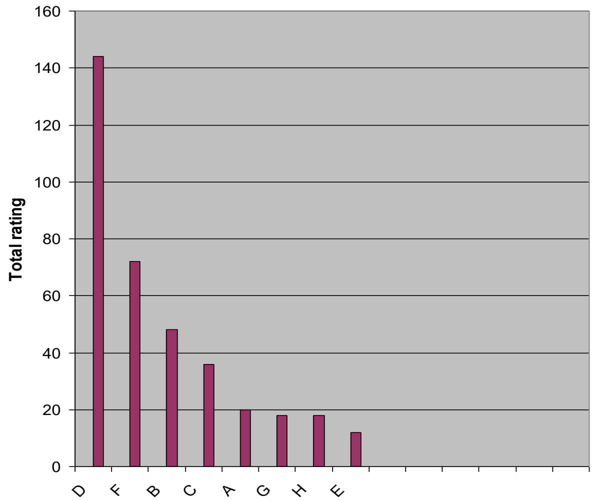
Focus your efforts to increase levels of support on the critical stakeholders — those with the highest total ratings.

A template for this analysis is in *Student Files \ blank stakeholder analysis*.

154

Stakeholder analysis (cont'd) 155

Student Files → stakeholder analysis example - Pareto



Sort the stakeholders in decreasing order by total rating.

(You may have to unprotect the sheet to do so.)

PAINT your way into stakeholder support *Getting It Done* by Roger Fisher & Allan Sharp 156

P	*Persuade* them by creating a compelling case using data, examples, what competitors are doing, links to strategic goals…
A	*Appeal* to their ideals, values, virtues, visibility, personal ambition…
I	*Involve* them in the project — perhaps not on the core team, but get them in the loop as soon as possible, avoid surprises.
N	*Negotiate* with them. Is there a *quid pro quo* for their support?
T	*Tell* them to cooperate. (This only works if you have the authority. Even so, use as a last resort.)

Lean Six Sigma Green Belt Training

Supplement:
Stages of Team Development

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Effective Teams

For teams to be effective, the members must work collectively to achieve desired outcomes.

- This does not happen automatically
- Initially, the team is just people assigned to work together
- The ability to work together effectively develops as the team works together. They:
  - get to know each other
  - learn what they can expect from each other
  - figure out how to divide labor and assign tasks
  - determine how to coordinate the work of the team

158

Stages of Team Development

159

Team Development is the process of learning to work together effectively.

In 1965, Bruce Tuckman published a widely adopted model of this process*

He proposed a development sequence consisting of four stages:

- Forming
- Storming
- Norming
- Performing

* Tuckman, B. W. (1965). Developmental sequence in small groups. Psychological Bulletin, 63(6), 384–399.

159

Forming

160

The Forming Stage is a period of orientation and getting acquainted with each other and the project

- Usually, the team is meeting for the first time
- Team members are polite and positive, and possibly anxious or excited
- Uncertainty is high
- Members strive to get to know each other
- People are looking for leadership and authority
- Questions they may have:
  - What does this team have to offer me?
  - Will I fit in?
  - What's expected of me and others?

160

Storming

161

As the name indicates, the Storming Stage is marked by conflict, competition and polarization

- Energy is put into unproductive activities
- Members may disagree on team goals
- There is resistance to group influence and task requirements
- Subgroups can form around strong personalities or areas of agreement
- Individual personalities emerge
- Members may:
  - question boundaries established in the Forming Stage
  - think they are working harder than others on the team
  - be frustrated by the different working styles of other team members

161

Norming

162

The team becomes more cohesive and members have more in-group feeling as they enter the Norming Stage

- Members learn to cooperate and focus on team goals
- They appreciate each other's strengths
- Consensus is reached on who the leader(s) are and the roles of individual members
- Members ask each other for help and provide constructive feedback
- The new-found harmony can be precarious, easily slide back into storming due to:
  - changes in team membership
  - disagreements re-emerging
  - the uncertainty surrounding new tasks

162

Performing

In the Performing Stage, the team is well-functioning and mature

- Roles become flexible and functional
- Structural issues have been resolved
- Cooperation and consensus have been well established
- Problems and conflict are dealt with constructively
- Members are committed to the team's mission
- Group energy is channeled into the task

Adjourning

In 1977, Tuckman and Mary Ann Jensen updated the model, adding Adjourning, noting that "a perfect rhyme could not be found."

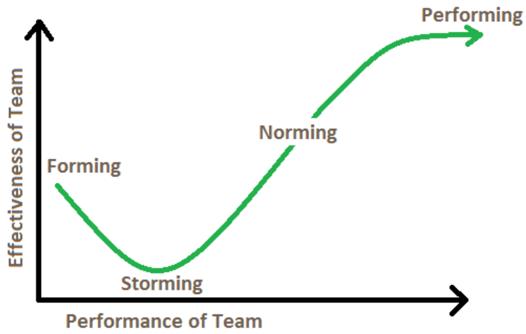
The Adjourning Phase involves team dissolution

- Most of the team's goals have been accomplished
- The focus is on wrapping of final tasks and documentation
- Some team members may move off the team, as the workload diminishes
- Working relationships that have developed come to an end
  - The process can be stressful, especially when the dissolution is unplanned or unexpected by the team
  - Some describe this stage as "mourning"
- Ceremonial recognition of the effort and success of the team is recommended!

Team Development and Effectiveness

165

A team's effectiveness is impacted by its level of development



As may be expected, effectiveness is lowest during the Storming Phase but in the long run, successful navigation of this phase is critical to the team's success.

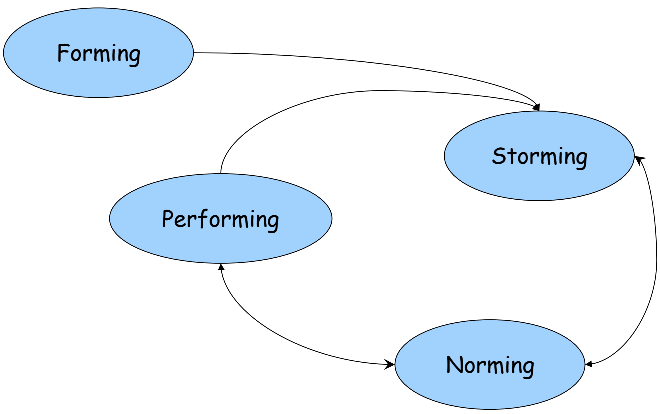
Leaders must help their team move out of Storming as constructively as possible.

165

Moving through the Stages

166

Groups do not always move sequentially from Forming to Storming to Norming to Performing



A key role of team leaders is to help the team progress through Forming and Storming, and to and remain in Norming and Performing, as much as possible.

166

Stages of Team Development Activity:

167

Your instructor will break you into groups. You will have 15 minutes in your group to complete this activity, for each phase assigned.

As a group:

- Quickly review the guidelines for brainstorming.
- Brainstorm specific ideas on the question for your assigned phase(s) [~ 10 min.] Consider the question from the team leader perspective.
- List all ideas on a white board or flipchart during the brainstorming session.
- Discuss the brainstormed list and make ideas more specific so they are actionable, as needed. Indicate all "good" ideas. [~ 5 min.]
- Choose someone to report out.
- Present all ideas deemed 'good' by your team.

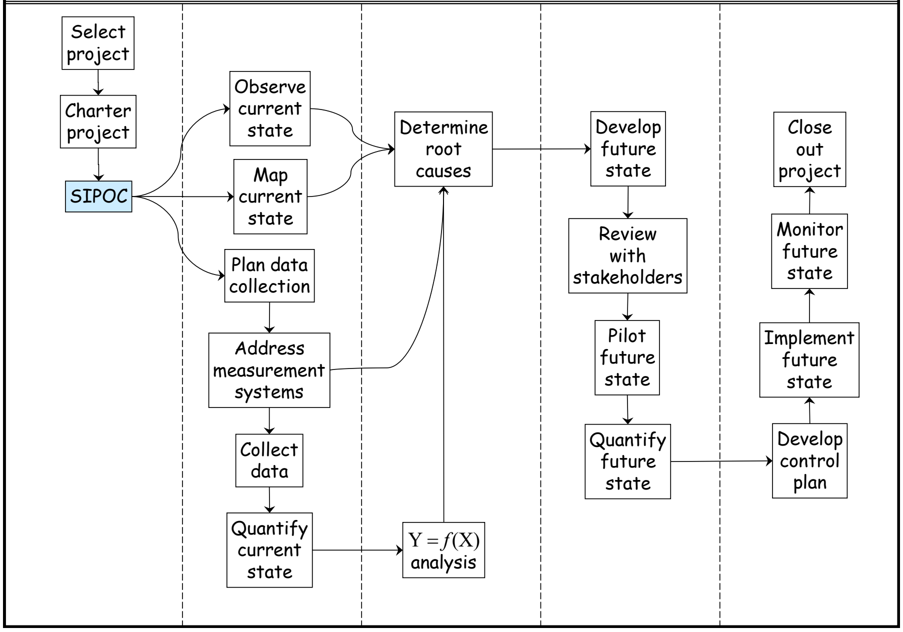
Stages of Team Development Activity (cont'd)

168

Assigned Phase	**As the team leader, what specific things can you do in team meetings, or with individual members between meetings, to help your team work together effectively in this phase and . . .**
Forming	. . . move from Forming to Storming?
Storming	. . . move from Storming to Norming?
Norming	. . . move from Norming to Performing?
Performing	. . . remain in Performing?

10 Project Scope and SIPOC

169



169

Value stream scope

170

Defines the project scope in terms of . . .

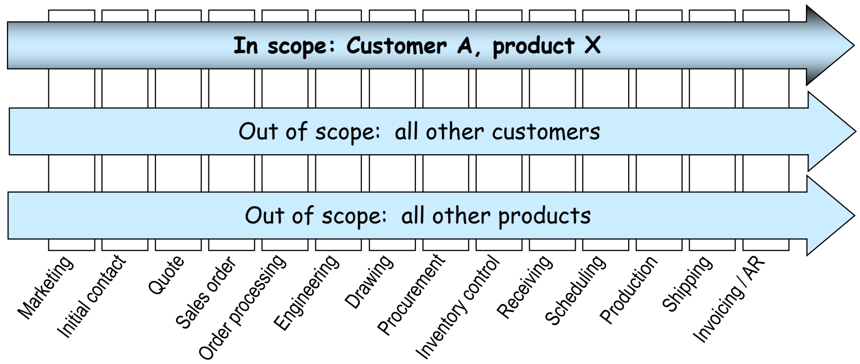
- ✓ Which customers?
- ✓ Which products?
- ✓ Which locations?
- ✓ Which materials?
- ✓ Which suppliers?
- ✓ . . .

Value stream	All activities needed to provide a specified family of products or services to customers

170

Value stream scope (cont'd)

171



Example 1 — value stream scope

172

Project to reduce cost and lead time of extrusion tool development

In scope

PVC products

Location A

Out of scope

Composite products

Locations B & C

Workflow scope

173

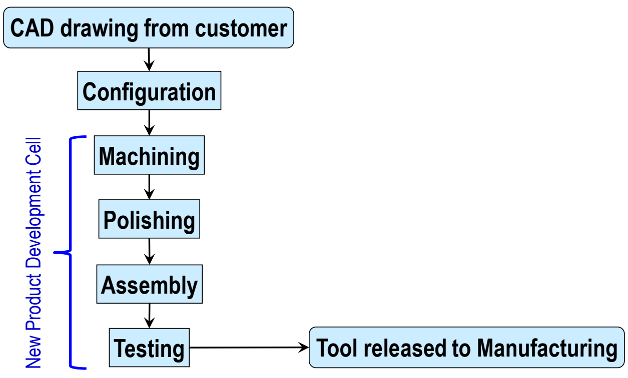
Defines the project scope in terms of . . .

- ✓ Which activities in the value stream are addressed by the project?
- ✓ Which operations?
- ✓ Which processes?
- ✓ Which areas?
- ✓ Which departments?
- ✓ . . .

Example 1 — workflow scope

174

Project to reduce cost and lead time of extrusion tool development

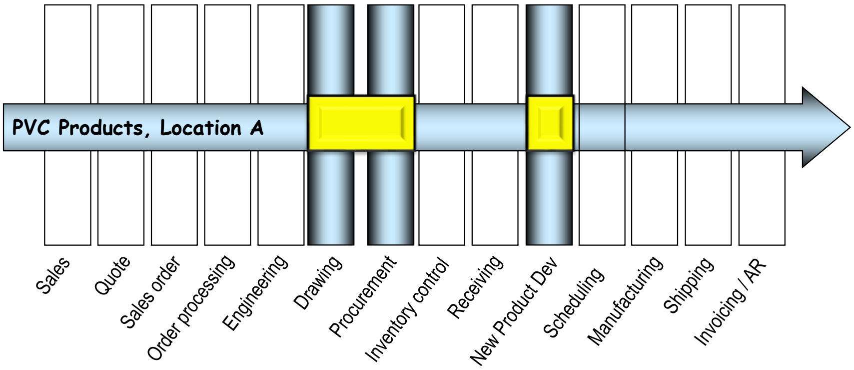


- Manufacturing is out of scope
- The project is not chartered to analyze and improve Manufacturing
- What is the relationship between Manufacturing and the workflow scope?

Example 1 — project scope

175

The *intersection* of value stream and workflow scope

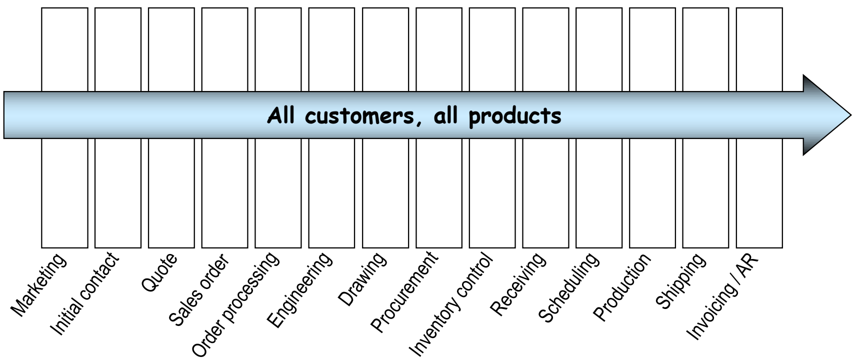


175

Example 2 — value stream scope

176

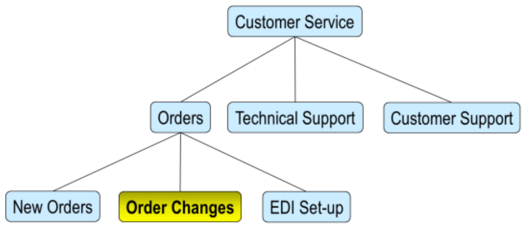
Project in Customer Service to address *order changes*



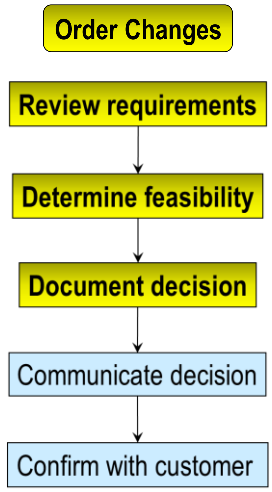
176

Example 2 — workflow scope

177



The project will address only the *first three steps* of the order change process

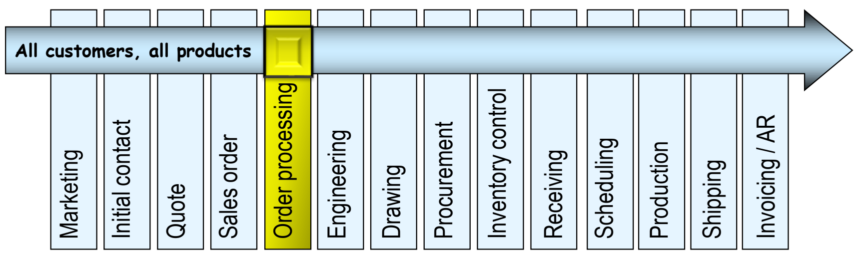


177

Example 2 — project scope

178

The *intersection* of value stream and workflow scope



- ***Order Processing of Changes*** is in scope
- Everything else is out of scope
- How will this affect the activities of the project team?

178

Exercise 10.1

179

Our company makes prototypes for various types of mounting brackets. These are classified as either standard or non-standard. A project has been launched to reduce the lead time for designing and building prototypes for non-standard brackets (see next slide for a typical prototype example).

Open *Student Files* → *Case Studies* → *MBDP*→ *MBDP charter* and use the Problem Statement to answer the following questions:

What is the value stream scope for this project?

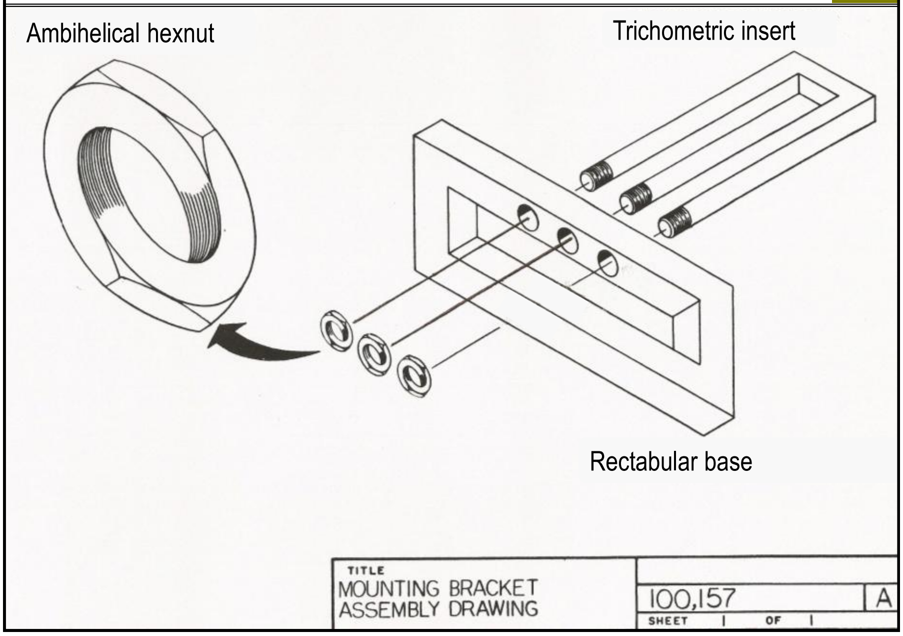
What is the workflow scope for this project?

Update the *MBDP charter* by entering your description of the value stream and workflow scopes; save your file for reference later in the course.

179

A non-standard mounting bracket

180



180

Introduction to SIPOC

181

- The project charter frames the project in the *business* space
- SIPOC is a separate document that frames the project in the *process* space:

  Suppliers → **I**nputs → **P**rocess → **O**utputs → **C**ustomers

- A SIPOC diagram is helpful at both the macro project level as described here, and at more detailed levels within a process.
- SIPOC also documents the *data collection* needed for the project
- The five elements of SIPOC are defined on the next slide.
- The logical sequence for reading or creating a SIPOC:

  P → O → C → I → S

181

SIPOC definitions

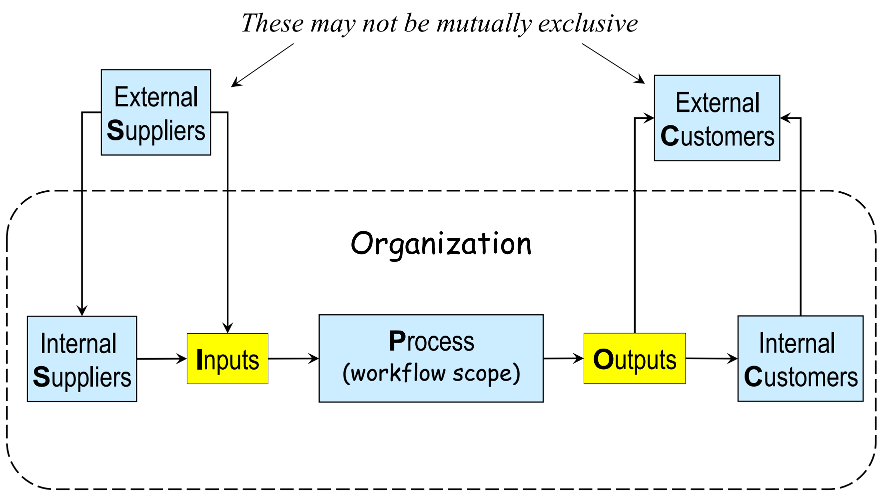
182

5) Suppliers	Entities who provide necessary *inputs* to the workflow scope. Suppliers may be internal or external to the organization.
4) Inputs	Products, services, or information provided to the workflow scope by suppliers.
1) Process	The workflow scope: the activities to be analyzed and improved. A *high-level* description including first step, main intermediate steps, and last step.
2) Outputs	Products, services, or information provided by the workflow scope to customers.
3) Customers	Entities who receive *outputs* from the workflow scope. Customers may be internal or external to the organization.

182

Graphical presentation of SIPOC

183



183

Blank SIPOC template

184

Project	The title of your project
Suppliers	Internal; External
Inputs and Xs	Inputs; Inputs
Process and Xs	First step; Main step; Main step; Main step; Main step; Last step
Outputs and Ys	Outputs; Outputs
Customers	Internal; External

184

Blank SIPOC (cont'd)

185

The slide shows a graphical SIPOC template. All you have to do is edit the various boxes and text. You can also add or delete boxes or text.

The digital version of this template, *blank SIPOC,* can be found in the *Student Files* folder.

The following three slides show the graphical SIPOCs for three case studies.

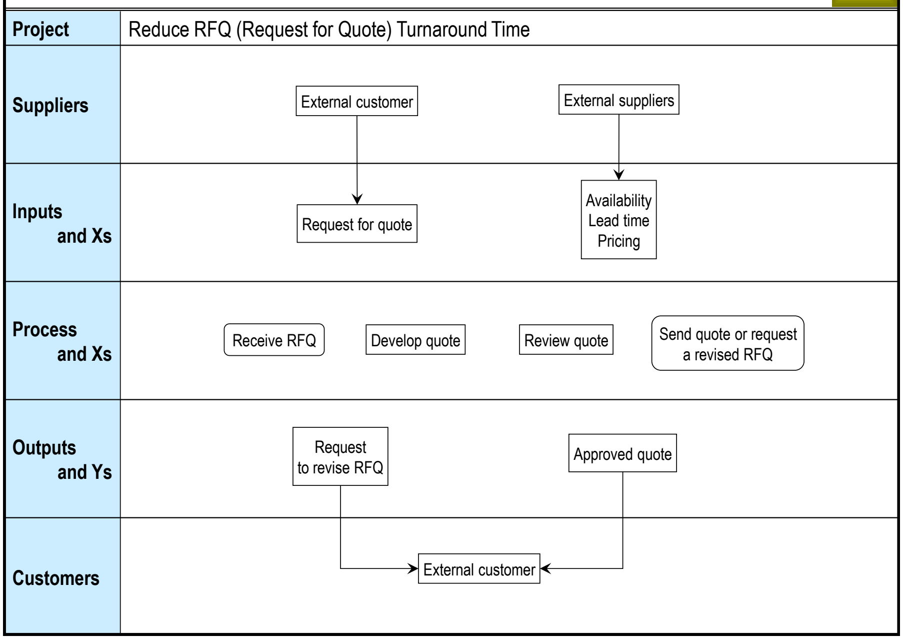
Digital versions can be found in *Student Files \ Case Studies* within each case study's folder:

- *quotation process SIPOC #1*
- *Ti casting SIPOC #1*
- *tool development SIPOC #1*

185

SIPOC example 1: Quotation Process

186



186

SIPOC example 2: Titanium Casting

187

Project	Reduce Alpha Case on Titanium Castings
Suppliers	External customer; Wax molding & assembly; External suppliers
Inputs and Xs	Blueprints, Dim'l specs, Wax molding tools, O_2 spec; Wax patterns; Ceramic shell materials, Ti alloy, Chemical milling
Process and Xs	Slurry make-up; Shell build; Autoclave; Casting; Shell removal; Heat treat; Backend processing
Outputs and Ys	Finished casting, Certificate of O_2 compliance
Customers	External customers

187

SIPOC example 3: Tool Development

188

Project	Reduce Cost and Lead Time of Extrusion Tool Development
Suppliers	External customers; External suppliers
Inputs and Xs	CAD drawing, Dimensional specs, Weight spec; Raw materials for machining and extrusion
Process and Xs	CAD drawing from customer; Configuration; Machining; Polishing; Assembly; Testing; Tool and run conditions released to Mfg
Outputs and Ys	Approved tool, Run conditions; Sample extrusions
Customers	Manufacturing; External customer

188

Exercise 10.2

189

Our company makes prototypes for various types of mounting brackets. The process of designing and building the prototypes is referred to as the Mounting Bracket Development Process (MBDP). A project has been launched to reduce the MBDP lead time for non-standard brackets (see next slide for an example). For background on the project and process, please refer to the following documents in *Student Files \ Case Studies \ MBDP*:

MBDP charter

MBDP description for SIPOC

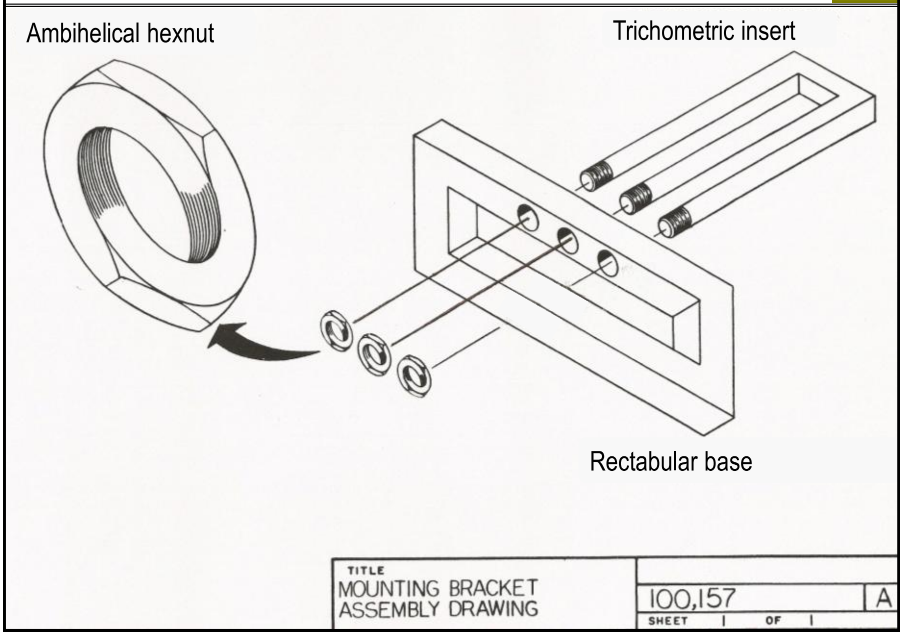
Use the information in these documents to create a SIPOC for this project using the template in *Student Files \ blank SIPOC* (use "Save As" to preserve the template). Remember that the SIPOC is used to show a high-level view of the process for establishing boundaries according to the project scope; avoid too much detail.

Do not fill in the X and Y variables shown on the *blank SIPOC* template (but do not delete their placeholders); we will discuss this topic later in the course.

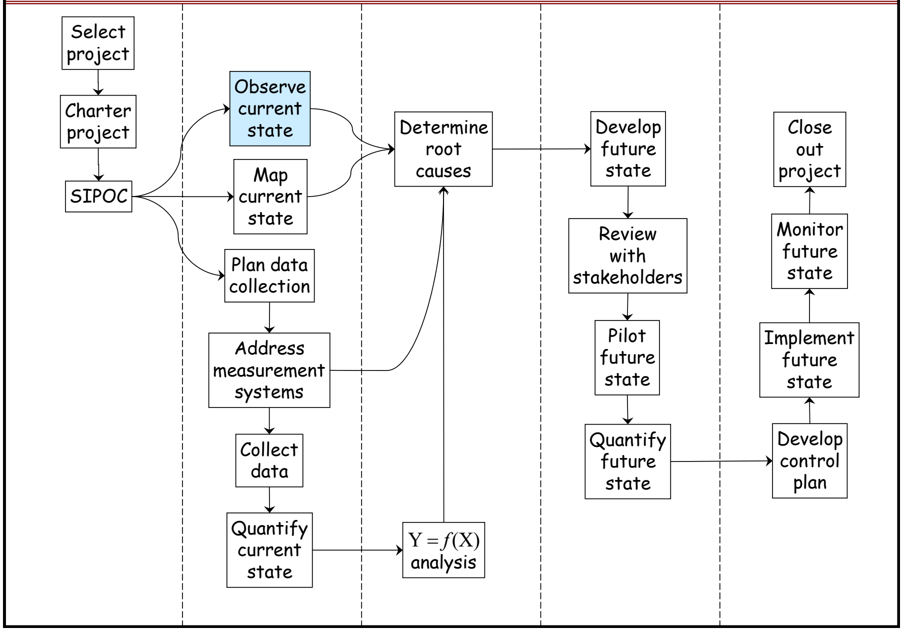
Save your MBDP SIPOC file for reference later in the course.

A non-standard mounting bracket

190



11 Observing the Current State



Guidelines

- The purpose is to improve the process, not to audit work performance
- Workflow observation periods should be scheduled in advance with appropriate supervisors and/or managers
- Workflow participants must be briefed on the project charter
- Participants must have adequate advance notice of observation periods
- Observations should be limited to the value stream and workflow scopes for the project

Guidelines (cont'd)

193

- Don't "gang up" on a few participants or process steps—deploy team members effectively to get as many perspectives as possible
- Ask permission to take notes, photographs or videos — this helps team members get the information they need without having to repeat questions later
- Observations should begin with introductions and guided tours, in some cases
- This should be done on all relevant shifts
- Subsequent "unguided" observations are often needed

193

Typical elements of workflow observation

194

- Interview workflow participants within the project scope
- Identify data variables and inspection points for inputs provided by internal suppliers
- Interview internal suppliers and customers of the workflow scope
- Identify data variables and inspection points for outputs provided to internal customers
- Identify NVA activities — these may be opportunities for improvement within the project scope
- Confirm or revise process map(s)

194

Team roles & responsibilities

195

	Bob	Carol	Ted	Alice	Moe	Larry	Curly
Interview workflow participants	✓			✓			
Observe and record changes to process map		✓			✓		
Identify workflow data variables and inspection points			✓			✓	
Identify data variables and inspection points for workflow inputs				✓			✓
Interview internal customers	✓				✓		
Identify data variables and inspection points for workflow outputs		✓				✓	
Focus on measurement systems			✓				✓

195

Asking questions

196

- The *way* you ask questions can affect the usefulness of the answers you get
- *Closed* questions can be answered with “yes” or “no” — if the person is reluctant to talk to you, closed questions will not get you anywhere
- *Open* questions start with words like *what, why, when, where, who, which, how,* etc.
- Open questions are much better for eliciting information, ideas, opinions, etc.

196

Asking questions (cont'd)

197

Open questions	Closed questions
"How do you do that?" "Why is it done this way? "How do you think that would help?" "When you say ___ , what do you mean?" "What would be an example of that?" "What are some possible causes of ___ ?" "Why do you think that could be a cause?" "Why do you think that happens?"	"Can you see from where you're sitting?" "To confirm, are we in agreement on the workflow scope?" "So, do you agree with this project metric goal?" "Have we decided to meet on Fridays?" "Did we cover that topic earlier?" • *Closed questions are useful for moving a conversation along* • *Try to phrase them so that the answer you want is "yes"*

197

Correcting bad listening habits

198

Concentrate . . . . on what is being said.

Observe . . . . .facial expressions and body language.

Respond . . . . with eyes, voice, gestures, and posture to communicate empathy and understanding.

Reflect . . . . information by paraphrasing.

Elicit . . . . information by asking questions.

Control . . . . the urge to interrupt, judge, or change the subject.

Take . . . . advantage of lags between question and answer to record observations or further questions.

198

Lean (and quality) checklist

199

- ❑ Are there opportunities for reducing batch size?
- ❑ Where is the greatest amount of work-in-process (WIP)?
- ❑ What are the most common do-overs, defects, errors?
- ❑ Is the physical layout causing excessive movement of people or material?
- ❑ Is there unnecessary complexity?
- ❑ Where are the most time-consuming changeovers?
- ❑ Are there opportunities for mistake proofing?
- ❑ Are there places where inspections/tests can be performed sooner?

199

Lean (and quality) checklist (cont'd)

200

- ❑ Are there serial activities that could be parallel?
- ❑ Are there redundant activities/inspections/tests that should be eliminated?
- ❑ Are there separate steps that should be combined into a single step?
- ❑ Are there single steps that should be split into separate steps?
- ❑ Are work instructions missing, outdated, or not visible?
- ❑ Are there problems with availability of equipment or material?
- ❑ . . .

200

Observation log

201

- Team members may see possible causes of problems and solutions as soon as they start observing and mapping the current state
- These observations should *not* be publicized until the appropriate point in the project roadmap
- These observations *should* be logged as they arise, preferably in Excel (facilitates categorization and prioritization)
- The possible causes will be reviewed in the *Analyze* phase, along with data analysis results, to determine root causes
- The possible solutions will be reviewed in the *Improve* phase to develop the future state

201

Observation log (cont'd)

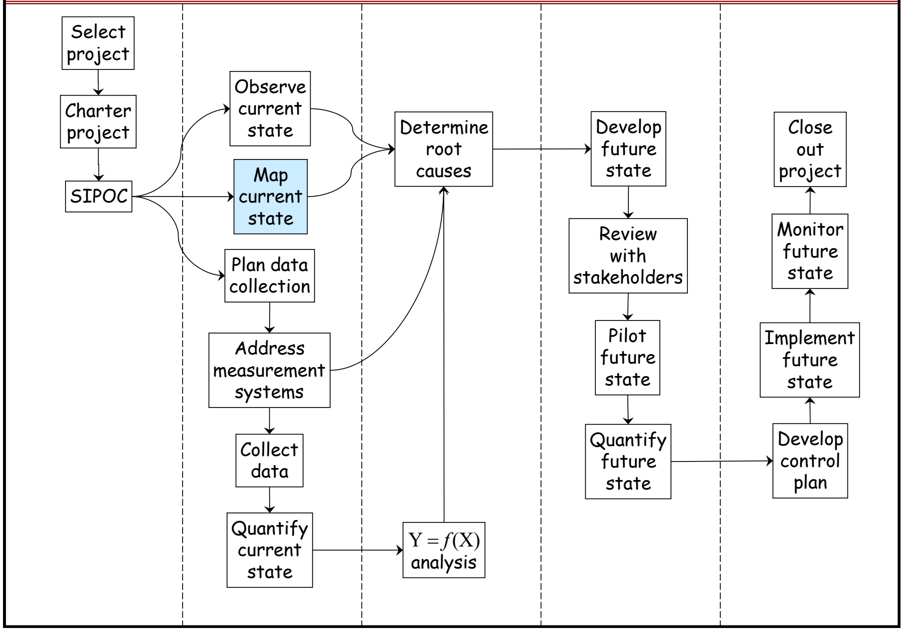
202

Team member	Date	Location	Possible cause	Possible solution

202

12 Basic Process Mapping

203



Basic process mapping

204

A basic process map shows the flow of individual tasks and decision points within the main steps of the process.

Benefits of process mapping:

- easy to learn
- produces useful documentation of the current state
- great team building activity

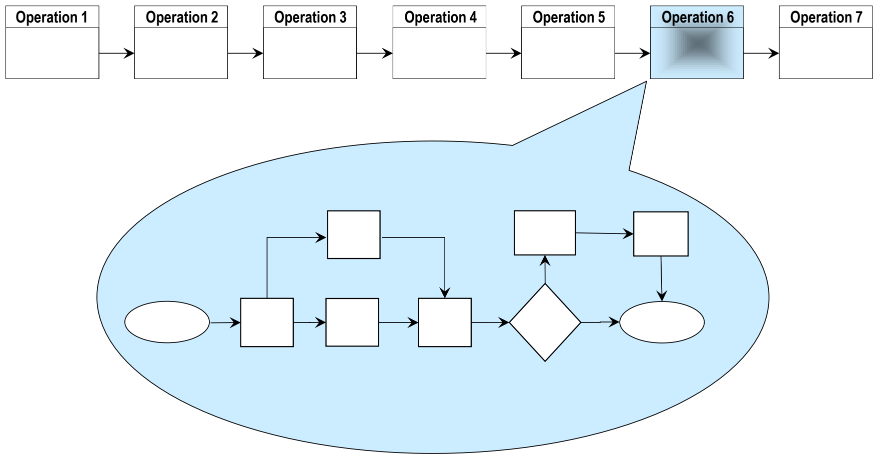
Keys to successful mapping:

- focus on the appropriate level of activity
- start with a high-level map before starting more detailed mapping
- leverage the SIPOC diagram: first, last, and main steps of the in-scope workflow will form the high-level process map

Basic process mapping (cont'd)

205

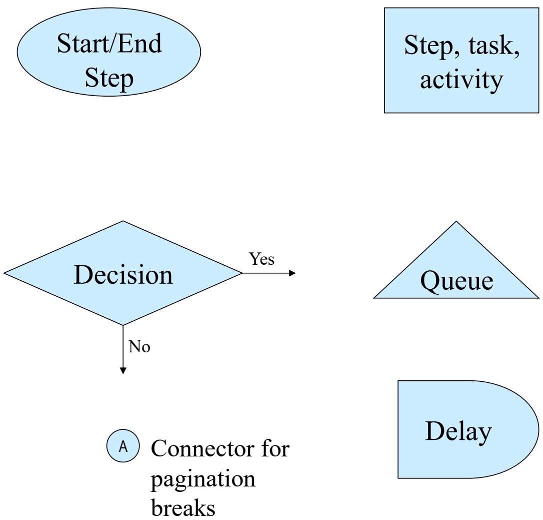
Often, we want to create detailed maps for some or all of the main steps given in the SIPOC



205

Standard (basic) process mapping symbols

206



206

Mapping as a team activity

207

Suspend your disbelief	Map the process the way it really is, not the way you think it should be.
Don't make assumptions	If you don't know what happens at a certain point, or can't agree on what happens, put a question mark there. Then, go ask someone who does know.
Solicit feedback	Ask participants of the in scope workflow, and their internal customers, to review the map for accuracy and clarity.
Document your work	Use mapping software to create an electronic version of the map.

207

Writing good narrative

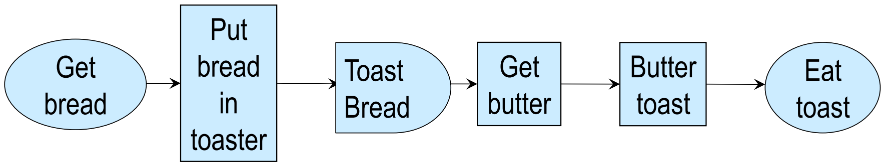
208

- ✓ Use active voice, not passive voice
  - ☹ Order is entered
  - ☺ Enter the order
- ✓ Use verb/object, not name of activity
  - ☹ Order Entry
  - ☺ Enter the order
- ✓ Use short sentences with familiar words
  - ☹ Twilight's last gleaming
  - ☺ Dusk
- ✓ Use present tense
- ✓ Use logical, consistent layout

208

A high-level map for making toast

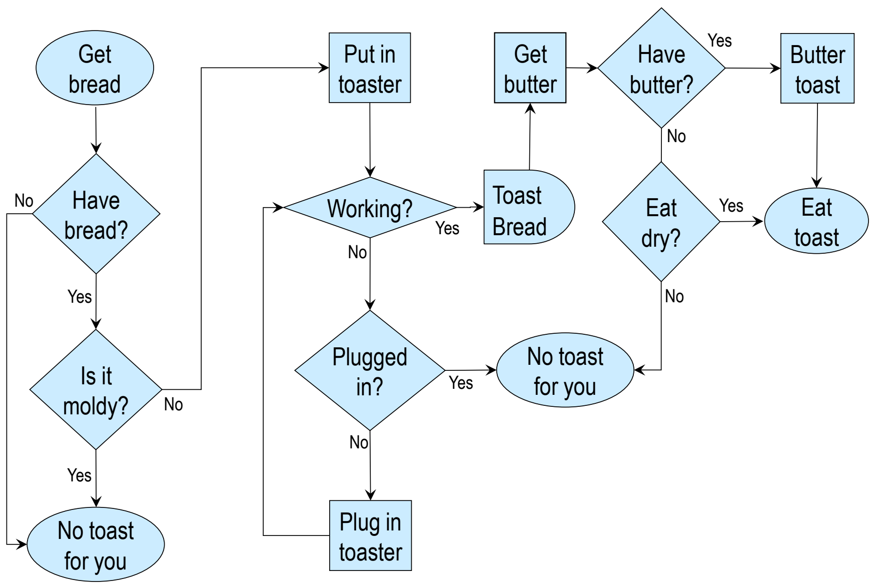
209



209

Decision steps show what really happens

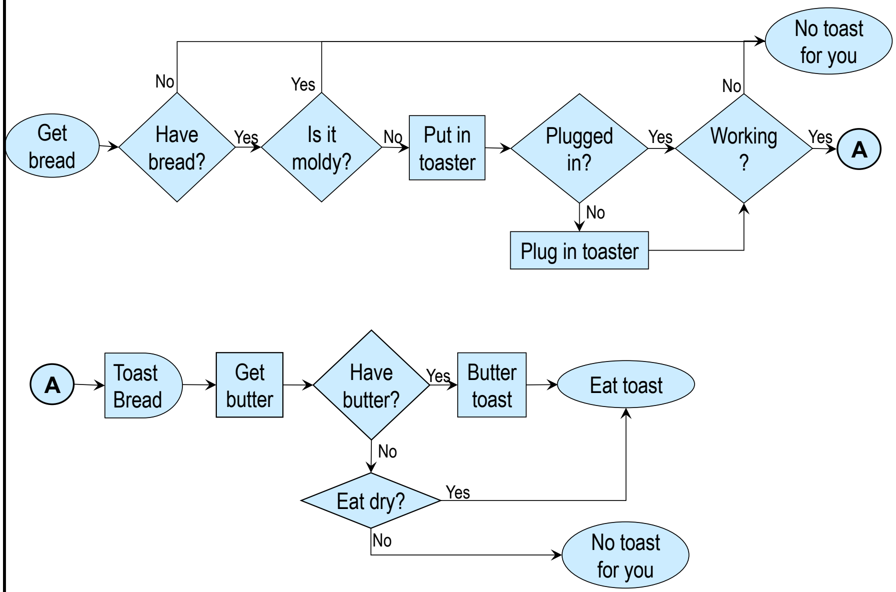
210



210

Best practice: follow a qualitative timeline

211

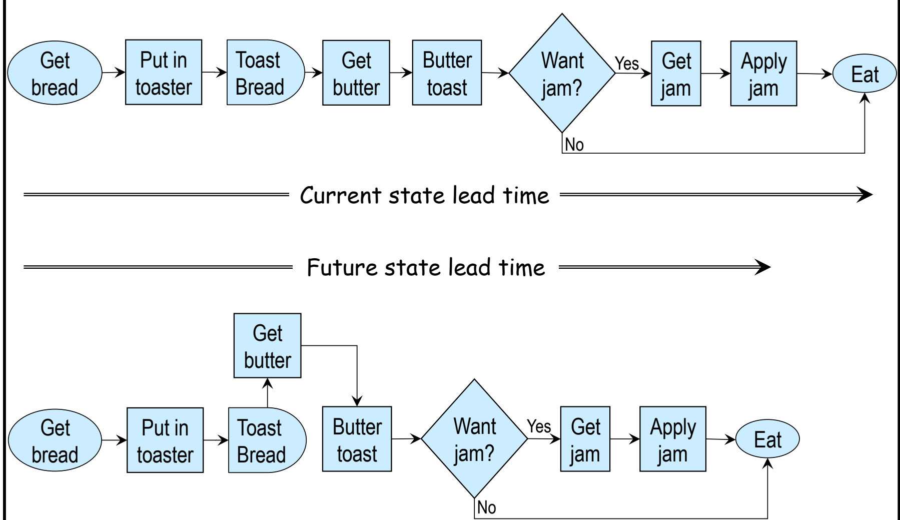


211

Parallel activities

212

Common technique for reducing lead time: convert *serial* to *parallel*

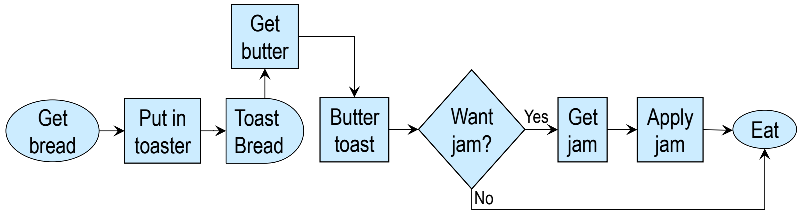


212

Exercise 12.1

213

How would you modify the toast-making process to further reduce the lead time?



213

Notes

214

214

Exercise 12.2

215

You are to create a process map based on the information given on the slide below. It will be beneficial to work in small groups.

This is not *your* process. Someone else is describing *their* process to you. Do not make unwarranted assumptions!

The instructor will provide guidance on options for creating the map either digitally or in hard copy.

Use a qualitative timeline and show each individual step, decision and path — our goal is a very detailed step-by-step map!

215

Exercise 12.2 (cont'd)

216

There are two types of material, A and B. The material must be processed before it can be used. There are two steps in this process. For Process 1, the A and B materials must be processed in separate Type 1 machines. If two Type 1 machines are available, load the A material into one machine, the B material into the other, and run the two machines at the same time. If there is only one Type 1 machine available, run the two loads sequentially in that machine.

When Process 1 is completed, unload the material, and move on to Process 2. Process 2 requires Type 2 machines. If two Type 2 machines are available, load the A material into one machine, the B material into another, and run the two machines at the same time.

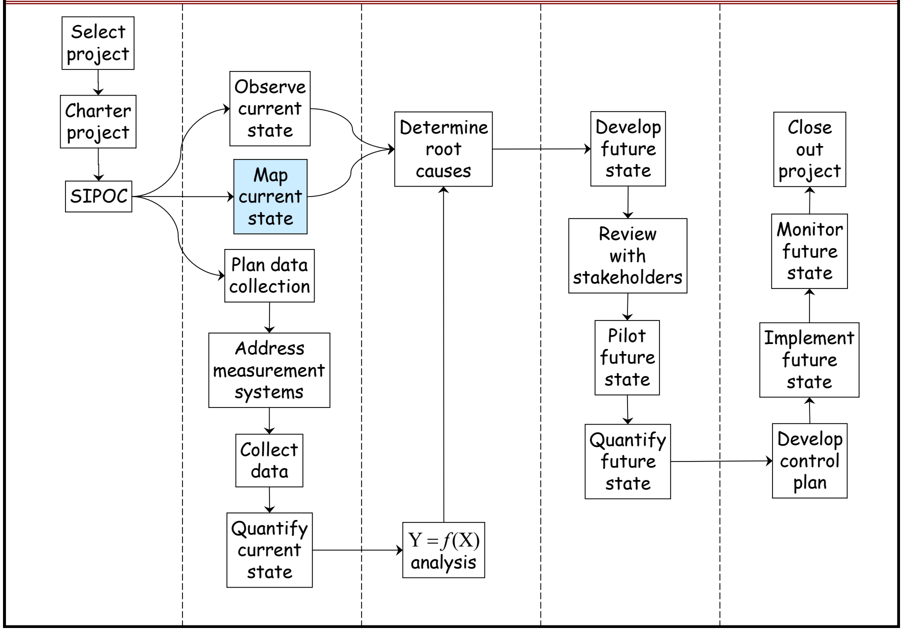
Unlike the Type 1 machines, the A and B material can be processed together in the same Type 2 machine. If there is only one Type 2 machine available, load both the A and B material into that machine for processing. This will take longer than processing the A and B materials in separate machines, but not as long as running two loads sequentially.

When Process 2 is completed, unload the material, separate the A and B materials if necessary, then store them for subsequent use.

216

13 Other Common Mapping Formats

217



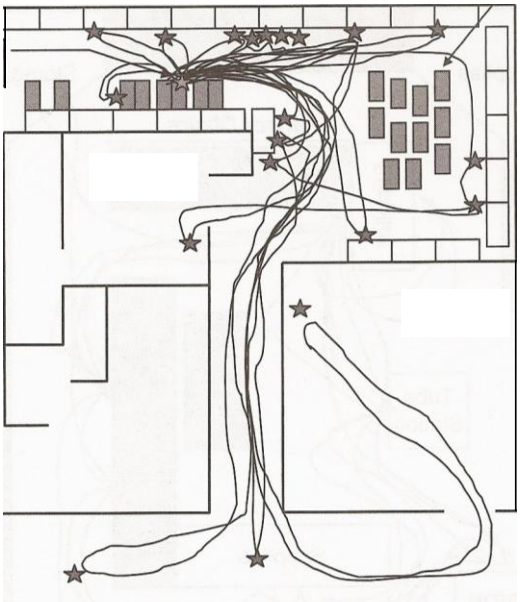
Other common process mapping formats

218

- Geographic (aka Spaghetti): tasks and decision points are overlaid on the "geographic" setting of the process.
- Cross-functional (aka Swimlane): tasks and decision points are placed in "lanes" of role responsibility.
- Topological: process activities are overlaid on a contextual map to shown connections or relationships.
- Value Stream Mapping (VSM): starts with a high-level map, combines visualization of the process steps with certain forms of data analysis (discussed in next module).

Spaghetti Diagram

219

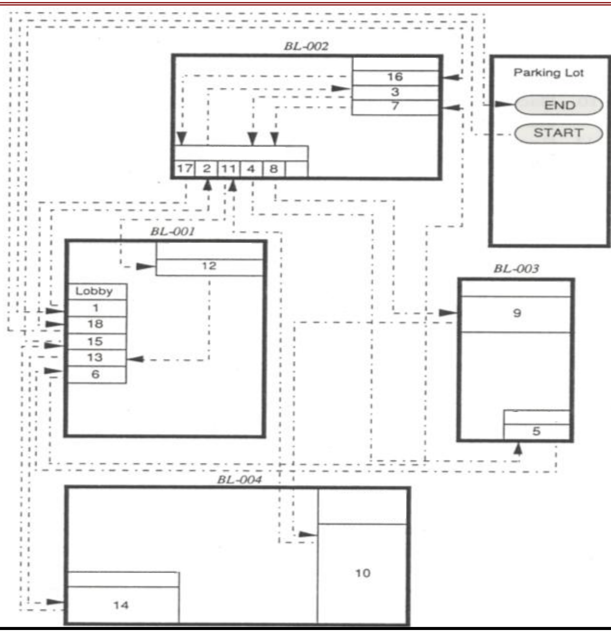


- Most useful in the Analyze Phase
- Requires a floor plan or scale drawing
- Shows typical travel patterns
- Quantify distance travelled
- Also known as a *geographic map*

219

Large scale spaghetti diagram

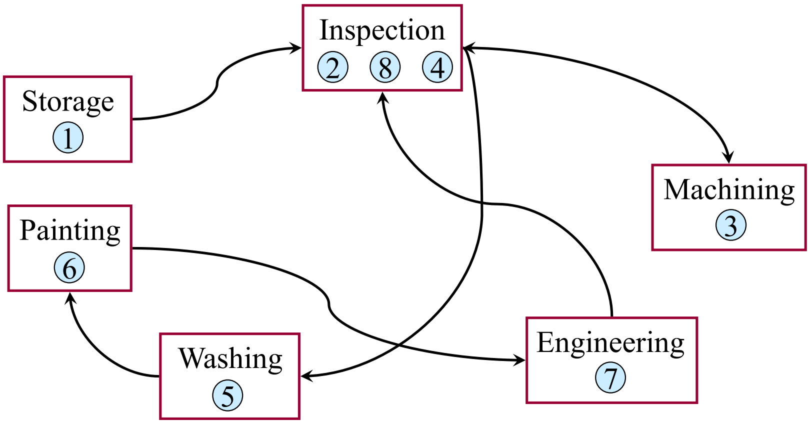
220



220

Spaghetti Diagram: current state

221

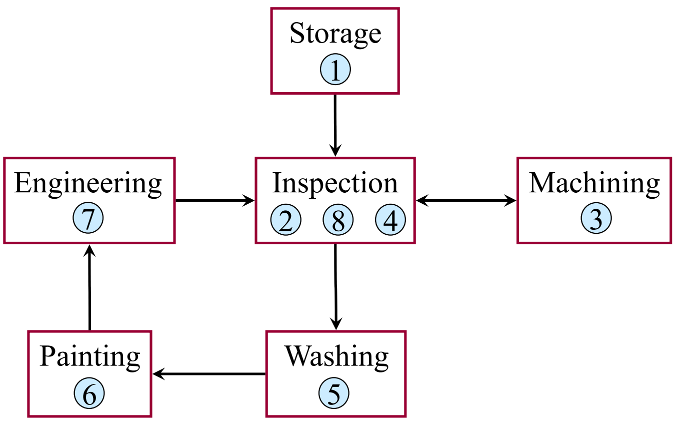


- Should rearrange to minimize transport
- Good opportunity for a Kaizen event

221

Spaghetti Diagram: future state

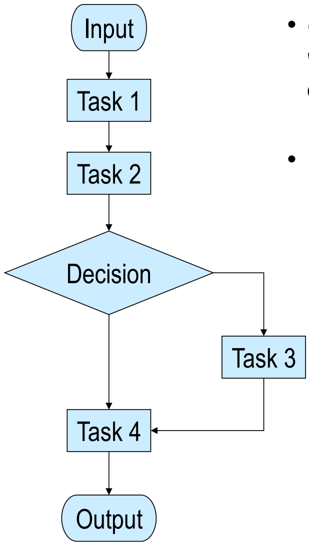
222



222

Basic process map revisited

223



- Often it is important to document who is responsible for each activity and decision in a process
- How do we do this?

Basic process map (cont'd)

224

We could make a table like the one shown here . . .

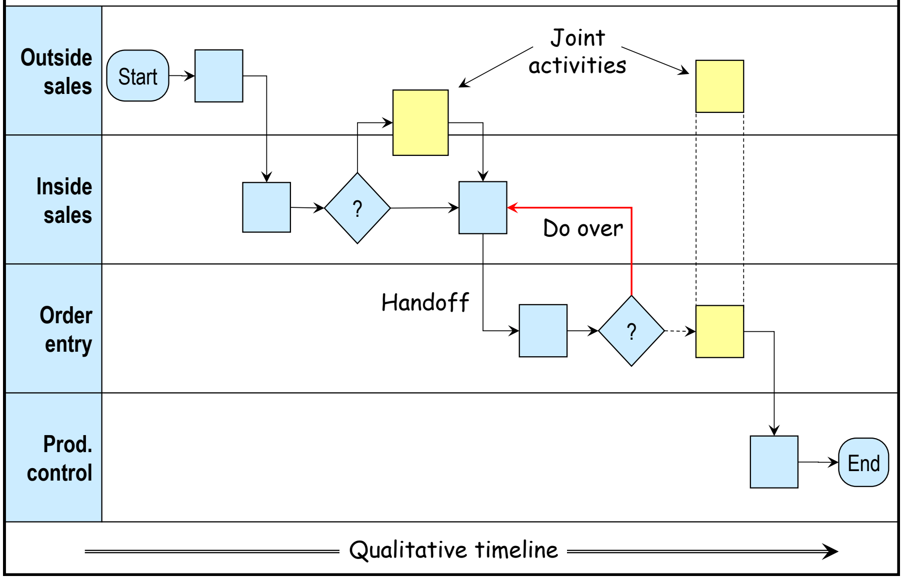
. . . but there is a better way!

	Responsibility
Input	
Task 1	
Task 2	
Decision	
Task 3	
Task 4	
Output	

Swimlane Diagram

225

Also known as *cross-functional map*



225

Swimlane Diagram (cont'd)

226

A swimlane diagram visually portrays the responsibilities for all process activities and decisions. In addition to showing responsibilities, swimlane diagrams are much better than simple maps for identifying opportunities for improvement.

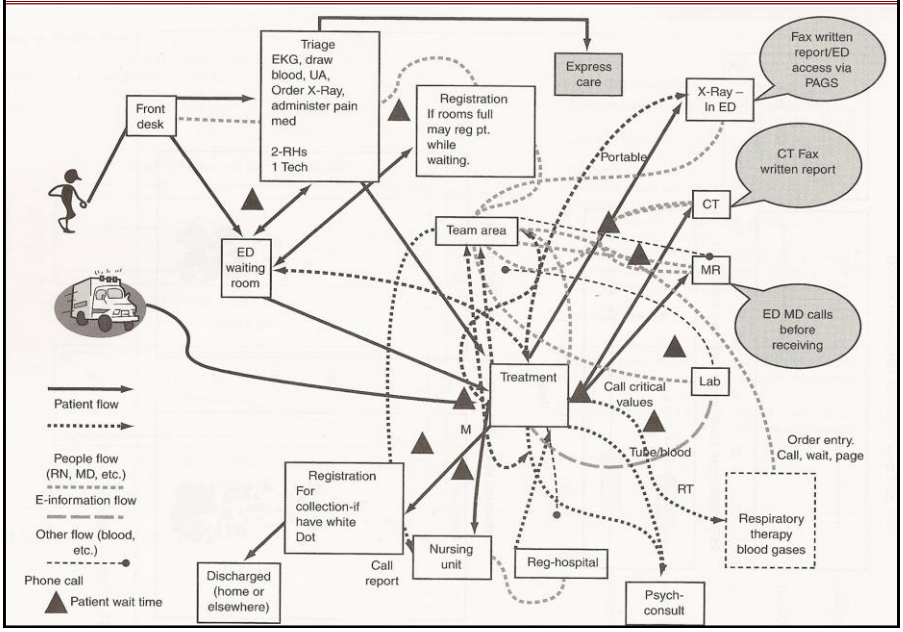
To create a swimlane diagram, first determine all the departments or functions involved in the activities and decisions you want to map. Enter swimlanes for departments or functions from top to bottom in the order they are first called for in the sequence of activities and decisions. Also, you should follow a qualitative timeline in placing activities and decisions on the map.

With this method, the general flow of the activities and decisions will be from top left to bottom right on the map. This usually leads to the simplest and easiest to read depiction of the process.

226

Emergency Department (ED) Topological map of patient flow

227



227

ED patient flow (cont'd)

228

topological *adj* **:** concerned with relations between objects abstracted from exact quantitative measurement

A topological map is similar to a spaghetti diagram, but without the geography/scale. It shows connections, but not distances. It may or may not indicate a time or process sequence. The routing diagrams in the London Underground are famous examples of topological maps.

The ED patient flow map shows the flow of patients, staff, and information or patient specimens in a hospital Emergency department.

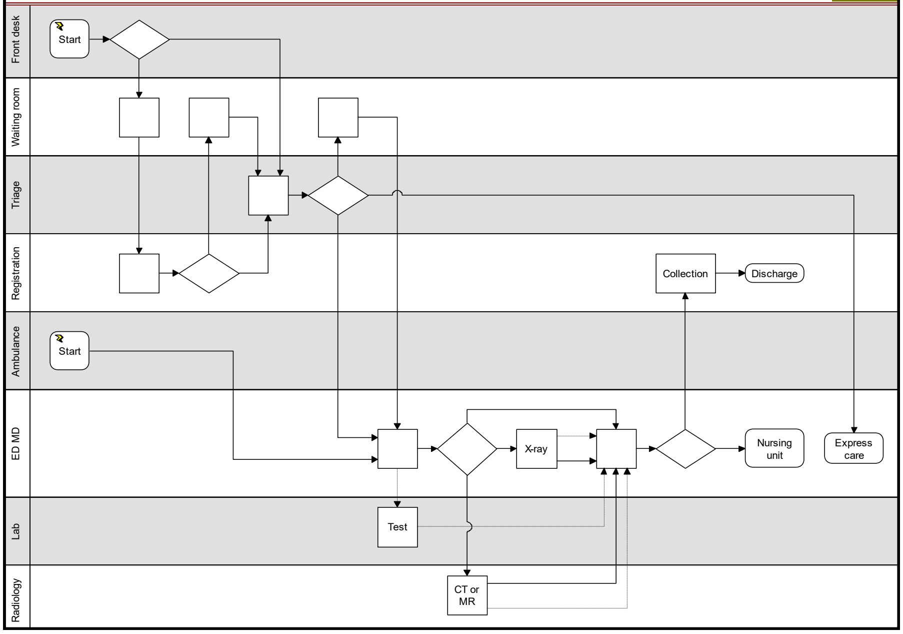
Like geographic maps, topological maps are extremely effective for conveying the complexity of a process. Also, the free form nature of topological mapping lends itself to team brainstorming.

On the other hand, we often need information on the sequence and location of process steps to move beyond the first impression of complexity. Topological mapping is typically not a very good format for displaying this kind of information.

228

ED patient flow in swimlane format

229



229

ED patient flow swimlane format (cont'd)

230

- Swimlane diagram of the same patient/information flow
- Shows the back and forth among different areas
- Gives a visual representation of the time sequence
- Clearly defines the possible patient pathways
- Solid arrows represent movement of the patient
- Dotted arrows represent movement of patient information, test results, X rays, blood samples, etc.
- Easier to follow

230

Exercise 13.1

231

Each team (same teams as for the SIPOC) will create a cross functional process map for the current state mounting bracket development process (MBDP). Review your MBDP SIPOC for overall boundaries and use the information in the following file:

Student Files \ Case Studies \ MBDP \ MBDP description for process map

The instructor will provide guidance on options for creating the map either digitally or in hard copy.

Enter swimlanes (departments) as they occur in the narrative; it's recommended to combine QE and ME in one lane. If using "sticky notes," make the swimlanes at least two sticky notes wide.)

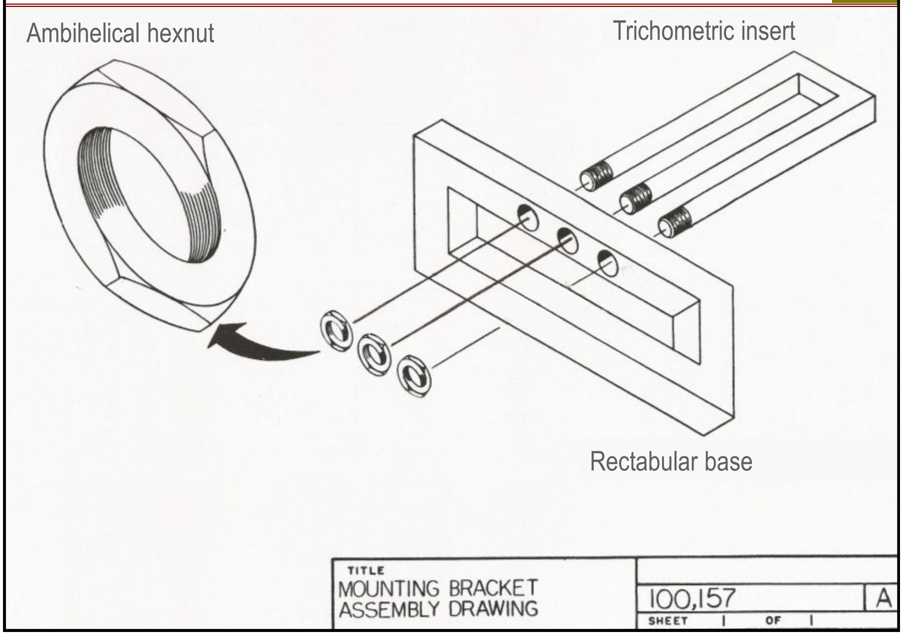
Add an appropriate process map shape for *each* step or decision in the process. Include all internal and external entities who play a role in the process.

You'll need to add flow lines as you go; draw them lightly and wait until your map is finished to make them permanent.

231

A non-standard mounting bracket

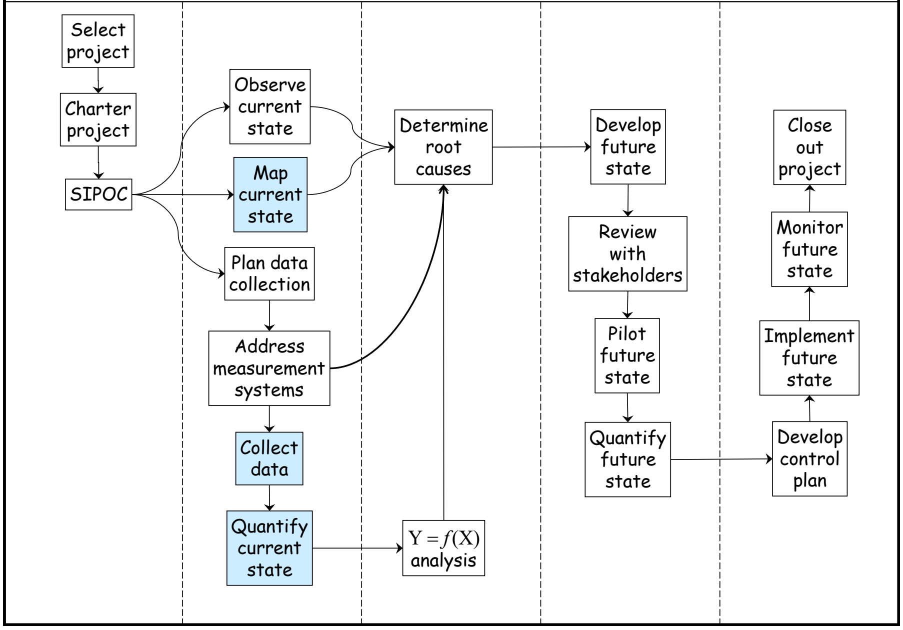
232



232

14 Value Stream Mapping

233



233

The nature of Value Stream Mapping

234

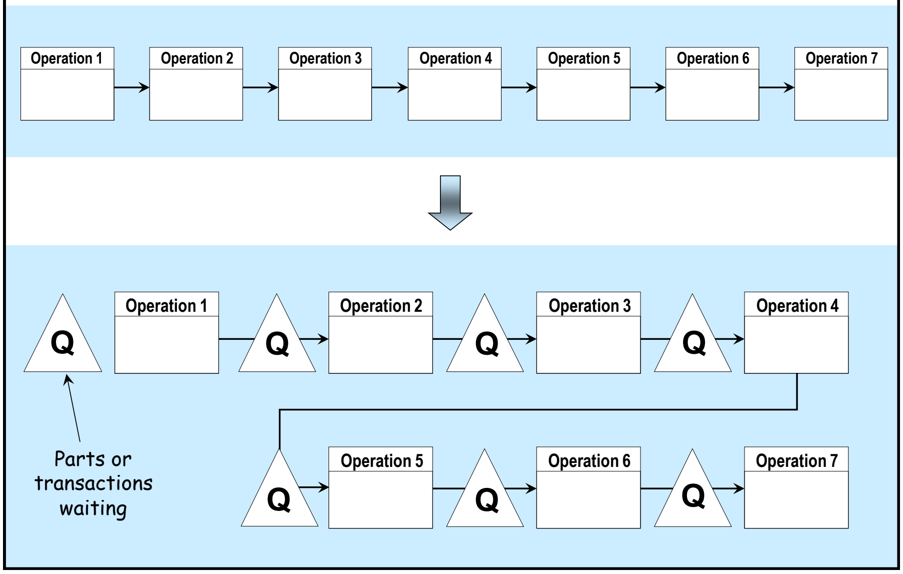
- Value stream mapping (VSM) combines several things:
  - ✓ Visualization of the current state
  - ✓ Documentation of the current state
  - ✓ Certain types of data collection and analysis
- VSM is an effective way to identify improvement opportunities
  - ✓ Especially in projects involving WIP, capacity, and lead time reduction
  - ✓ Also used to document the future state

234

From SIPOC to VSM

235

High-level map from SIPOC



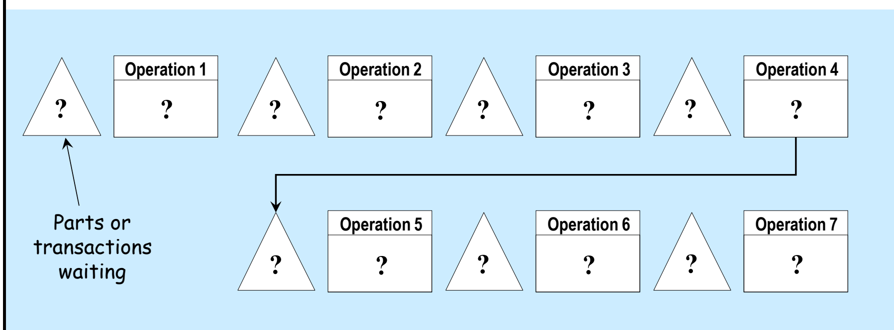
VSM, no data yet

236

What is the average lead time?

How much time is spent in each box or triangle?

How do we get this information?



Definitions

237

Available Working Time (AWT)	• The time a process is available to conduct work • AWT excludes time when work isn't occurring such as time for breaks, meetings, lunch, preventative maintenance, estimates of unplanned downtime, change overs, etc.
Throughput (Tput)	• The average number of good parts or transactions completed over a period of time • Typically measured as average over at least several days • Throughput, lead time, and WIP are related through Little's Law

237

Definitions (cont'd)

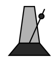
238

Lead time (LT)	• The total elapsed time to produce one defect free product or transaction • The time difference between when a part or transaction enters and leaves a process
Customer Demand Rate (CDR)	• The number of parts or transactions that the customer desires over a period of time (usually a day, week, or month)

238

Definitions (cont'd)

239

Takt time (TT)	• The pace at which an operation should complete products or transactions in order to meet customer demand during the Available Working Time.  • Available working time during a period divided by the number of products or transactions *required* during that same period
Cycle time (CT)	• The fastest repeatable time between part or transaction completions using the current processes and resources • Shows how a process is capable of performing  • Combines with AWT to determine capacity

239

Definitions (cont'd)

240

Process Cycle Efficiency (PCE)	• The percentage of time that WIP is being transformed by VA activities. In other words, the percentage of lead time that is value added.
Work In Progress (WIP)	• Includes items waiting to be worked on and items actively being worked on. WIP includes all of the inventory in the production system.

240

Example 1

241

Available Working Time per day = 480 min – 90 min breaks, lunch, meetings

= 390 min

Avg. daily Customer Demand Rate = 32 units

$$\text{Takt time} = \frac{390 \text{ minutes}}{32 \text{ units}} = 12.2 \text{ mins}$$

During a study of this process, parts were completed at the following times:

9:00, 9:09, 9:17, 9:28, 9:37, 9:46, 9:58, 10:07, 10:16, 10:24, 10:33, 10:42

Based on this, the elapsed time in minutes between completed units was:

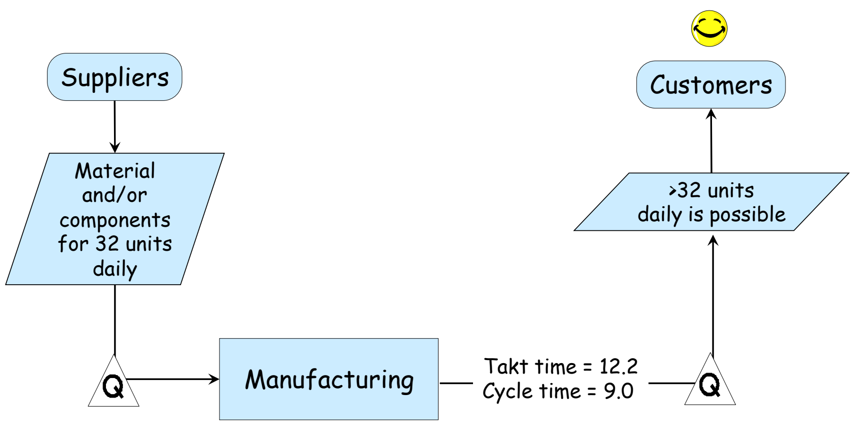
9, 8, 11, 9, 9, 12, 9, 9, 8, 9, 9

Cycle Time = 9 minutes (the fastest repeatable value)

241

Example 1 (cont'd)

242



242

Getting used to takt time and cycle time

243

- Units of takt and cycle time: time divided by quantity
  - Shorter cycle time → more output
  - Longer cycle time → less output
- Cycle time *longer* than takt time
  - **Cannot** meet customer demand with current processes and resources
- Cycle time *shorter* than takt time
  - **Can** meet customer demand with current processes and resources, but may need to eliminate process variation

243

We may not want to operate as fast as possible

244

- Takt time longer than cycle time
- Downstream operations constrained to cycle time of upstream bottleneck
- Upstream operations pace themselves to cycle time of downstream bottleneck (pull system)

244

Exercise 14.1

Using the information provided in Example 1, consider the scenario where the customer wants to increase their purchases from 32 to 42 units per day.

a) What is the new takt time?

b) What is the cycle time and is the new takt time faster or slower than the cycle time?

c) Can you accommodate this demand increase?

d) What problems might need to be solved?

e) Why should cycle time measurements not typically be taken from process output data in an ERP system?

How do we get lead time data?

Method	Drawbacks
Download accurate, time stamped records from database	• The best scenario, if such data exists • Make sure WIP time is accounted for properly
Shadow parts or transactions	• Tedious • Logistically difficult • Time consuming for team members
Tag documentation	• Anything identified as “special” is likely to be expedited • Data will not represent reality
Enter “file cabinet data” into Excel	• Tedious and time consuming • Likelihood of data entry errors • May not exist
Little’s Law	• Allows calculation of LT from WIP and T’put

Little's law

247

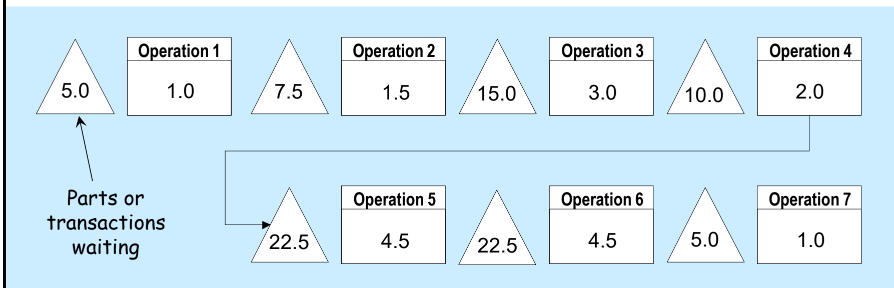
Lead Time = (WIP) / (Throughput)

- WIP is easy to count during process observation
- If WIP varies, count multiple times and use average or min/max to show range in lead time
- Throughput is the quantity of good parts or transactions completed during an observation period. This period should be at least several days.
- Lead time = amount of time that passes between when a piece enters and leaves a process or processes
- These values can be calculated for individual processes or for an entire production process chain

VSM with WIP data

248

Average WIP for each box and triangle during an observation period



- Suppose in the system shown above, each operation has a throughput of 6 good pieces per hour, so the entire production process is also making 6 pieces per hour
- We can use Little's Law to calculate the overall lead time for the process, for individual processes, or for subsets of processes

Applying Little's Law

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	Avg. WIP
Queue 1	5.0
Operation 1	1.0
Queue 2	7.5
Operation 2	1.5
Queue 3	15.0
Operation 3	3.0
Queue 4	10.0
Operation 4	2.0
Queue 5	22.5
Operation 5	4.5
Queue 6	22.5
Operation 6	4.5
Queue 7	5.0
Operation 7	1.0
Total	**105.0**

The previously described process was studied and the average WIP counts are shown here. They are measured as follows:

- Queue WIP is the average pieces waiting to be processed. For example, Queue 1 WIP is the typical amount of work waiting to be processed by Operation 1.
- Operation WIP is the average pieces actively being processed. For example, Operation 1 is typically processing one piece.
- The Total WIP in the process is the sum of all of the Queue and Operation WIPs

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Applying Little's Law

250

	Avg. WIP
Queue 1	5.0
Operation 1	1.0
Queue 2	7.5
Operation 2	1.5
Queue 3	15.0
Operation 3	3.0
Queue 4	10.0
Operation 4	2.0
Queue 5	22.5
Operation 5	4.5
Queue 6	22.5
Operation 6	4.5
Queue 7	5.0
Operation 7	1.0
Total	**105.0**

We can apply Little's Law to the entire process, an individual process, or a subset of processes. Remember:

Lead Time = (WIP) / (Throughput)

Since each operation, and therefore the entire process sequence, averages 6 pieces per hour, Little's Law lets us calculate lead times as follows:

- For the entire process:

Lead Time = 105 pieces / 6 pieces per hour
= 17.5 hours or 1050 minutes

- For Queue 1 and Operation 1:

Lead Time = 6 pieces / 6 pieces per hour
= 1 hour or 60 minutes

250

VSM with waiting and process times

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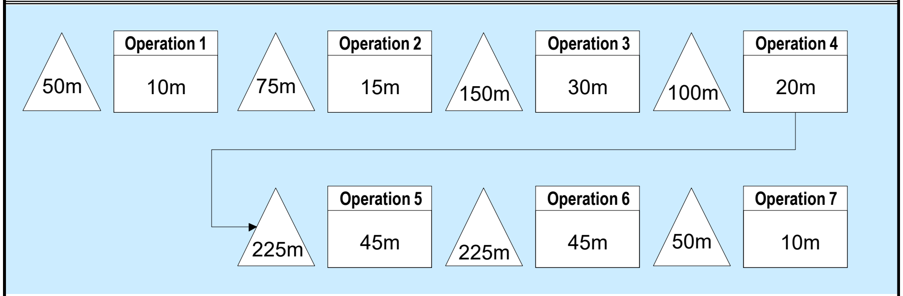

Lead time = 1050 minutes or 17.5 hours

Waiting time = Sum of time in queue
= 50 + 75 + 150 + 100 + 225 + 225 + 50 = 875 minutes

Process time = Sum of time the pieces are being worked on
= 10 + 15 + 30 + 20 + 45 + 45 + 10 = 175 minutes

Process Cycle Efficiency = The percent of lead time that a part is being worked on
= (175 / 1050)*100 = 16.7%

251

Exercise 14.2

252

a) A manufacturing process completes an average of 45 defect-free parts each day. The average WIP is 15 parts. Calculate the average lead time in hours (use a 24-hour day).

b) A manufacturing operation runs 365 days a year. They produce about 416 defect-free units of a particular product per year. The average WIP for this product is 40. Calculate the average lead time in days.

c) Should externally supplied inputs used at the first step of a process (aka "raw" materials) be counted as WIP?

252

Exercise 14.3

253

Open *Student Files* → *Case Studies* → *MBDP* → *MBDP VSM*. Average WIP and estimates of process times (in hours and days) are given for the six main steps in this process. The quantity completed in 260 work days is also given. Use Excel formulas to calculate the following:

a) Throughput, total process time in days, total WIP.

b) PO-PD (lead time) for the six main steps individually and the overall process. Use the overall throughput for these calculations.

c) Where are the bottlenecks? Do these steps have anything in common?

d) What would the overall lead time be if all transactions were handled immediately upon receipt at each step (i.e., if there were no wait time)?

e) Save your work.

Exercise 14.4

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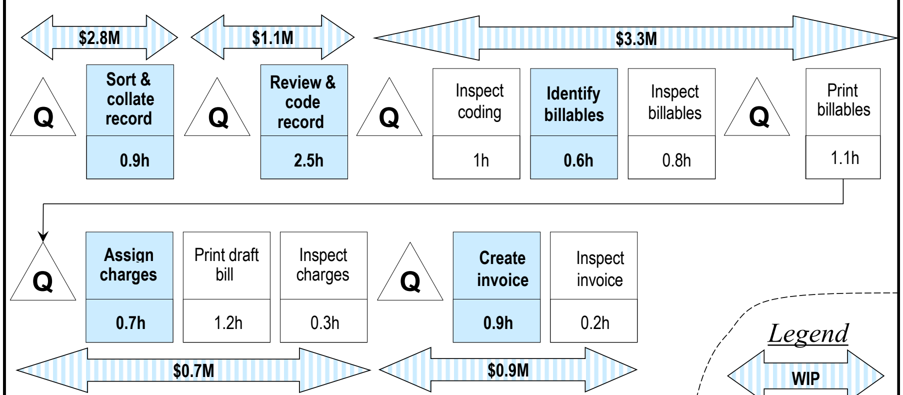
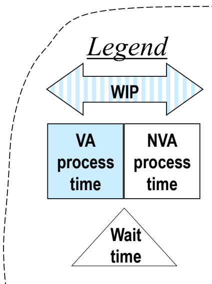
Billing process VSM with process times and WIP





- From this data we can calculate lead time, VA process time, NVA process time, and total NVA time.
- To get the total wait time, we need the following calculation:

Wait time = Total NVA time – NVA process time

Exercise 14.4 (cont'd)

255

The average annual revenue of the company whose billing process is shown in the previous slide is \$300M. Its average dollars in accounts receivable (AR) is \$60M. Consider the following translations:

- AR is a process
- Dollars in AR is the WIP quantity
- Annual revenue is the quantity completed in 365 days
- Average days in AR is the average lead time of this process

Use Little's law to calculate the average days in AR.

The result will explain why the Accounts Receivable (billing) process was targeted for improvement.

255

Exercise 14.4 (cont'd)

256

Open *Data Sets* → *billing process VSM*. Use Excel formulas to calculate the following in units of \$M (dollars in millions) and days (use a 24-hour day):

a) Throughput, total VA process time, and total WIP.

b) Lead time for the five main process steps, and overall.

c) Total NVA Lead Time, NVA Process Time and Process Cycle Efficiency.

d) Wait time and Wait time as a percentage of total NVA time.

e) Where does WIP indicate a capacity constraint? If each process had the same resources and AWT, where would the constraint be? Why might there be little WIP in front of a constraint?

256

15 X and Y Variables

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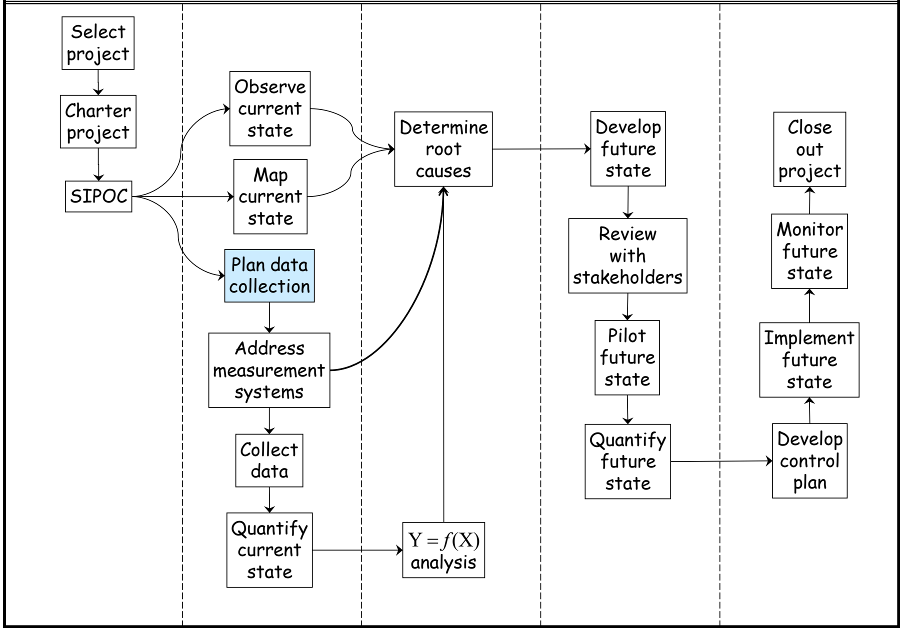

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Topics

258

- X variables
- Cause & Effect (aka Fishbone) Diagram
- Prioritizing X variables
- Y variables
- Operational definitions for data variables
- “Big Y” and “little y”

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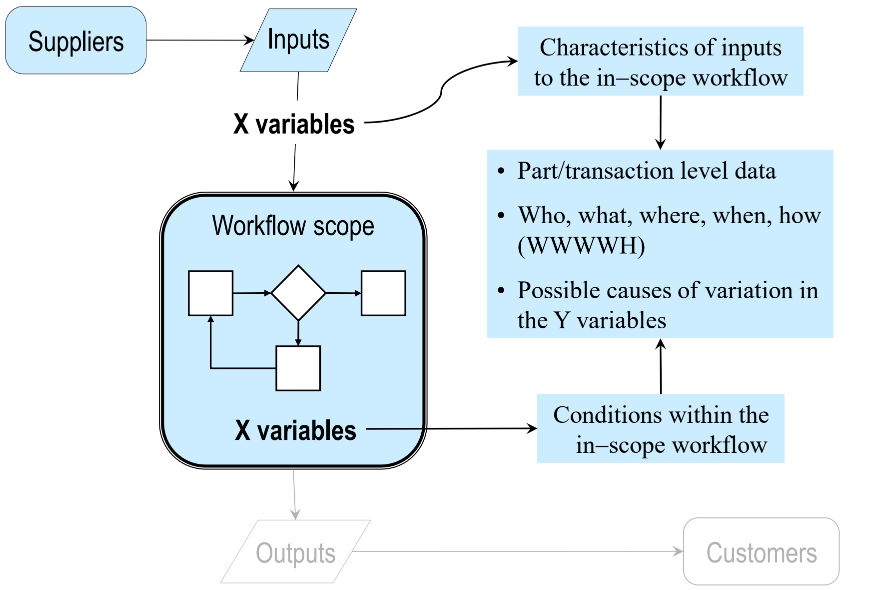
X variables

259



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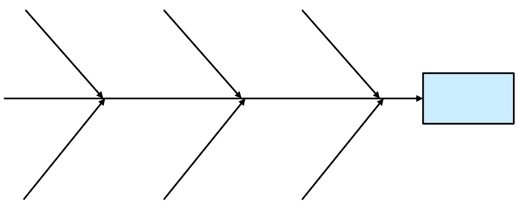
Cause & Effect (aka Fishbone) Diagram

260

The Fishbone Diagram is:

- used to identify all potential causes (X's or inputs) of the effect (output or problem of interest), usually the primary metric.
- part of identifying process inputs during the Measure Phase
- most often associated with root cause analysis
- also known as Cause-and-Effect Diagram and Ishikawa Diagram



- The greater the number of X variables identified, the greater the chance of solving the problem. (Why?)

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Fishbone Diagram (cont.)

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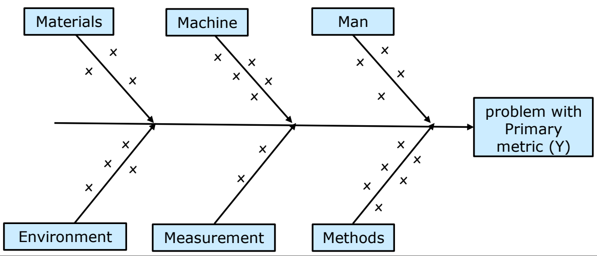
The Fishbone Diagram is created with the project team.

- It focuses the team on the particular effect, shown in the "head of the fish"
- All ideas for potential causes (critical x's) are collected using brainstorming
- Categories on the main "bones" help trigger ideas
  - Standard categories are Man, Machine, Materials, Methods, Measurement and Environment ("5 M's and an E" or the "6 M's" if "Mother Nature" is subbed for "E")
  - The team can choose to use different categories
  - Standard categories (with minor modifications) are recommended for your first uses



Steps for Creating a Fishbone Diagram

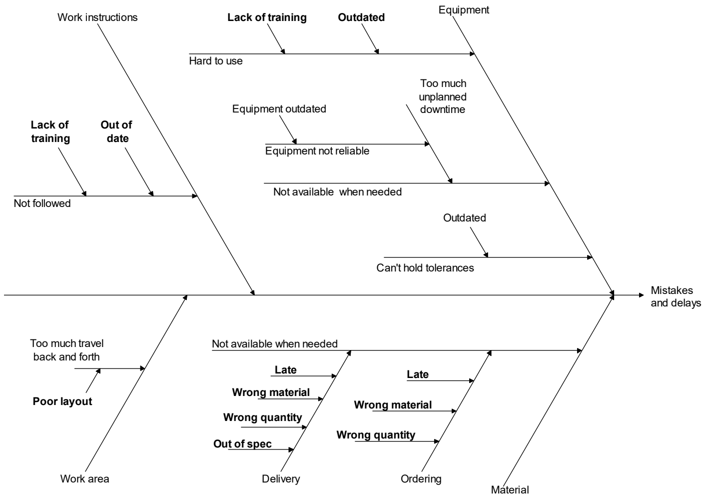
262

The Fishbone Diagram must be visible to the entire team during the brainstorming (creation) session.

1. Put output of interest (usually primary metric) in the "head of the fish."
2. Choose categories for "bones"
   - Standard Categories: Man, Machine, Materials, Methods, Measurement, Environment
   - The team can choose to use other categories
3. Brainstorm all possible inputs (x's) that could cause the problem seen in the output (primary metric—Y)
   - Rules for Brainstorming: Accept all stated ideas and add to diagram; No ideas are evaluated or rejected during the brainstorming session
4. Break broad categorical x's into more useful, more measurable features
   - Measurable features can be verified as causes of performance issues in the primary metric during the Analyze Phase
   - We can act upon them to improve the process
   - They need to be identified early in the project
   - Example: Work instructions not followed—out of date; lack of training
5. Highlight those x's deemed most important by the team

Fishbone Diagram Example (non-standard categories)

263



263

Exercise 15.1

264

A project has been launched to improve the mounting bracket development process (MBDP) in a company that makes mounting brackets. Background on the project and process may be found in the following files in *Student Files \ Case Studies \ MBDP*:

MBDP charter

MBDP description for process map

Based on the information in these documents and the process map you created earlier, create a Fishbone Diagram for this project.

Save your work and keep your Fishbone diagram and the other two MBDP files open for reference in upcoming exercises.

264

Prioritizing X variables for data collection

265

- X’s are identifiable characteristics of process inputs
- Who/what/where/when/how within the workflow scope
- They are shown on your Fishbone diagram
- It may not be feasible to collect data on all X variables of interest
- You may need to prioritize them

Instructions for prioritizing X variables

266

1. Open *Student Files → blank C&E matrix - Pareto method*
2. In the *Metrics* sheet, change *Metrics* to *Y variables*
3. List your Y variables and relative weights
4. In the *Items to be ranked* sheet, change *Items to be ranked* to *X variables*
5. List the X variables you wish to rank
6. Rate each X variable for degree of association with each Y variable: none (blank), low (L), medium (M), high (H). The numerical codings for H, M, and L are specified in the sheet *Calculations*.
7. Copy your X variable list, paste it into the *Pareto* sheet under *Paste items to be ranked*
8. Copy your overall rankings, *Paste Special → Values* into the *Pareto* sheet under *Paste overall rankings*
9. Select the range B3:C27, select *Data → Sort*, uncheck *My data has headers*, sort by column C, largest to smallest

Student Files → prioritizing X variables - example

Y variables	Relative weights
Audit Cycle Time	2
Report Quality	1

Metrics sheet

- You can also include one or more *feasibility* metrics on this list
- Or use *blank C&E matrix - impact & feasibility*

Example (cont'd)

Y variables	Audit Cycle Time	Report Quality	0	0	0	0	0	0	0	0	
Relative weights	**2**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**Overall rankings**
Which auditor	H	H									27
Which audit	H	L									19
Which sites	M										6
# Records reviewed	H	M									21
# Times touch same record/auditee	M										6
# People required to review findings	H	H									27
Audits started on time	H										18
Which auditee	H										18
Location of records	M										6
Where audit is conducted (desk, etc)	M	L									7
Accuracy of recorded observations	L	M									5
Auditor experience	H	H									27
Auditees given adequate time to respond to NCs	L	H									11
# Functional area SOPS required in audit	M	L									7
Audit SOPs readily available	M	L									7
Data delivery time	M	L									7
Perceived value of audits	M	M									9
Perceived value of findings	M	L									7
Availability and use of audit templates	M	H									15
											0
											0

X variables

Degree of positive association of each item (X variable) with each metric (Y variable): None (blank) Low (L) Medium (M) High (H)

Example (cont'd)

269

	A	B	C	D
1				
2		**Paste items to be ranked**	**Paste overall rankings**	
3		Which auditor	27	
4		# People who have to review findings	27	
5		Auditor experience	27	
6		# Records reviewed	21	
7		Which audit	19	
8		Which auditee	18	
9		Audits started on time	18	
10		Availability and use of audit templates	15	
11		Auditees given adequate time to respond to NCs	11	
12		Perceived value of audits	9	
13		Where audit is conducted (desk, etc.)	7	
14		Perceived value of findings	7	
15		Data delivery time	7	
16		# Functional area SOPS required in audit	7	
17		Audit SOPs readily available	7	
18		Which sites	6	
19		Location of records	6	
20		# Times touch same record/auditee	6	
21		Accuracy of recorded observations	5	
22				
23				
24				

Pareto sheet

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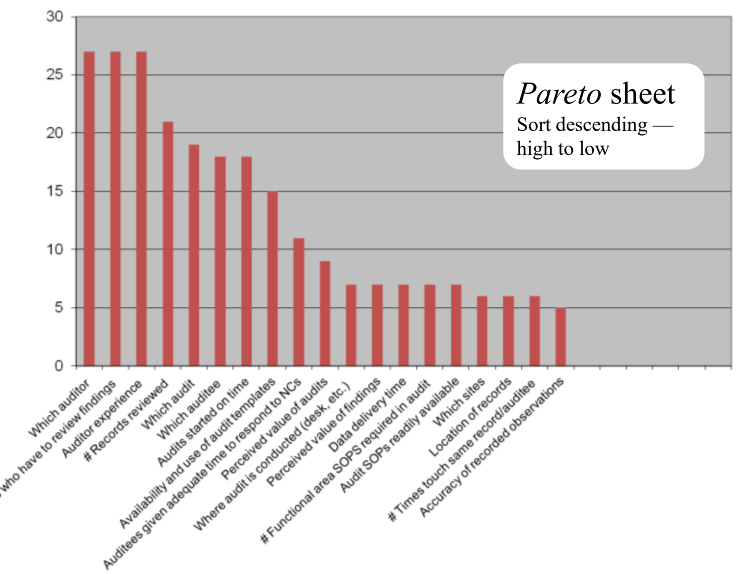
Example (cont'd)

270



270

Exercise 15.2

271

Open *Student Files → Case Studies → MBDP → MBDP X variable prioritizer*.
Y variables and X variables are given. Use your knowledge and experience to rate the X variables for degree of association with the Y variables and produce the Pareto Chart.

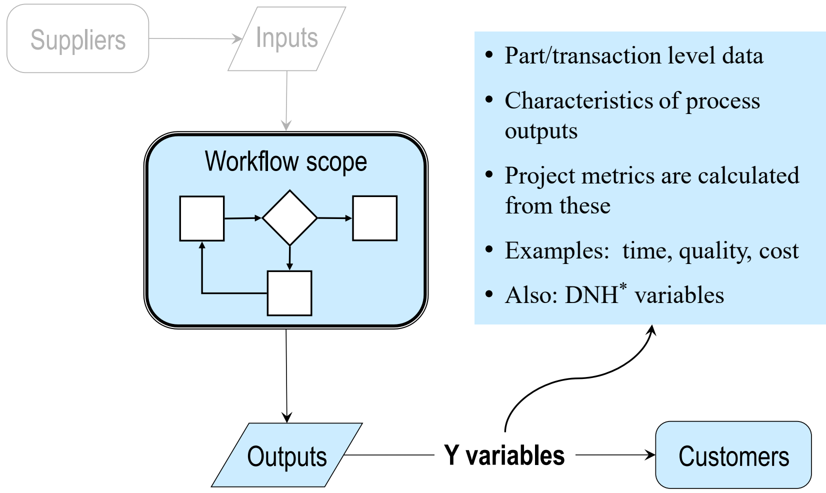
Prioritizing X's using Multi-voting

272

Another method for prioritizing X's for data collection is to use multi-voting:

1. Count the number of X's
2. Divide the total number of X's by 3. Each team member gets that many "votes"
3. Each team member decides how they will apply their votes, giving one vote to each X they think is a most likely main contributor to the problem
   - Give a marker to each team member and have them write their votes on the fishbone diagram or list
   - Use a *secret ballot* if there are concerns of undo influence among team members
4. Focus data collection on those X's that rise to the top

Y variables



- Part/transaction level data
- Characteristics of process outputs
- Project metrics are calculated from these
- Examples: time, quality, cost
- Also: DNH* variables

*Do No Harm — not trying to improve them, just don't want to make them worse. These may be secondary project metrics.

Y variables

- A *data variable* is a measurable characteristic defined for individual parts or transactions (What does "variable" mean?)
- *Y variables* are measurable characteristics of *outputs* from the workflow scope
- They are the data variables from which the statistical **project metrics,** such as average or percent defective, are calculated
  - Examples: lead time, turnaround time, pass/ fail result, counts of errors like transaction mistakes or rework occurrences, specified properties/ parameters: dimensions (length, width), electrical (resistance), chemical (pH); costs associated with these measures
- The Y variables are the reason we are doing the project in the first place. (The project's "Why?")
- The Y variables themselves need to be operationally defined to enable proper collection of this data

Operational definition for a Y variable

275

- If Y is a quantitative parameter, how will it be measured and what are its units of measure?
- If Y is a "count" of time or occurrences, how and from where will it be summed or calculated? For times, what are the units of measure (seconds, minutes, hours, days, weeks, etc.)?
  - If Y is a time span, like a lead or turnaround time, what are the exact start and stop points?
    - If using start/stop dates to calculate Time, consider how to account for same-day times, e.g., (stop date – start date) + 1.
    - If Y is unplanned downtime, how will you gather your data? Examples: machine-clocked minutes, or data from event logs, Maintenance reports, etc.?
- If Y is categorical (pass/fail, yes/no) what are the possible defects and what are the inspection/acceptance criteria?
- If you are going to count defects per opportunity (DPMO), how are the opportunities defined?
- If there is existing data, can you use it? What minor modifications to your operational definition(s) may be needed? (Data readily available will jump start your project. Use it whenever possible, even if minor adjustments to the project scope are needed.)

Notes

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Case study example: Tool Development

277

Y variable: count of reworks per tool Associated Project Metric: Average Rwks per tool

- If Y is a quantitative parameter, how will it be measured and what are its units of measure?

  NA to this Y variable, but for learning purposes: dimensions on the tool itself are quantitative and are measured with calipers.

- If Y is a "count" of time or occurrences, how and from where will it be summed or calculated? For times, what are the units of measure (seconds, minutes, hours, days, weeks, etc.)?

  Can pull number of reworks from the job order record in the ERP system, using the record of routings between Tool Testers and Machining Group. Alternately, Tool Testers could maintain a spreadsheet of # of reworks per tool PN, by job order# and dates.

  - If Y is a time span, like a lead or turnaround time, what are the exact start and stop points?
    - Time is NA to this Y variable, but for learning purposes: Average order-to-sell time in days is another Y metric that will be calculated. Start point = date of Order Receipt; End point = Shipment date to customer. Will calculate from ERP records, using Y = (Ship Date – Order Date) + 1.
    - If Y is unplanned downtime, how will you gather your data? Examples: machine-clocked minutes, or data from event logs, Maintenance reports, etc.? NA to this project but for learning purposes: if we needed downtime data, we would access the Facilities department's maintenance/time logs kept for each piece of equipment.

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Case study example: Tool Development (cont'd)

278

Y variable: count of reworks per tool Associated Project Metric: Average reworks per tool

- If Y is categorical (pass/fail, yes/no) what are the possible defects and what are the inspection/acceptance criteria?

  NA to this Y variable, but for learning purposes: cosmetic quality is a "Do No Harm" metric for this project. The inspection procedure would be referenced for the defects associated with the inspection criteria.

- If you are going to count defects per opportunity (DPMO), how are the opportunities defined?

  NA to this Y variable, but for learning purposes: the inspection criteria noted above could be used to define the defect opportunities.

- If there is existing data, can you use it? What minor modifications to your operational definition(s) may be needed?

  The ERP system contains data on reworks per tool. We will work with IT to create a report for extracting this data in a useable format. No modifications to the operational definition are needed.

- Additional thoughts?

  Not at this point.

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Exercise 15.3

279

Working with one or more others:

1. Give an operational definition for PO-PD in the Mounting Bracket Development Process (MBDP) project.
   Refer to the file *MBDP charter* in *Student Files \ Case Studies \ MBDP.*
   Use the checklist on the next slide to address the relevant questions.

2. (Optional) Give an operational definition for one of the Y variables for your project. Use the checklist on the next slide to address the relevant questions.

Exercise 15.3 (cont'd)

280

Y variable: ___________________________ Associated Project Metric: ___________________

- ❑ If Y is a quantitative parameter, how will it be measured and what are its units of measure?
- ❑ If Y is a "count" of time or occurrences, how and from where will it be summed or calculated? For times, what are the units of measure (seconds, minutes, hours, days, weeks, etc.)?
  - ❑ If Y is a time span, like a lead or turnaround time, what are the exact start and stop points?
    - ❑ If using start/stop dates to calculate Time, consider how to account for same-day times, e.g., (stop date – start date) + 1.
    - ❑ If Y is unplanned downtime, how will you gather your data? Examples: machine-clocked minutes, or data from event logs, Maintenance reports, etc.?
- ❑ If Y is categorical (pass/fail, yes/no) what are the possible defects and what are the inspection/acceptance criteria?
- ❑ If you are going to count defects per opportunity (DPMO), how are the opportunities defined?
- ❑ If there is existing data, can you use it? What minor modifications to your operational definition(s) may be needed?
- ❑ Additional thoughts?

“Big Y” and “little y”

281

Often, we collect data based on a high-level breakdown
of the in-scope workflow

Sort & collate
Code
Identify billables
Assign charges
Prepare bill

A billing process:
by main steps

Regional Sales
Technical Sales Coordinator
Business Unit Sales
Business Unit Engineering
Service
Finance
Legal

A quotation process:
by functional roles

PO: Sales/PE
Design Spec: PE
Design Spec: ME/QE
Drawing: Drafting/PE
Drawing: ME/QE
Proto

The MBDP:
by main steps ***and***
functional roles

“Big Y” and “little y” (cont’d)

282

In-scope workflow

$y_1 \rightarrow y_2 \rightarrow y_3$

“Little y” variables

- Each “little y” is specific to one element in the breakdown
- Common types of “little y” data:
  - ✓ WIP
  - ✓ process time
  - ✓ lead time
  - ✓ Number of defects
  - ✓ Cost of waste
- “Little y” data can help pinpoint root causes
- “Big Y” is the sum of “little y” over all elements
- “Big Y” is what the *customers* care about

Output — $Y = y_1 + y_2 + y_3$ → Customers

Pitfall: setting goals for each "little y"

283

- Suppose $Y = y_1 + y_2 + y_3$
- Suppose we have a 50% reduction goal for Y
- One way to achieve this is to reduce each of y_1, y_2, and y_3 by 50% . . .
- . . . but we should *not* set separate 50% reduction goals for y_1, y_2, and y_3
- Why?

SIPOC with X & Y variables

284

- The SIPOC diagram is an excellent way to summarize the X and Y variables to be studied
- Prioritized X variables are listed with the associated Suppliers, Inputs and Process steps
- Finalized Y variables are listed for the associated Outputs delivered to Customers
- The case study examples of SIPOC diagrams with X and Y variables provided in the following slides can be found in the applicable folder of *Student Files \ Case Studies,* labeled by case as *SIPOC #2 with Xs and Ys*
- Extra Credit! Create a SIPOC with X and Y variables for the MBDP case study using results from your Exercise 15.1 Cause and Effect (Fishbone) diagram

SIPOC with X's & Y's example 1: Quotation Process

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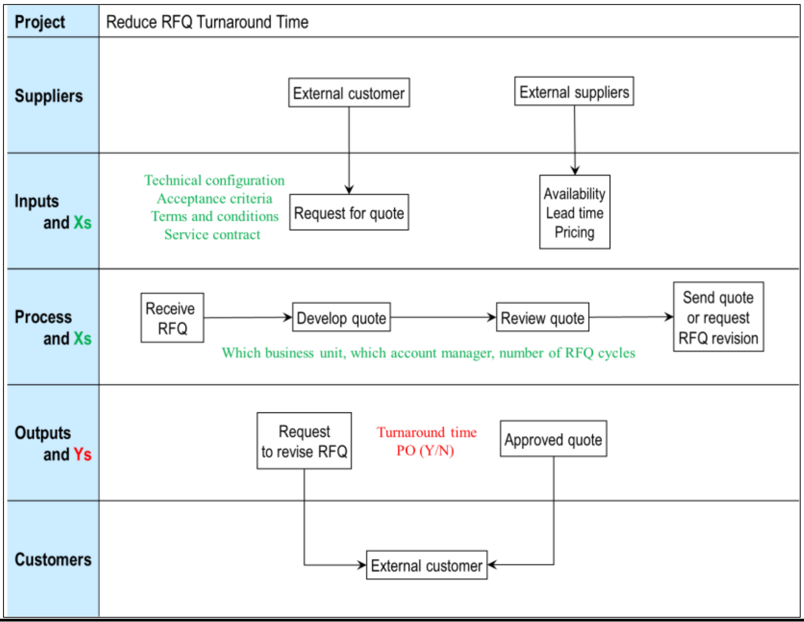
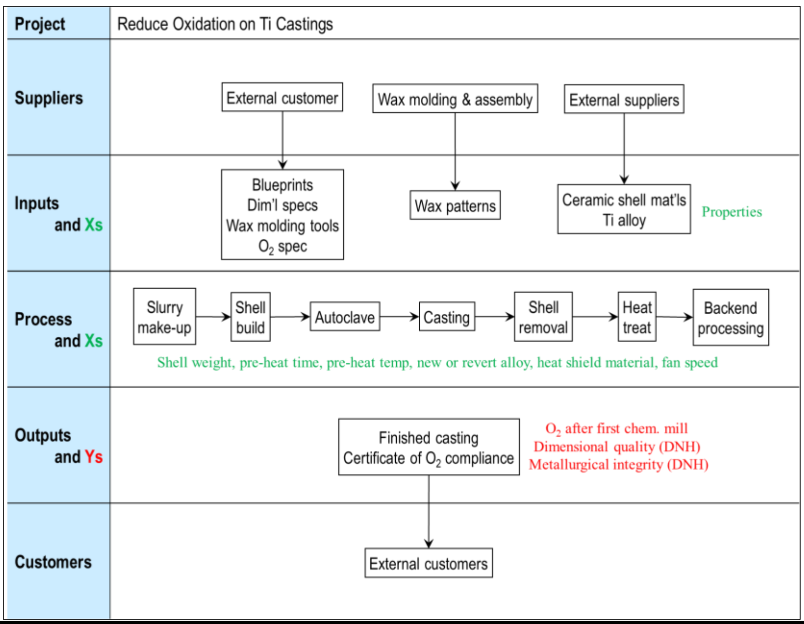


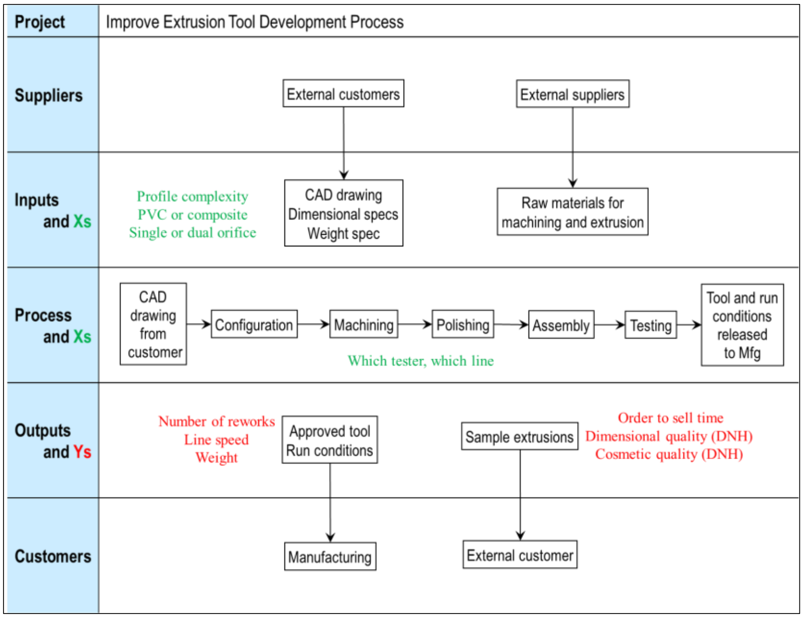
SIPOC with X's & Y's example 2: Titanium Casting

286



SIPOC with X's & Y's example 3: Tool Development

287



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Notes

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16 Data Formatting

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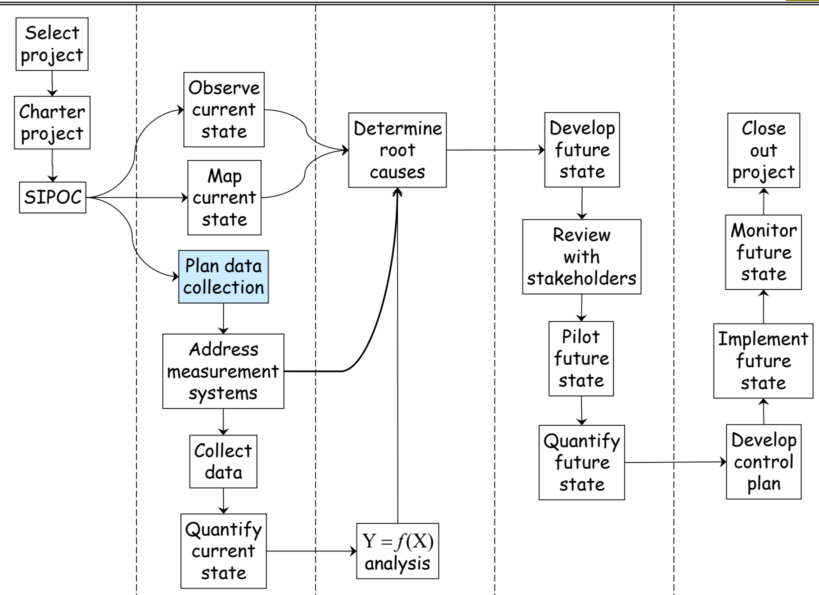

The spreadsheet: a truly marvelous invention

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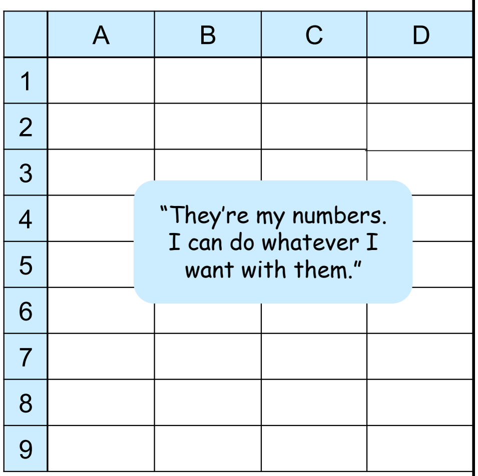
- Automates arithmetic
- Dynamic cell formulas
- Addins expand functionality
- No rules for formatting data
- No rules for analyzing data



Standard data matrix format

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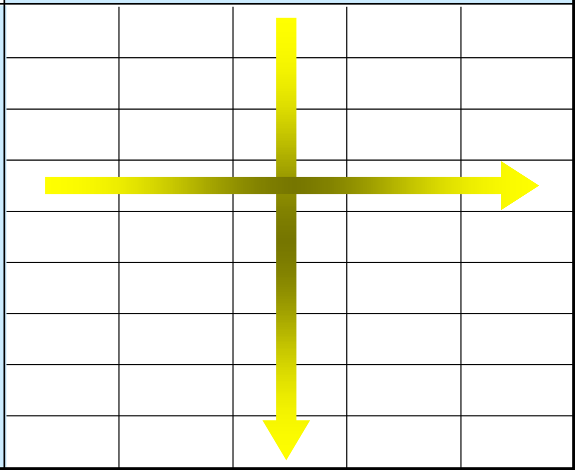
Each column

- A unique *field* (database terminology)
- A unique *variable* (statistical terminology)

Each row

- A unique *record* (database terminology)
- An observation (Statistical terminology)
- A part, sample, lot, batch, transaction, time period, person, . . .
- The number of rows is the *sample size*



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Data matrix example 1

292

← *Data variables* →

S/N	Length	Diameter
501	599.54	48.92
502	598.31	47.89
503	598.37	48.16
504	599.06	48.06
505	598.14	47.78
506	598.93	48.21
507	599.28	47.44
508	599.66	48.22
509	599.60	49.09
510	597.52	47.38
511	598.39	48.78
512	599.31	48.48
513	600.20	48.89
514	599.63	48.23

Each row represents one serial number of a particular part number

292

Data matrix example 2

293

Data variables

Quote Num	AcctMgr	BU	Initial RFQ	Month	Cycles	Finance reviews	TAT
3250024	8	3	12-Jun-03	2003.06	1	1	2
3250029	2	3	04-Jul-03	2003.07	1	0	2
3250031	5	3	29-Aug-03	2003.08	1	1	1
3250032	4	3	16-Jun-03	2003.06	1	0	1
3250033	3	3	06-Jun-03	2003.06	1	1	2
3250034	20	3	30-Jun-03	2003.06	1	1	4
3250035	3	3	09-Jun-03	2003.06	1	1	1
3250036	4	3	16-Jun-03	2003.06	1	0	1
3250037	4	3	16-Jun-03	2003.06	1	0	2
3250038	4	3	26-Jun-03	2003.06	1	0	1
3250039	8	3	30-Jun-03	2003.06	1	1	9
3250040	4	3	26-Jun-03	2003.06	1	0	1
3250041	4	3	26-Jun-03	2003.06	1	0	1
3250042	4	3	01-Jul-03	2003.07	1	0	1
3250043	11	3	07-Jul-03	2003.07	1	0	1
3250045	20	3	12-Aug-03	2003.08	1	1	2
3250046	3	3	14-Jul-03	2003.07	1	0	11
3250047	2	3	14-Jul-03	2003.07	1	0	3

Each row represents one quote

293

Data matrix example 3

294

Data variables

WORK ORDER	PARENT P/N	COMP P/N	AREA	CATEGORY	SCRAP QTY
35709	672-5668-00	162-4219-66	HDSI	TRAINING ISSUE	16
88198	174-B983-00	178-2758-66	WC	RECUT	40
88198	174-B983-00	178-2764-66	WC	RECUT	82
96772	180-9272-66	M83519/2-3	CH	TRAINING ISSUE	5
97130	672-6163-66	174-5274-00	HDSI	SPLICES	22
97166	180-8208-66	178-2564-66	WC	FAILED TEST	16
97166	180-8208-66	388-5021-66	NC	BAD MOLDING	1
97166	180-8208-66	388-5021-66	NC	FAILED TEST	1
97327	H542E371-01	162-4356-66	CH	FAILED TEST	1
97327	H542E371-01	162-4718-66	CH	FAILED TEST	2
97327	H542E371-01	47180GY-25	CH	FAILED TEST	1
97544	180-0829-66	178-1565-66	PR	FAILED TEST	5
97555	196-3501-66	47439-001LF	WC	MACHINE/TOOLING	200
97563	170-0135-66	178-0103-66	WC	MACHINE/TOOLING	12
97563	170-0135-66	178-0104-66	WC	MACHINE/TOOLING	7
97564	170-0148-66	131-0965-00	WC	MACHINE/TOOLING	300
97570	180-8728-66	132-6158-66	CH	TRAINING ISSUE	10
97582	010-0735-00	131-7989-00	HDSI	VENDOR MATL	32
97582	010-0735-00	174-5274-00	HDSI	TRAINING ISSUE	25
97582	010-0735-00	174-5274-00	HDSI	VENDOR MATL	17

Each row represents one work order, one component part number,
one process area, one defect category

294

Data matrix example 4

295

← *Data variables* →

Week	Inspected	Defective
1	400	2
2	169	1
3	208	1
4	510	3
5	132	1
6	500	3
7	393	2
8	625	3
9	167	1
10	395	3
11	200	1
12	122	1
13	178	2
14	527	4
15	132	1
16	171	2
17	610	5
18	446	5
19	428	5
20	207	3
21	708	15
22	565	13
23	149	3

Each row represents one week

Exercise 16.1 (a)

296

Average monthly WIP

	2001	2002	2003
Jan	19	20	20
Feb	27	22	15
Mar	20	19	27
Apr	16	16	25
May	18	22	17
Jun	25	19	19
Jul	22	25	28
Aug	24	22	
Sep	17	18	
Oct	25	20	
Nov	15	16	
Dec	17	17	

Is this a valid data matrix?

If not, give the column headings for the standard data matrix format.

Exercise 16.1 (b)

297

Patients admitted to an emergency department

Jan '01	Feb '01	Mar '01	Apr '01	May '01	June '01	July '01	Aug '01	Sept '01	Oct '01	Nov '01	Dec '01
3114	2778	3026	2869	3009	3119	3000	3069	2841	2962	2707	2815
Jan '02	**Feb '02**	**Mar '02**	**Apr '02**	**May '02**	**June '02**	**July '02**	**Aug '02**	**Sept. '02**	**Oct. '02**		
3015	2991	2769	2961	2991	3055	3328	3337	3209	2921		

Is this a valid data matrix?

If not, give the column headings for the standard data matrix format.

297

Exercise 16.1 (c)

298

Pass/fail & failure reasons

Test Date & Time	Model Number	Serial Number	Test Station	Result	Failure Reason
3/1/2006 6:02	690	6099948	3	Passed	
3/1/2006 6:03	692	6087149	1	Passed	
3/1/2006 6:05	690	6099949	3	Failed	DoBatteryAccuracyTest
3/1/2006 6:06	690	6099949	3	Passed	
3/1/2006 6:12	692	6087150	1	Passed	
3/1/2006 6:12	690	6099932	3	Passed	
3/1/2006 6:13	692	6099622	2	Passed	
3/1/2006 6:15	690	6099933	3	Failed	Operating current outside of allowed range
3/1/2006 6:17	692	6099623	2	Passed	

⋮

Is this a valid data matrix?

If not, give the column headings for the standard data matrix format.

298

Exercise 16.1 (d)

De-ionized (DI) water used in machining and cutting operations is sampled every 20 minutes

Tuesday		Wednesday		Thursday		Friday	
Hour	Resist	Hour	Resist	Hour	Resist	Hour	Resist
10	1609	0	1549	0	1746	0	1563
10	1832	0	1658	0	1539	0	1621
10	1808	1	1841	1	1735	1	1842
11	1714	1	1593	1	1754	1	1546
11	1846	1	1725	1	1637	1	1737
11	1686	2	1845	2	1895	2	1790
12	1559	2	1631	2	1696	2	1608
12	1888	2	1784	2	1715	2	1813

. . .

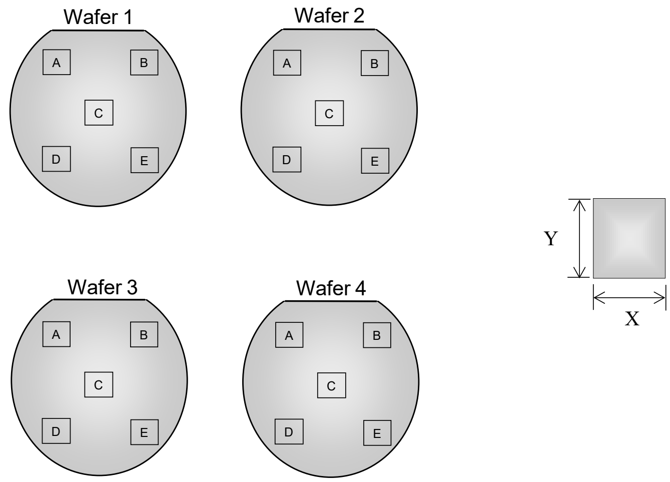
Is this a valid data matrix?

If not, give the column headings for the standard data matrix format.

Notes

Exercise 16.2

301



Exercise 16.2 (cont'd)

302

Computer chips are cut from silicon wafers. We selected chips cut from the same 5 locations on 4 wafers. We measured the X and Y dimensions of each chip. (It may help to sketch the data matrix.)

(a) Give the column headings for the standard data matrix format.

(b) How many rows are there?

(c) What does each row represent?

Example formats for manual data collection

303

Business Unit 1, 2, etc.	Quote Number XXXXXXX	Rev AA, AB, etc.	First quote? Yes/No	FY Requested 06, 07, etc.	Date Requested Format: 6/2/06	Service Approval Yes/No	Finance Approval Yes/No	Date Sent Format: 6/3/06	Region See code sheet	Account Manager AG, ET, GR, etc.

DATE Format: 10/28/04	JOB NO. 31, 32, etc.	TASK See code sheet	OPER AG, ET, GR, etc.	T0TAL HOURS X.XX	VA HOURS X.XX

303

Data collection forms (cont'd)

304

These examples are set up to match the desired data matrix format. This makes data entry easier.

The most important thing about a data collection form is to eliminate as much variation in data entry as possible. Specify desired date and time formats. Use codes instead of free form text. Use uppercase initials instead of names. Specify desired numeric formats precisely.

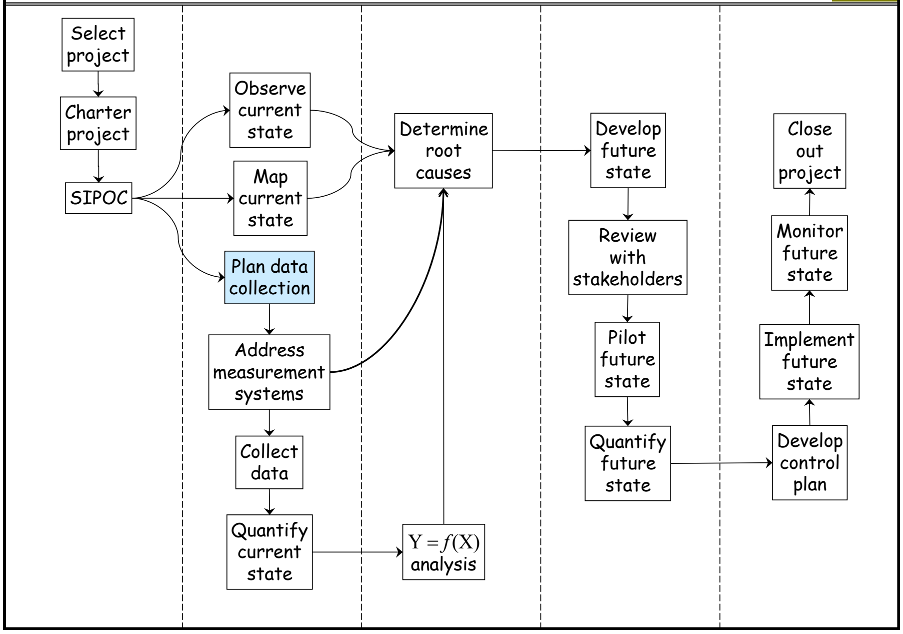
Try to fit all the variables for which you want data collected on one page. Try to make the spaces big enough to write in. These things may work against each other. If there are too many columns to fit into portrait mode, use landscape mode instead. Do not include variables that can be calculated from other variables after the data are entered into a spreadsheet.

Best Practice: Have at least one person ***test the form*** or spreadsheet by collecting data for a short period of time, to make sure it works well before deploying it more broadly for data collection.

304

17 Types of Data

305



305

Summary of data types

306

	Also known as	Examples
Quantitative measurement	✓Continuous ✓Variable ✓Parameter	Physical/chemical/electrical/optical properties, dimensions, distance, time, counts, . . .
Categorical classification	✓Qualitative ✓Discrete ✓Attribute	**Y variables** Pass/fail, type of defect, quality rating, . . . **X variables** Batch, lot, part number, supplier, customer, machine, operator, method, time period, location, condition, . . .

306

Quantitative Y variables

307

Dimensions of cylindrical castings

S/N	Length	Diameter
501	599.54	48.92
502	598.31	47.89
503	598.37	48.16
504	599.06	48.06
505	598.14	47.78
506	598.93	48.21
507	599.28	47.44
508	599.66	48.22
509	599.60	49.09
510	597.52	47.38
511	598.39	48.78
512	599.31	48.48
513	600.20	48.89
514	599.63	48.23
515	601.10	50.14
516	599.90	49.20
517	599.37	49.17

⋮

- True values may be infinitesimally close to each other
- Data resolution is determined by the measurement system
- Is **S/N** a quantitative measurement?

Quantitative Y variables

308

Resistivity of DI water

Tuesday		Wednesday	
Hour	Resist	Hour	Resist
10	1609	0	1549
10	1832	0	1658
10	1808	1	1841
11	1714	1	1593
11	1846	1	1725
11	1686	2	1845
12	1559	2	1631
12	1888	2	1784
13	1592	3	1704
13	1752	3	1676
13	1784	3	1860
14	1443	4	1619
14	1502	4	1398
14	1700	5	1556
15	1500	5	1687
15	1675	5	1574
15	1707	6	1733

- De-ionized water used in machining and cutting operations
- Electrical resistivity is the opposite of conductivity
- Higher resistivity means lower conductivity, which is good
- Data resolution is determined by the measurement system
- **Day of week** is a categorical classification
- **Hour of day**: quantitative or categorical?

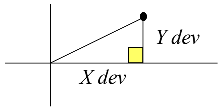
Quantitative Y variables

309

X dev	Y dev
8	-6
-7	-2
-9	-4
-10	-5
-21	-7
-20	6
-13	-3
-16	9
-20	-1
-14	-4
-14	-6
-16	3
-14	-6
-23	-4
-11	-10
-19	7
-14	3
-10	-6

⋮

Alignment of assembled components



- Deviations from target in X and Y directions
- Reported to the nearest thousandth of an inch
- Decimal point dropped

309

Quantitative Y variables

310

ED patient visits

Jan '01	Feb '01	Mar '01	Apr '01	May '01	June '01	July '01	Aug '01	Sept '01	Oct '01	Nov '01	Dec '01
3114	2778	3026	2869	3009	3119	3000	3069	2841	2962	2707	2815
Jan '02	**Feb '02**	**Mar '02**	**Apr '02**	**May '02**	**June '02**	**July '02**	**Aug '02**	**Sept. '02**	**Oct. '02**		
3015	2991	2769	2961	2991	3055	3328	3337	3209	2921		

✓ **Count data** — number of occurrences of some defined event

✓ Whole numbers only, no negative numbers

✓ **Month-year** is categorical

310

Quantitative Y variables

311

Date	# Units	# Defects	DPU
9-Feb-90	8	8	1.00
10-Feb-90	8	17	2.13
11-Feb-90	9	18	2.00
12-Feb-90	8	15	1.88
15-Feb-90	8	23	2.88
16-Feb-90	7	9	1.29
17-Feb-90	7	19	2.71
18-Feb-90	8	6	0.75
19-Feb-90	8	14	1.75
22-Feb-90	8	17	2.13
23-Feb-90	7	13	1.86
24-Feb-90	8	15	1.88
25-Feb-90	9	16	1.78
26-Feb-90	9	22	2.44
1-Mar-90	8	13	1.63
2-Mar-90	8	10	1.25
3-Mar-90	4	14	3.50
4-Mar-90	8	9	1.13
5-Mar-90	12	23	1.92
8-Mar-90	12	21	1.75
9-Mar-90	16	51	3.19
10-Mar-90	8	31	3.88
11-Mar-90	4	3	0.75

Defects per unit

- Scratches on lenses, particles on silicon wafers, bubbles in a laminate, errors in documents, . . .
- **DPU** = number of defects divided by number of units inspected
- Used instead of DPMO when multiple defects per unit are possible, but there is not a finite number of identifiable defect opportunities per unit
- In this case, because the defect count is relatively high, DPU is treated as quantitative data
- If the number of units is always 1, this is count data
- **Date**: quantitative or categorical?

311

Quantitative Y variables

312

Date requested	Date sent	Calendar days	Business days
05/26/04	05/26/04	1	1
05/26/04	05/26/04	1	1
06/02/04	06/02/04	1	1
06/02/04	06/02/04	1	1
06/02/04	06/02/04	1	1
06/02/04	06/02/04	1	1
06/02/04	06/03/04	2	2
06/03/04	06/04/04	2	2
06/04/04	06/04/04	1	1
06/04/04	06/07/04	4	2
06/07/04	06/07/04	1	1
06/07/04	06/07/04	1	1
06/07/04	06/08/04	2	2
06/08/04	06/08/04	1	1
06/08/04	06/08/04	1	1
06/08/04	06/08/04	1	1
06/09/04	06/09/04	1	1
06/11/04	06/11/04	1	1
06/11/04	06/11/04	1	1
06/14/04	06/14/04	1	1
06/14/04	06/14/04	1	1

Transaction turnaround time

- (Date sent) - (date requested)

or

- (Date sent) – (date requested) + 1
- Calendar or business* days
- The whole number resolution is a limitation of the measurement system

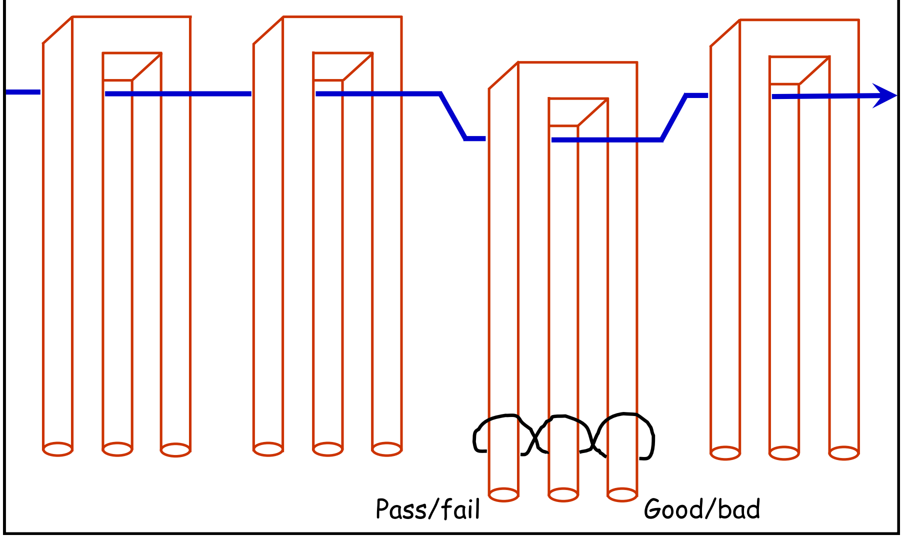
*The Excel function NETWORKDAYS subtracts out the weekends

312

Pass/fail Y variable

313

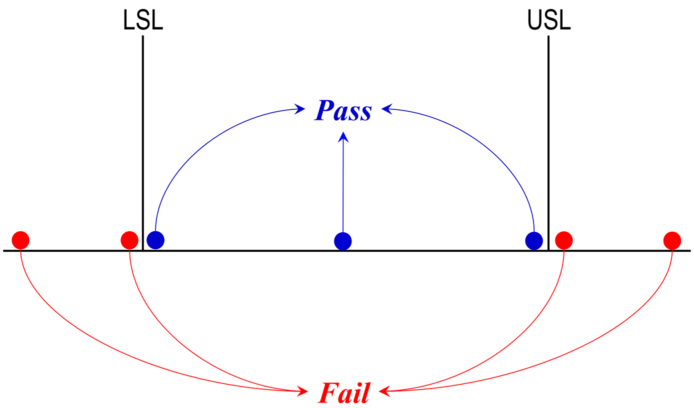
Testing fit, form and function on the mounting bracket production line



Pass/fail Y variable

314

Can be derived from quantitative data and spec limits



- Necessary for computing % out of spec
- Do not discard or ignore the underlying quantitative data!

Pass/fail Y variable

315

Monthly late account closings

	2001	2002	2003
Jan	3	6	2
Feb	5	4	2
Mar	3	3	4
Apr	2	2	6
May	3	4	2
Jun	7	4	5
Jul	5	1	10
Aug	4	5	
Sep	3	2	
Oct	3	7	
Nov	3	2	
Dec	2	1	

- Data for 35 offices
- Tabulated pass/fail data
- Underlying raw data:

  On time or late for each office for each month
- What we really want is **days late** for each office for each month

315

Pass/fail Y variables

316

Result & failure reasons

Test Date & Time	Model Number	Serial Number	Test Station	Result	Failure Reason
3/1/2006 6:02	690	6099948	3	Passed	
3/1/2006 6:03	692	6087149	1	Passed	
3/1/2006 6:05	690	6099949	3	Failed	DoBatteryAccuracyTest
3/1/2006 6:06	690	6099949	3	Passed	
3/1/2006 6:12	692	6087150	1	Passed	
3/1/2006 6:12	690	6099932	3	Passed	
3/1/2006 6:13	692	6099622	2	Passed	
3/1/2006 6:15	690	6099933	3	Failed	Operating current outside of allowed range
3/1/2006 6:17	692	6099623	2	Passed	
3/1/2006 6:18	690	6099933	3	Failed	DoBatteryAccuracyTest
3/1/2006 6:18	690	6099933	3	Failed	Operating current outside of allowed range
3/1/2006 6:19	692	6087151	1	Passed	
3/1/2006 6:20	690	6099782	3	Passed	
3/1/2006 6:21	692	6099624	2	Passed	
3/1/2006 6:22	692	6087152	1	Passed	
3/1/2006 6:22	690	6099934	3	Passed	
3/1/2006 6:24	690	6099935	3	Failed	DoSwitchTest
3/1/2006 6:24	692	6087153	1	Failed	Sleep current outside of allowed range
3/1/2006 6:25	692	6099625	2	Passed	
3/1/2006 6:27	690	6099935	3	Failed	DoSwitchTest

316

Tabulated defect data

317

Date	Shift	Defect	Freq
3/1/1991	A	Contamination	15
3/1/1991	A	Corrosion	2
3/1/1991	A	Doping	1
3/1/1991	A	Metallization	2
3/1/1991	A	Miscellaneous	3
3/1/1991	A	Oxide Defect	8
3/1/1991	A	Silicon Defect	1
3/1/1991	B	Contamination	8
3/1/1991	B	Corrosion	2
3/1/1991	B	Doping	1
3/1/1991	B	Metallization	4
3/1/1991	B	Miscellaneous	2
3/1/1991	B	Oxide Defect	10
3/1/1991	B	Silicon Defect	3
3/2/1991	A	Contamination	16
3/2/1991	A	Corrosion	3
3/2/1991	A	Doping	1
3/2/1991	A	Metallization	3
3/2/1991	A	Miscellaneous	1
3/2/1991	A	Oxide Defect	9
3/2/1991	A	Silicon Defect	2

Defects by type

- **Defect** is a categorical classification
- **Freq** is quantitative — it counts the number of defects of each type for each day and shift
- *Good for Pareto analysis*
- *Can we get actual occurrence rates? What is missing?*
- **Shift** is a categorical classification
- **Date**: quantitative or categorical?

317

Categorical Y variable

318

Application	Appraiser	Rating
1	Simpson	5
1	Montgomery	5
1	Holmes	5
1	Duncan	4
1	Hayes	5
2	Simpson	2
2	Montgomery	2
2	Holmes	2
2	Duncan	1
2	Hayes	2
3	Simpson	4
3	Montgomery	3
3	Holmes	3
3	Duncan	3
3	Hayes	3
4	Simpson	1
4	Montgomery	1
4	Holmes	1
4	Duncan	1
4	Hayes	1
5	Simpson	0
5	Montgomery	0

Quality rating

- Five-point scale: 1, 2, 3, 4, 5
- In this case, higher is better
- Treated as quantitative when we want to average the ratings (for example, GPA)
- **Appraiser** is a categorical classification
- **Application**: quantitative or categorical?

318

Exercise 17.1

Pretend the data shown in the next slide contains actual data on actual cars. Check the appropriate data type for each variable.

In some cases, the data type may go either way, depending on how the variable is used.

	Quantitative	Categorical
Model year		
Origin		
Make		
Model		
Cylinders		
Displacement		
Horsepower		
Weight		
Accel		
MPG		

Exercise 17.1 (cont'd)

Model year	Origin	Make	Model	Cylinders	Displace	Horsepower	Weight	Accel	MPG
79	Europe	Mercedes	300D	5	183	77	3530	20.1	25.4
80	Europe	Mercedes	240D	4	146	67	3250	21.8	30.4
79	America	Cadillac	Eldorado	8	350	125	3900	17.4	23.0
81	Japan	Toyota	Cressida	6	168	116	2900	12.6	25.4
81	Europe	Volvo	Diesel	6	145	76	3160	19.6	30.7
81	Europe	Peugeot	505S DI	4	141	80	3230	20.4	28.1
82	America	Chevrolet	Camaro	4	151	90	2950	17.3	27.0
81	Japan	Datsun	810 Maxima	6	146	120	2930	13.8	24.2
81	Europe	Saab	900S	4	121	110	2800	15.4	
80	Japan	Datsun	280-ZX	6	168	132	2910	11.4	32.7
80	Europe	Audi	5000S DI	5	121	67	2950	19.9	36.4
82	Japan	Toyota	Celica GT	4	144	96	2665	13.9	32.0
82	America	Oldsmobile	Cutlass DI	6	262	85	3015	17.0	38.0
82	America	Buick	CenturyLmt	6	181	110	2945	16.4	25.0
80	Japan	Mazda	RX-7 GS	3	70	100	2420	12.5	23.7
80	Europe	Volkswagen	Rabbit	4	98	76	2144	14.7	41.5
80	Europe	Volkswagen	Rabbit	4	89	62	1845	15.3	29.8
81	America	Oldsmobile	Cutlass LS	8	350	105	3725	19.0	26.6
81	America	Buick	Century	6	231	110	3415	15.8	22.4
82	Japan	Honda	Accord	4	107	75	2205	14.5	36.0
82	Japan	Nissan	Stanza XE	4	120	88	2160	14.5	36.0

Exercise 17.2

321

(a) Which useful statistical project metrics can be calculated from a quantitative Y variable?

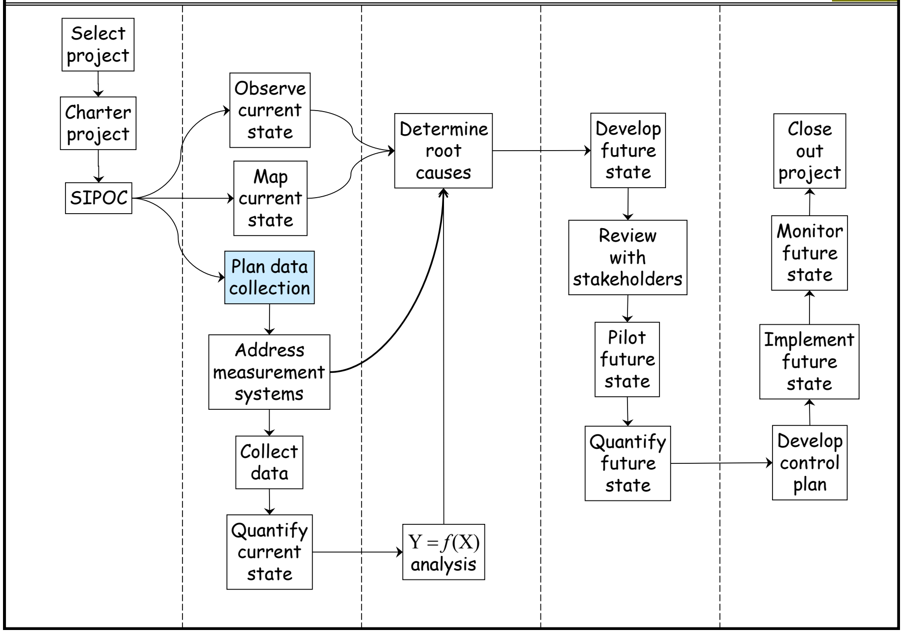
(b) Which useful statistical project metrics can be calculated from a pass/fail Y variable?

Notes

322

18 Basic Statistics and Normal Distribution

323



323

Basic statistical summary for quantitative data

324

$$\text{Average} = (\text{Sum of N numbers})/\text{N}$$

$$\text{Sample mean} = \text{Average of a sample from a population}$$

A set of numbers: 76, 80, 80, 81, 82, 82, 88, 92

$$\text{N} = 8$$

$$\begin{aligned}\text{Average} &= (76 + 80 + 80 + 81 + 82 + 82 + 88 + 92)/8 \\ &= 661/8 \\ &= 82.6\end{aligned}$$

$$\text{Minimum} = 76$$

$$\text{Maximum} = 92$$

324

Basic statistics (cont'd)

325

Sample standard deviation $=$

$$\sqrt{\frac{(76-82.6)^2+(80-82.6)^2+(80-82.6)^2+(81-82.6)^2 +(82-82.6)^2+(82-82.6)^2+(88-82.6)^2+(92-82.6)^2}{7}}$$

$$= 5.04$$

325

Average and standard deviation in Excel

326

C2 f_x =AVERAGE(A2:A9)

	A	B	C	D	E	F
1	**Data**		**Average**	**Std. Dev.**		
2	76		82.6	5.0		
3	80					
4	80					
5	81					
6	82					
7	82					
8	88					
9	92					

D2 f_x =STDEV.S(A2:A9)

	A	B	C	D	E	F
1	**Data**		**Average**	**Std. Dev.**		
2	76		82.6	5.0		
3	80					
4	80					
5	81					
6	82					
7	82					
8	88					
9	92					

326

327

Open *Student Files → anatomy of STDEV*

A	C	D	E	F	G	I	J
	Data		**Average**		**Difference**		
	76		82.6		-6.6		
	80		82.6		-2.6		
	80		82.6		-2.6		
	81		82.6		-1.6		
	82	−	82.6	=	-0.6	**Sum =**	**0.000000**
	82		82.6		-0.6		
	88		82.6		5.4		
	92		82.6		9.4		
Sums of Squares (SS)	54793.0	−	54615.1	=	177.9		
Degrees of Freedom (DF)	8	−	1	=	7		
Mean Square (MS)*	(SS ÷ DF)				25.41		
Standard Deviation	(Square root of MS)				**5.04**		

*Also known as **Variance**

327

328

Anatomy of STDEV (cont'd)

This sheet lays out the calculation of the sample standard deviation (the STDEV.S function in Excel).

The *Data* column contains 8 independent measurements (no constraints among them). We describe this by saying this column has 8 *degrees of freedom* (DFs).

The *Average* column contains a single value, repeated 8 times. We describe this by saying this column has 1 DF.

The *Difference* column is mathematically constrained to sum to 0, so it contains only 7 mathematically independent values. From any 7 values in this column, we can calculate the remaining value. (What is the formula?) We describe this by saying this column has 7 DFs.

This is why the sum of the squared differences is divided by 7 rather than 8. Dividing by 8 would bias it downwards.

328

Exercise 18.1

329

a) Open *Data Sets* → *solution properties*. Calculate the average and standard deviation for *Spec grav*. Save your work and keep this file open for the next exercise.

b) Open *Data Sets* → *ED patient visits*. ED stands for Emergency Department (aka ER, Emergency Room). Calculate the average and standard deviation of *Visits*. Save your work and keep this file open for the next exercise.

Notes

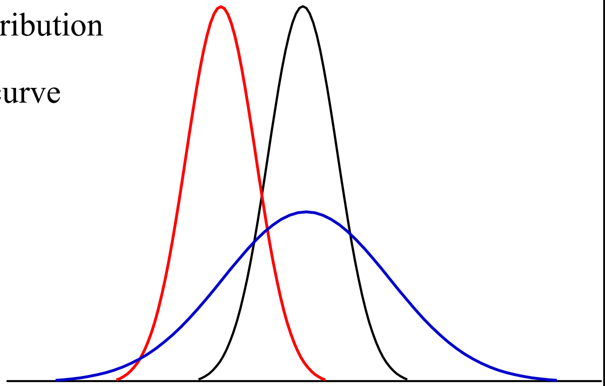
330

The Normal Distribution

331

Also known as

- Gaussian distribution
- Bell-shaped curve



Everyone believes in the Normal curve: experimenters think it is a mathematical theorem, mathematicians think it is an experimental fact. —G. Lippman

331

Normal distribution (cont'd)

332

The Normal distribution is an abstraction, an idealization, a mathematical construct. At the same time, it has been a device of great practical value in Statistics.

It's called the Gaussian distribution because the German mathematician Carl Friedrich Gauss made important early applications to astronomy in the 1820s. As we will see, it was actually discovered a century earlier by the French mathematician Abraham de Moivre.

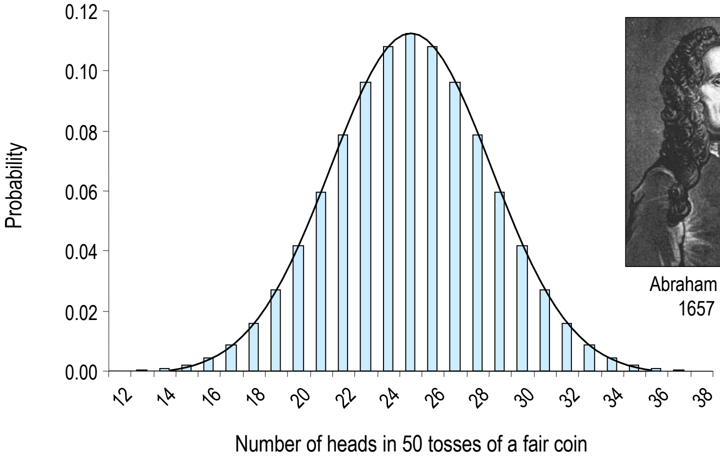
Life really isn't fair…

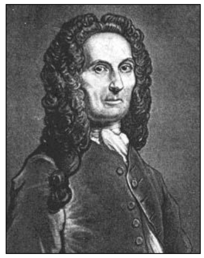
332

Origin of the Normal distribution

333

As the number of tosses of a fair coin increases,
the probability distribution of the number of heads
approaches a bell-shaped curve.





Abraham de Moivre
1657 - 1754

333

Origin of Normal distribution (cont'd)

334

The statistical model for the number of heads in N tosses of a coin is called the Binomial distribution. In 1730, the French mathematician Abraham de Moivre discovered the bell-shaped curve as the limiting form approached by the Binomial distribution as the sample size N increases without bound. He never made any money on his discovery of the Normal distribution, and in fact died a pauper. To add insult to injury, it was eventually named after someone else (Gauss).

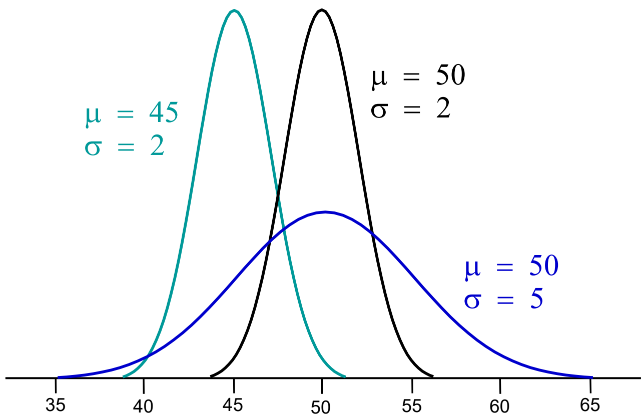
Over the next 200 years, de Moivre's discovery was extended far beyond coin tossing. Today, we know that many quantitative measurements are sums of large numbers of small, independent, possibly unobservable contributing factors. Measurements of this type in a stable population will follow the Normal distribution, at least as a good approximation. Statisticians call this phenomenon the Central Limit Theorem.

The Normal distribution is the default population model for quantitative measurements.

334

The bell-shaped curve

μ	=	Greek letter *mu*	→	Population mean
σ	=	Greek letter *sigma*	→	Population standard deviation



Bell-shaped curve (cont'd)

A population model is an equation that can be used to make predictions about a population. When we represent the mean and standard deviation by Greek letters, as shown in the previous slide, we are thinking of the mean and standard deviation of the entire population, not just the numbers in our data set. It means we are thinking of the Normal distribution as a population model.

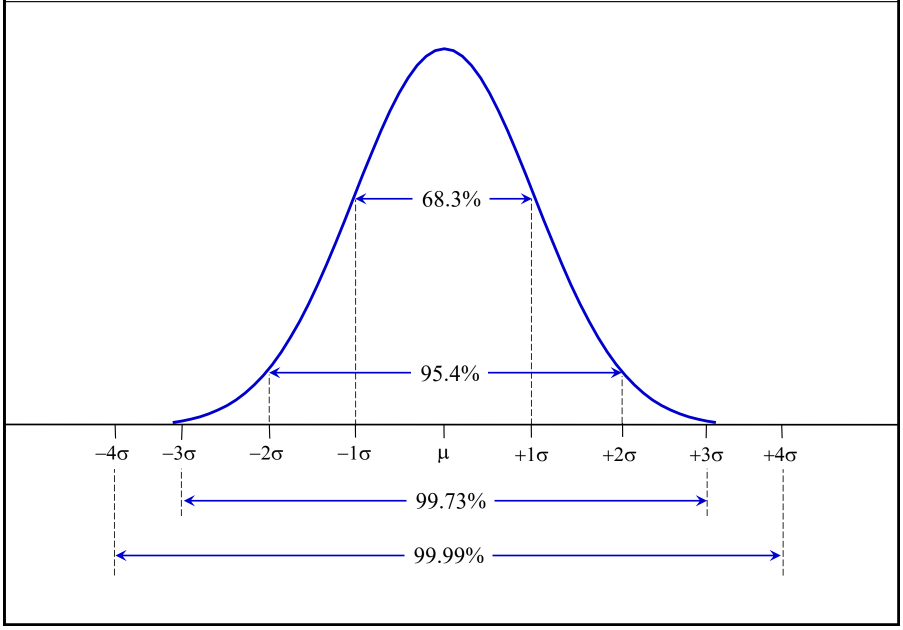
The formula for the bell-shaped curve is given below. In this equation, $f(y)$ is the height of the curve above the value y on the horizontal axis.

$$f(y) = \frac{1}{\sqrt{2\pi}} \frac{1}{\sigma} e^{-\frac{1}{2}\left(\frac{y-\mu}{\sigma}\right)^2}$$

You may have been graded "on the curve" at some point in your academic career. Well, this is the curve.

Area under curve = % of population

337



337

Area under curve (cont'd)

338

For a Normal population:

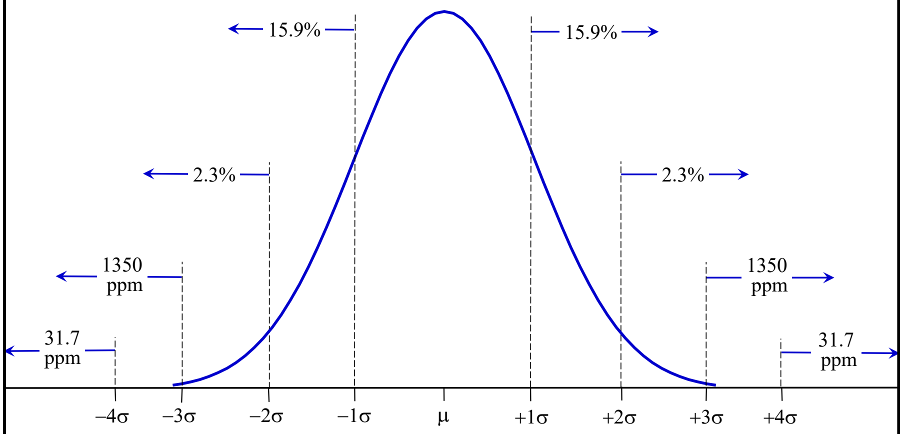
- The 1.960σ limits contain 95% of the population.
- The 2σ limits contain 95.45% of the population.
- The 2.576σ limits contain 99% of a Normal population
- The 3σ limits contain 99.73% of the population.

338

Area under curve = % of population

339

Usually we care mostly about % *beyond* certain points



339

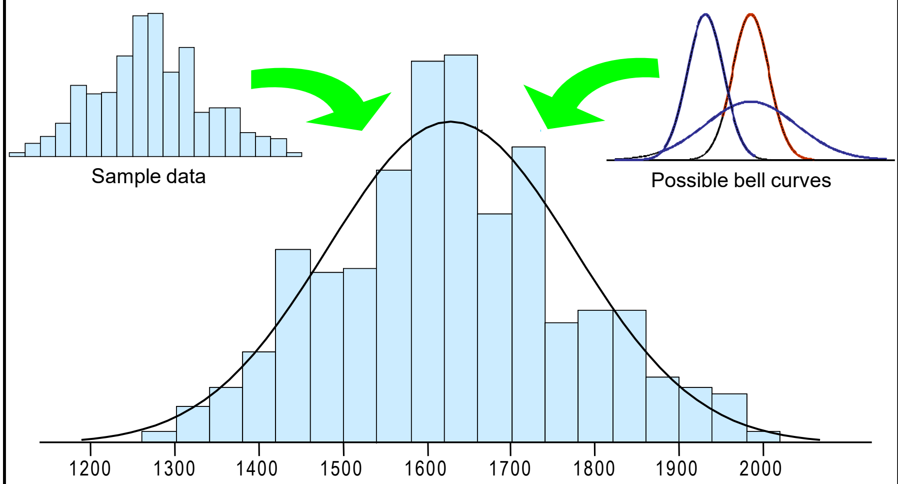
Fitting the bell curve to data

340

Sample mean (1628.7) $\rightarrow \mu$

Sample standard deviation (142.8) $\rightarrow \sigma$

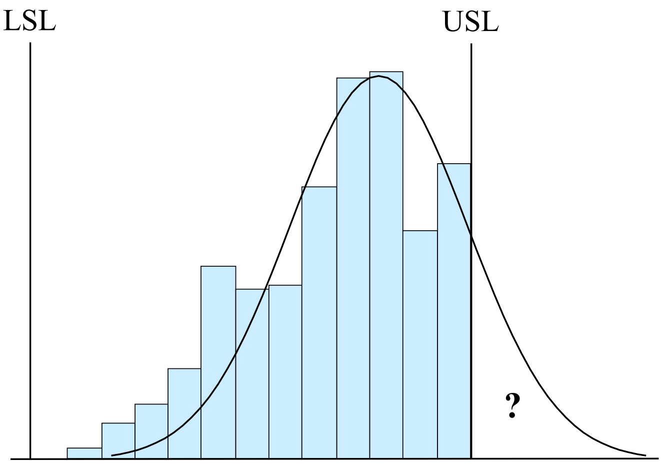
$$f(y)=\frac{1}{\sqrt{2\pi}}\frac{1}{\sigma}e^{-\frac{1}{2}\left(\frac{y-\mu}{\sigma}\right)^2}$$



340

Why use fitted distributions?

341



341

Why distributions? (cont'd)

342

The practice of calculating % defective or DPPM by means of fitted distributions instead of raw data came about historically as a crude but effective way for customers in the aerospace and automotive supply chains to expose the "hidden factories" of their suppliers.

Suppliers would present final inspection data to customers to document their process capability. In the example shown in the previous slide, the supplier claims 100% yield. When plotted as a histogram, the data mysteriously disappears right at the upper spec limit. This is because parts exceeding the upper limit are either scrapped or reworked to the limit. Often the rework is done by the inspector and not recorded as rework. In many cases, the first pass data is not recorded.

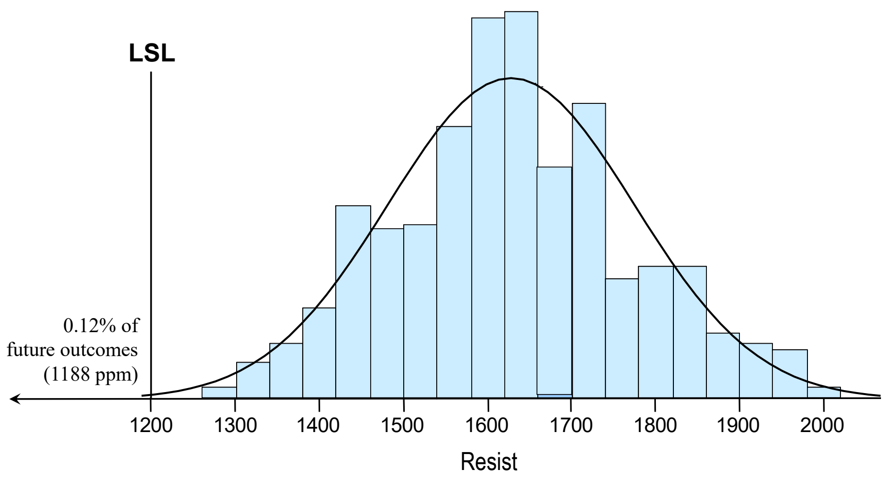
A distribution curve pays no attention to spec limits and will always produce a positive value for % defective or DPPM. This gives an estimate of the supplier's first pass yield. In the example shown in the previous slide, it is obvious that the first pass yield is far below 100%.

342

Using the Normal curve to predict % defective or DPPM

343

Allows extrapolation ( )



343

% below 1500

344

Student Files → calculator - Normal distribution

	A	B	C	D	E	F	G	H
1		1. Enter the quantities in the YELLOW cells.						
2		2. The other values are calculated for you.						
3								
4		LSL	1500			LSL	USL	Total
5		USL			Population % out of spec	18.37	0.00	18.37
6		Mean	1628.7		Population PPM out of spec	183725	0	183725
7		Standard deviation	142.8					
8								
9								
10		These calculations can be sensitive to round-off error. Don't round off the mean and standard deviation when you enter them into the calculator. The best thing to do is copy them from a basic statistical summary, then use *Paste Special* → *Values*.						

344

% below 1500 or above 1800

345

Student Files → calculator - Normal distribution

1. Enter the quantities in the YELLOW cells.
2. The other values are calculated for you.

LSL	1500
USL	1800
Mean	1628.7
Standard deviation	142.8

	LSL	USL	Total
Population % out of spec	18.37	11.52	29.89
Population PPM out of spec	183725	115151	298876

These calculations can be sensitive to round-off error. Don't round off the mean and standard deviation when you enter them into the calculator. The best thing to do is copy them from a basic statistical summary, then use *Paste Special → Values*.

345

Exercise 18.2

346

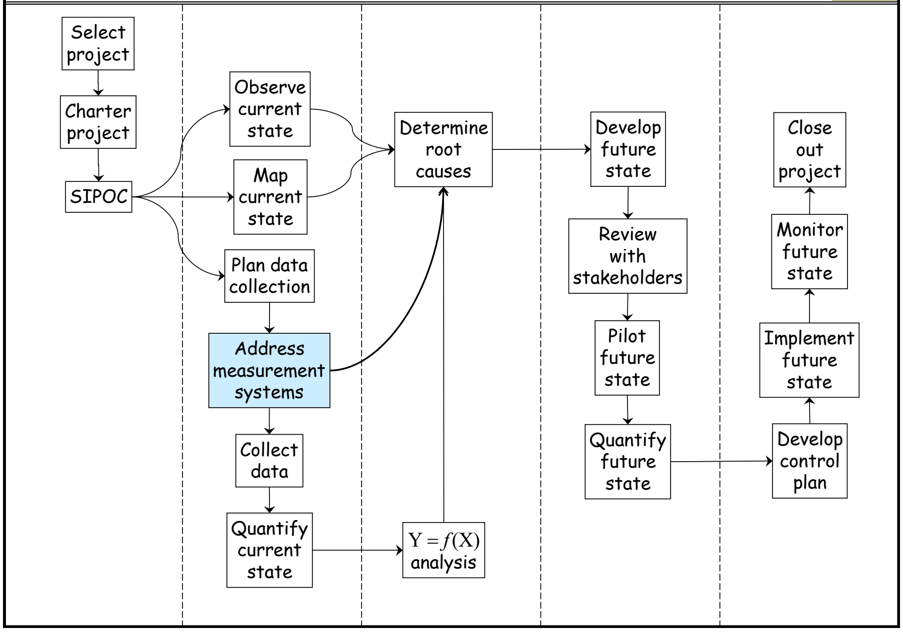
a) Open *Data Sets → solution properties*. Use the mean and standard deviation you calculated in the previous exercise to find the % or PPM for which *Spec grav* is greater than 0.925.

b) Open *Data Sets → ED patient visits*. Use the mean and standard deviation you calculated in the previous exercise to find the % or PPM for which *Visits* is either less than 2700 or greater than 3300.

346

19 Measurement Variation

347



347

Topics

348

- Population model for measurement variation
- How components of variation add up
- Calculating measurement variation*
- Degrees of freedom

*In the situation where there is only one appraiser.

348

Measurement Example

349

- Open *Student Files \ Line Length*
- Follow the instructions for taking the measurement
- Report your measured value using inches

349

Measurement Example (cont'd)

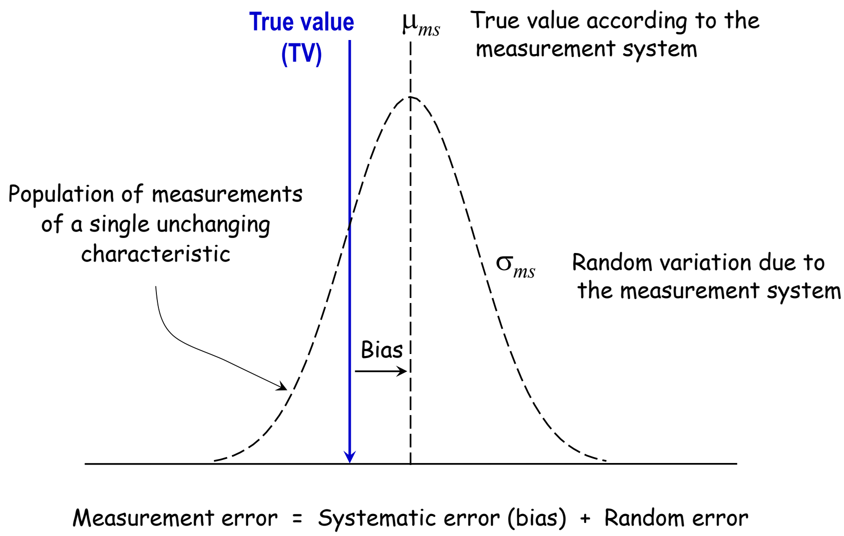
350

- What did you notice about the group's measurements?
- What might explain these results?

350

Population model for measurement variation

351



Population model (cont'd)

352

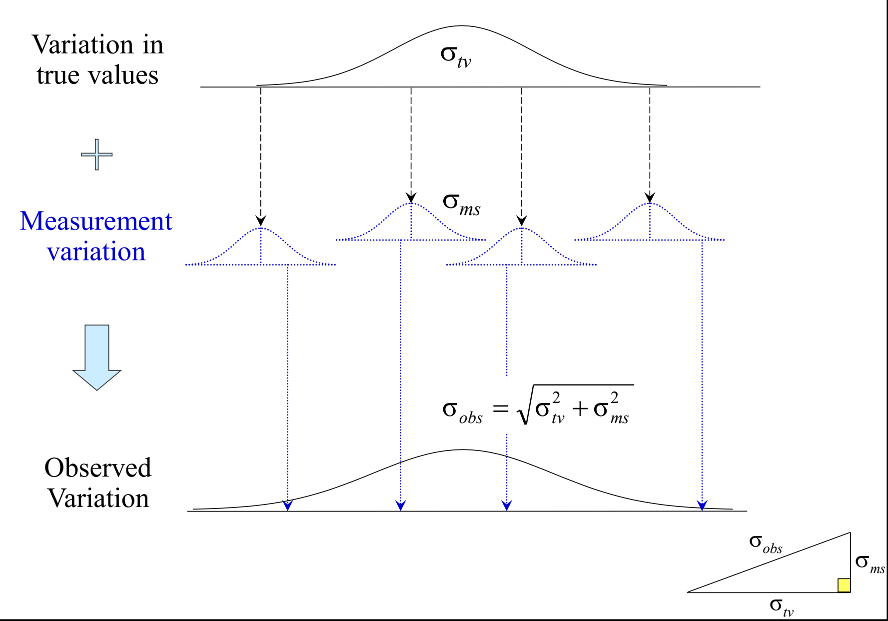
- The purpose of calibration is to eliminate gage bias
- Calibration requires standards (measurable items whose true values are known) or a calibrated second gage of higher accuracy
- The primary objective of quantitative measurement system analysis (MSA) is to determine the variation contributed by the measurement system, σ_{ms}, which is *more than gage bias*

To be clear, calibration is not enough!

- Quantitative MSA does not require standards
- If gage bias is constant during the MSA, the resulting σ_{ms} will be accurate
- If gage bias changes during the MSA, the resulting σ_{ms} will be biased upwards

How components of *variation* add up for the overall process

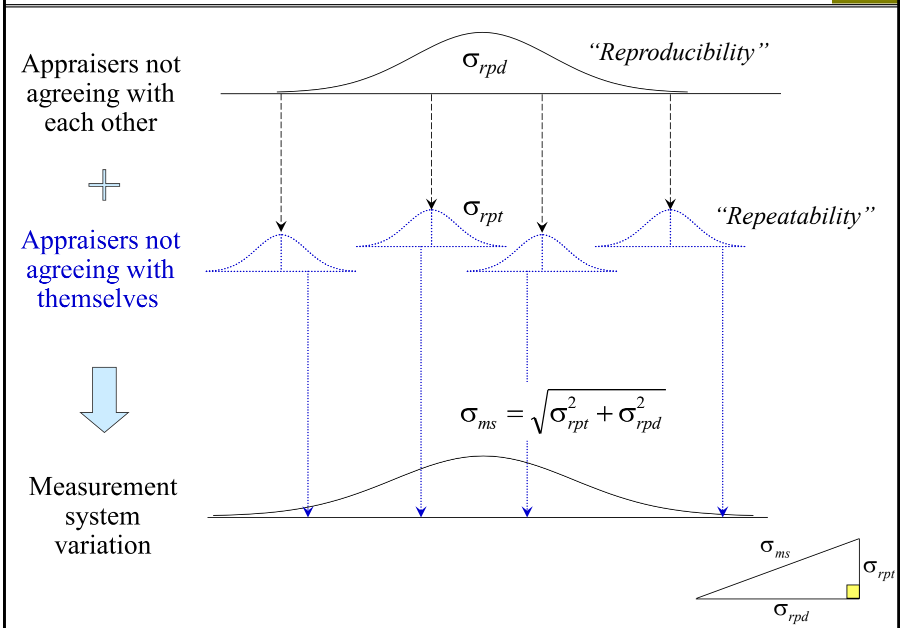
353



353

How components of *measurement system variation* add up

354



354

STDEV revisited: *Student Files→MSA - one appraiser→Observed variation* **355**

	Data		Average		Difference		
	9.61		9.691		-0.081		
	9.71		9.691		0.019		
	9.54		9.691		-0.151		
	9.67		9.691		-0.021		
	9.75		9.691		0.059		
	9.49		9.691		-0.201		
	9.55		9.691		-0.141		
	9.42	=	9.691	+	-0.271	Sum =	0.00000000
	9.58		9.691		-0.111		
	9.61		9.691		-0.081		
	9.87		9.691		0.179		
	9.93		9.691		0.239		
	9.81		9.691		0.119		
	9.89		9.691		0.199		
	9.94		9.691		0.249		
Degrees of freedom (DF)	15	=	1	+	14		
Sum of squares (SS)	1409.220	=	1408.829	+	0.391		
Mean square (MS)	*(SS / DF)*				0.028		
Square root of MS					**0.167**		

↑
Sample standard deviation
(STDEV)

355

STDEV revisited: *MSA - one appraiser → Observed variation* (cont'd) **356**

The previous slide is a screen shot of the worksheet *Observed variation* in *Student Files → MSA - one appraiser*. This sheet reviews the calculation of the sample standard deviation. In MSA, this is called the "observed variation." In other types of data analysis, it is called the "total variation."

Recap of *degrees of freedom* (DFs)

- The *Data* column has 15 DFs because it consists of 15 independent measurements.
- The *Average* column has 1 DF because it consists of a single value repeated 15 times.
- The *Difference* column is constrained to sum to 0, so it contains only 14 independent values, so it has 14 DFs.
- DFs have to add up. For example, 15 = 1 + 14.

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MSA - one appraiser → Measurement variation 357

	Part	Data		Part averages		Measurement variation		
	1	9.61		9.656		-0.046		
	1	9.71		9.656		0.054		
	1	9.54		9.656		-0.116	Sum =	0.00000000
	1	9.67		9.656		0.014		
	1	9.75		9.656		0.094		
	2	9.49		9.530		-0.040		
	2	9.55		9.530		0.020		
	2	9.42	=	9.530	+	-0.110	Sum =	0.00000000
	2	9.58		9.530		0.050		
	2	9.61		9.530		0.080		
	3	9.87		9.888		-0.018		
	3	9.93		9.888		0.042		
	3	9.81		9.888		-0.078	Sum =	0.00000000
	3	9.89		9.888		0.002		
	3	9.94		9.888		0.052		
Degrees of freedom (DF)		15	=	3	+	12		
Sum of squares (SS)		1409.220	=	1409.159	+	0.061		
Mean square (MS)		*(SS / DF)*				0.005		
Square root of MS						**0.072**		
						↑		
						σ_{ms}		

357

MSA - one appraiser → Measurement variation (cont'd) 358

The previous slide is a screen shot of the sheet *Measurement variation*. It lays out the calculation of σ_{ms} when each of 3 parts is measured 5 times by one appraiser.

The *Part averages* column has 3 DFs because it consists of 3 independent values (the part averages).

In the *Measurement variation* column, the values for each part are constrained to sum to 0, so any 4 of them determine the remaining value. There are 3 parts, so there are only $3 \times 4 = 12$ independent values in this column, so it has 12 DFs.

Because the calculation of σ_{ms} involves only 12 independent values, we could refer to σ_{ms} itself in this case as having 12 DFs. The greater the DFs for σ_{ms}, the more accurate it is.

As before, DFs have to add up: $15 = 3 + 12$.

358

MSA - one appraiser → Data format & analysis

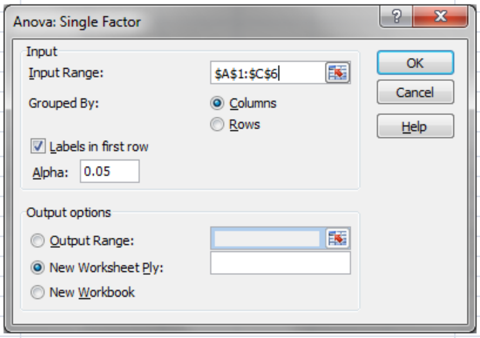
359

Part 1	Part 2	Part 3
9.61	9.49	9.87
9.71	9.55	9.93
9.54	9.42	9.81
9.67	9.58	9.89
9.75	9.61	9.94

Excel data format for MSA with one appraiser

Data > Data Analysis > ANOVA Single Factor

Instructions for doing the analysis



Screen shot of the sheet **Data format & analysis**

File: *Student Files \MSA-one appraiser*

MSA - one appraiser → Default output

360

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Part 1	5	48.28	9.656	0.00688
Part 2	5	47.65	9.53	0.00575
Part 3	5	49.44	9.888	0.00272

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.329773	2	0.164887	32.22541	1.5E-05	3.885294
Within Groups	0.0614	12	0.005117			
Total	0.391173	14				

Screen shot of the sheet **Default output**

MSA - one appraiser → Edited output

361

	A	B	C	D	E	F
1	ANOVA: Single Factor					
2						
3	SUMMARY					
4	*Groups*	*Count*	*Average*			
5	Part 1	5	9.656			
6	Part 2	5	9.530			
7	Part 3	5	9.888			
8						
9						
10	ANOVA					
11	*Source of Variation*	*SS*	*df*	*MS*		
12	Between Groups	0.330	2	0.165		
13	Within Groups	0.061	12	**0.005**	$(\sigma_{ms})^2$	
14				**0.072**	σ_{ms}	=SQRT(D13)
15				**0.215**	$3\sigma_{ms}$	=3*D14

Screen shot of the sheet **Edited output**

Exercise 19.1

362

Open *Student Files \ MSA-one appraiser*

Perform the analysis shown in the last three slides.

The value $3\sigma_{ms}$ is the *measurement error* — the amount by which a single measurement could vary (+ or -) from the true value.

Degrees of freedom for MSA with one appraiser

363

- Let: N = sample size of an MSA (total number of measurements)

  I = number of items in the MSA (parts, transactions, samples, . . .)

- DF for σ_{ms} = N – I

NOTE:
I, not 1 (one) !

- In the previous example: N = 15, I = 3
- DF for σ_{ms} = N – I = 15 – 3 = 12
- For Degrees of Freedom, higher is better

Exercise 19.2

364

For each scenario below, give the total number of measurements and the degrees of freedom for σ_{ms} for one appraiser.

	N	DF for σ_{ms}
(a) 1 item is measured 15 times		
(b) Each of 15 items is measured 1 time		
(c) Each of 3 items is measured 5 times		
(d) Each of 3 items is measured 10 times		
(e) Each of 15 items is measured 2 times		
(f) Each of 4 items is measured 10 times		
(g) Each of 20 items is measured 2 times		
(h) Each of 8 items is measured 8 times		
(i) Each of 36 items is measured 2 times		

Degrees of freedom for MSA with multiple appraisers

365

- Let: I = number of items in the MSA (parts, transactions, whatever)

  A = number of appraisers

  S = number of *sessions* (measurements per item per appraiser)

  N = sample size of an MSA, i.e., total number of measurements

  (N = I x A x S)

- In general: DF for σ_{ms} . . . . N – I

  DF for σ_{rpt} (repeatability) . . . . . IA(S – 1)

  DF for σ_{rpd} (reproducibility) . . . . I(A – 1)

- Note that the DFs for σ_{rpt} and σ_{rpd} add up to the DF for σ_{ms} (because N = I x A x S)

365

Example

366

- 5 items, 7 appraisers, 2 sessions
- N = (5)(7)(2) = 70
- DF for σ_{ms} = N – I = 70 – 5 = 65
- DF for σ_{rpt} (repeatability) = IA(S – 1) = 5(7)(1) = 35
- DF for σ_{rpd} (reproducibility) = I(A – 1) = 5(6) = 30

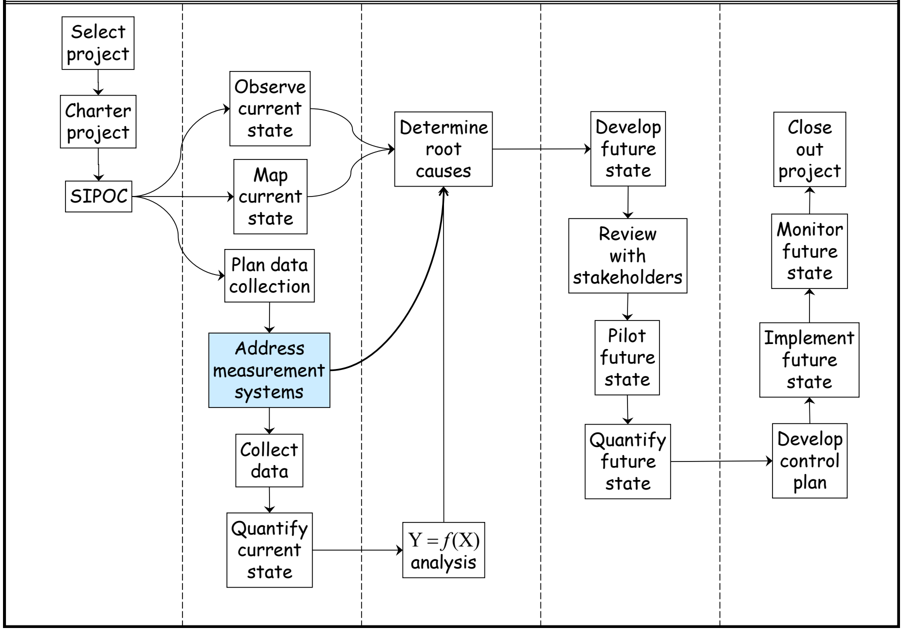
Exercise 19.3

Repeat these calculations for 10 items, 3 appraisers, and 3 sessions.

366

20 Measurement System Analysis

367



Topics

368

- Gages
- Measurement systems
- Statistical model for measurement variation
- Impact of measurement variation
- Measurement system analysis (MSA)
- Basic assumption for MSA
- MSA for quantitative measurements

Gages

369

- A *gage* is a measurement device
- Gages can produce quantitative measurements or categorical classifications
- The people who use the gages are usually called *appraisers*, *inspectors*, or *operators*
- For visual inspections, the appraisers are themselves the gages, but they are not called that
- For automated measurement systems, the appraisers may not play a significant role in producing the results

369

Measurement system

370

- A set of gages used to measure defined characteristics of a defined class of objects or events
- The gages produce the same type of data
- For quantitative measurements, the gages provide the same data resolution (x.x, x.xx, x.xxx, xx.x, . . .)
- The appraisers are part of the system
- The methods and documentation are part of the system
- If there are standards, they are part of the system

370

Impact of measurement variation

371

Action taken

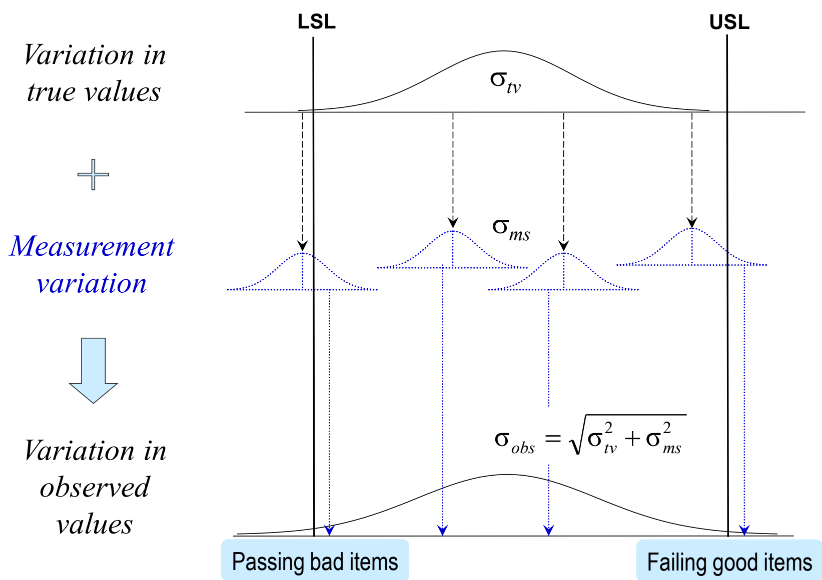
True outcome		Pass	Fail
	Good	☺	*"False alarm"*
	Bad	*"Escape"*	☺

Which type of error is more costly? For which is the cost easier to quantify?

371

Impact of measurement variation (cont'd)

372



372

Measurement system analysis (MSA)

373

- Companies should make decisions based on data
- Bad data → bad decisions
- One large company estimated the annual cost impact of excessive measurement variation as $33M
- MSA quantifies and classifies measurement variation
- MSA → corrective action → reduced measurement variation → reduced cost

373

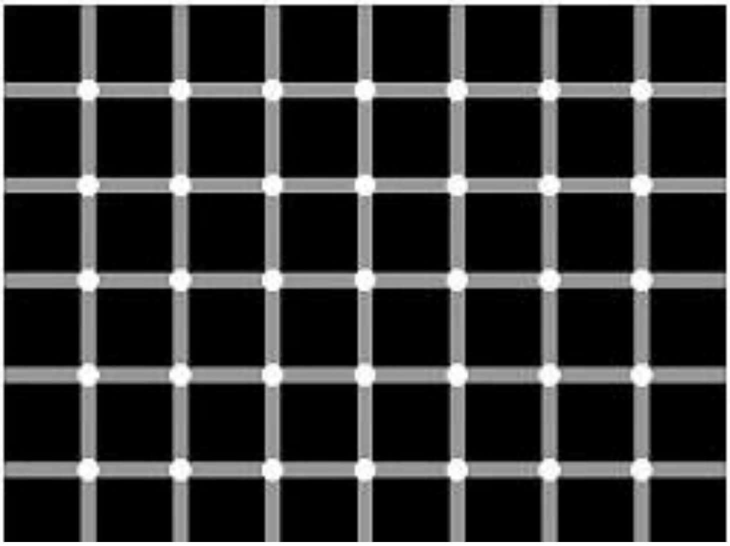
Common corrective actions

374

- Improving procedures and fixtures
- Improving gages
- Training appraisers
- Acquiring better gages

374

Exercise: count the black dots



Basic assumption for MSA

- MSA requires multiple measurements of "unchanging objects"
- This is not always possible
  - ✓ Measurement process may destroy measured items
  - ✓ Measurement process may change measured characteristics
  - ✓ Measured characteristics may change over time
- In such cases, ad hoc workarounds are used
  - ✓ Treat contiguous material samples as the same sample
  - ✓ Treat items categorized as "very similar" as the same item
- Workarounds bias σ_{ms} upwards
  - ✓ Measurement system looks worse than it really is

Capability metrics for quantitative MSA

377

% Tolerance	$100 \times \frac{3\sigma_{ms}}{(\mathrm{USL}-\mathrm{LSL})/2}$	• Most common metric • Must have both LSL and USL (usually product or process specs)
% Tolerance LSL only	$100 \times \frac{3\sigma_{ms}}{\mu - LSL}$	• Use when there is only LSL • Process mean (μ) should be based on historical data, not the MSA data
% Tolerance USL only	$100 \times \frac{3\sigma_{ms}}{USL - \mu}$	• Use when there is only USL • Process mean (μ) should be based on historical data, not the MSA data
% Process	$100 \times \frac{\sigma_{\mathrm{ms}}}{\sigma_{\mathrm{obs}}}$	• Doesn't require spec limits • Process standard deviation (σ_{obs}) should be based on historical data, not the MSA data
Measurement error	$3\sigma_{ms}$	• Has units of the measured characteristic • Intrinsic capability, not relative to product or process requirements

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Acceptability criteria for "percent" metrics

378

10% or less	Excellent
10-20%	Good
20-30%	Acceptable
Greater than 30%	Unacceptable

378

Designing a quantitative MSA

379

1. Choose <u>at least</u> 5 items (parts, samples, documents…) spanning the range of application of the measurement system. (Spanning the range is more important than the actual number of items.)

2. If the measurement system has only a few appraisers, include them all in the study. If there are many appraisers, include as large a representative sample as possible.

3. Let I = the number of items, A = the number of appraisers, and S = the number of *sessions* (measurements per item per appraiser).
   - The quantity IA(S – 1) is the number of independent opportunities for appraisers to agree *with themselves* (repeatability). It should be at least 30.
   - The quantity I(A – 1) is the number of independent opportunities for appraisers to agree *with each other* (reproducibility). It also should be at least 30.

   It is best to satisfy these requirements by increasing A, with I = 5 and S = 2. If this is not possible, increase I.

379

Designing a quantitative MSA (cont'd)

380

4. If the measurements are taken by devices, and operators have no influence on the results, the devices are the appraisers.

5. If devices are used to aid human inspection, combinations of devices and human inspectors should be treated as the appraisers. The ideal is to use all possible combinations of human inspectors and devices. If this is not possible, a DOE matrix with an acceptable number of combinations should be created.

380

Examples of step 3

381

Open *Student Files* → *calculator - sample size* → *MSA* sheet

Number of items	10	
Number of appraisers	3	
Number of sessions	3	
# Opportunities for appraiser self-agreement	60	These should be at least 30 for quantitative, at least 60 for categorical.
# Opportunities for appraiser cross-agreement	20	
Total sample size	90	

- The standard automotive gage study ("10 3 3")
- Not enough opportunities for appraiser cross agreement
- Unnecessarily many opportunities for appraiser self agreement

381

Examples of step 3

382

A better plan

Number of items	15	
Number of appraisers	3	
Number of sessions	2	
# Opportunities for appraiser self-agreement	45	These should be at least 30 for quantitative, at least 60 for categorical.
# Opportunities for appraiser cross-agreement	30	
Total sample size	90	

- Better balance of opportunities for self and cross agreement
- Same total sample size

382

Examples of step 3

383

Best plan, assuming there are actually 7 appraisers

Number of items	5	
Number of appraisers	7	
Number of sessions	2	
# Opportunities for appraiser self-agreement	35	These should be at least 30 for quantitative, at least 60 for categorical.
# Opportunities for appraiser cross-agreement	30	
Total sample size	70	

- Adequate opportunities for self and cross agreement
- Smaller total sample size

383

Conducting a quantitative MSA

384

1. Perform this sequence for each session:

   First appraiser measures all items once

   Second appraiser measures all items once

   .
   .
   .

   Last appraiser measures all items once.

2. The order in which the items are measured should be reversed each time the appraiser changes. Or, better yet, randomize the order each time.

3. The full measurement set-up process must be repeated each time a measurement is taken.

4. Allow some time separation between sessions to represent variation in operating conditions, and for human appraisers to "forget" the parts.

384

Analyzing a quantitative MSA

385

- Open *Data Sets* → *msa velocity gage*
- Measurements are of Drop Velocity
- Measurements need to be "unstacked" by Operator for analysis in Excel
- The standard analysis requires that every appraiser measures every part the same number of times
- I = 8, A = 3, S = 2
- Was this a well designed MSA?

	A	B	C	D	E
1	Session	Part	Oper A	Oper B	Oper C
2	1	1	9.61	9.54	9.67
3	1	2	9.49	9.44	9.58
4	1	3	9.87	9.77	9.89
5	1	4	9.78	9.66	9.74
6	1	5	9.89	9.91	9.89
7	1	6	10.15	10.12	10.16
8	1	7	9.96	9.87	9.97
9	1	8	9.80	9.72	9.72
10	2	1	9.71	9.61	9.75
11	2	2	9.55	9.42	9.61
12	2	3	9.93	9.81	9.94
13	2	4	9.75	9.63	9.72
14	2	5	10.03	9.84	9.93
15	2	6	10.31	10.08	10.18
16	2	7	10.05	9.96	9.97
17	2	8	9.87	9.74	9.78
18					

What do the numbers in cell range C2:C9 represent:
part variation, measurement variation, or observed variation?

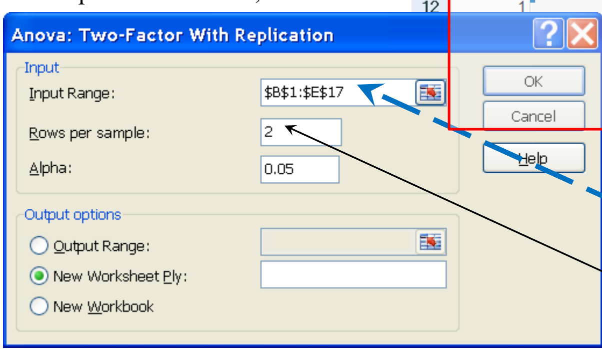
What do the numbers in cell range C2:E2 represent:
part variation, measurement variation, or observed variation?

Worked example

386

1. **Sort the data by *Part*** as shown to the right (the Excel procedure needs this). Select **ALL** columns (A thru E) for this sorting.
2. Data → Data Analysis → Anova: Two-Factor With Replication → OK.
3. Set up as shown below, click OK.

	A	B	C	D	E
1	Session	Part	Oper A	Oper B	Oper C
2	1	1	9.61	9.54	9.67
3	2	1	9.71	9.61	9.75
4	1	2	9.49	9.44	9.58
5	2	2	9.55	9.42	9.61
6	1	3	9.87	9.77	9.89
7	2	3	9.93	9.81	9.94
8	1	4	9.78	9.66	9.74
9	2	4	9.75	9.63	9.72
10	1	5	9.89	9.91	9.89
11	2	5	10.03	9.84	9.93
12	1	6	10.15	10.12	10.16
		6	10.31	10.08	10.18
		7	9.96	9.87	9.97
		7	10.05	9.96	9.97
		8	9.80	9.72	9.72
		8	9.87	9.74	9.78



Place cursor here, highlight this range

Enter the number of sessions here

Example (cont'd)

387

4. Scroll down to the ANOVA table as shown here.

	A	B	C	D	E	F	G
58							
59	ANOVA						
60	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
61	Sample	1.729748	7	0.247107	103.23	2.37E-16	2.422629
62	Columns	0.096329	2	0.048165	20.12097	7.39E-06	3.402826
63	Interaction	0.028371	14	0.002026	0.846575	0.618209	2.129797
64	Within	0.05745	24	0.002394			
65							
66	Total	1.911898	47				
67							
68							

5. Open *Student Files → calculator – Gage R&R*.

Example (cont'd)

388

6. Copy the shaded area.

	A	B	C	D	E	F	G	H
1	ANOVA							
2	Source of Variation	SS	df	MS				
3	Sample	22.4742	7	3.2106				
4	Columns	84.5409	2	42.2704				
5	Interaction	73.5770	14	5.2555				
6	Within	233.2751	24	9.7198				
7								
8	Total	413.8672	47					
9								
10		σ^2		3σ				
11	Reproducibility	2.3134	19.2%	4.5630				
12	Repeatability	9.7198	80.8%	9.3530				
13	Measurement System	12.0332	100.0%	**10.4067**				
14								
15	N	48						
16	Items	8						
17	Appraisers	3						
18	Sessions	2						
19								

Copy this area.
Paste into ANOVA table.

Example (cont'd)

389

7. Paste the shaded area below your ANOVA table exactly as shown.

$$3\sigma_{ms} = 0.2179$$

Reproducibility is the dominant component, but not by much.

	A	B	C	D	E
58					
59	ANOVA				
60	*Source of Variation*	*SS*	*df*	*MS*	*F*
61	Sample	1.729748	7	0.247107	103.23
62	Columns	0.096329	2	0.048165	20.12097
63	Interaction	0.028371	14	0.002026	0.846575
64	Within	0.05745	24	0.002394	
65					
66	Total	1.911898	47		
67					
68		σ^2		3σ	
69	Reproducibility	0.0029	54.6%	0.1611	
70	Repeatability	0.0024	45.4%	0.1468	
71	Measurement System	0.0053	100.0%	**0.2179**	
72					
73	N	48			
74	Items	8			
75	Appraisers	3			
76	Sessions	2			
77					

8. For this measurement "Drop Velocity," (USL–LSL)/2 = 1.65. Use Excel to calculate the *% Tolerance* metric. How would you classify this measurement system?

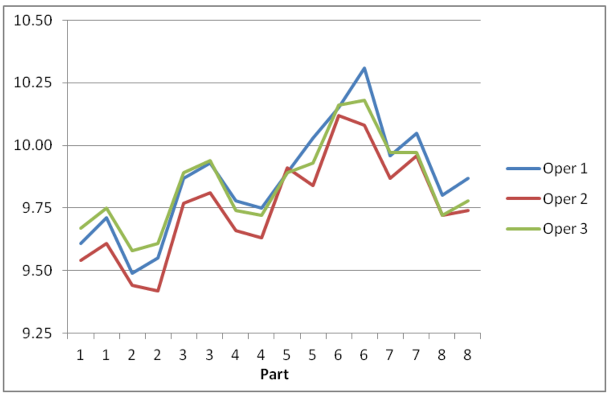
$$\%Tol = 100 \times \frac{3\sigma_{ms}}{1.65} = 13.2\%$$

Example (cont'd)

390

9. Create a line chart of the operator columns by part (Highlight columns > Insert Line Chart)

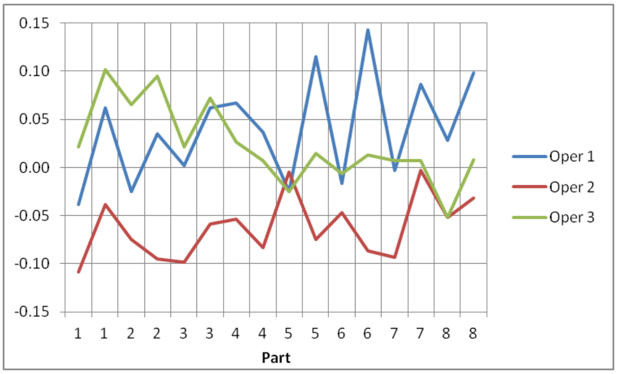
10. This is what a good one looks like. The operator curves are close together and roughly parallel, showing they are getting similar measurements for each part.



Example (cont'd)

391

- If part variation is large enough relative to measurement variation, the lines on the previous chart will appear to be superimposed on each other
- The file *Data Sets* → *msa velocity gage with charts* gives the calculations for the chart below, which shows the data with the part averages subtracted out.
- This helps you see what's going on with the measurements by each operator, when part variation in the study is large compared to measurement variation.



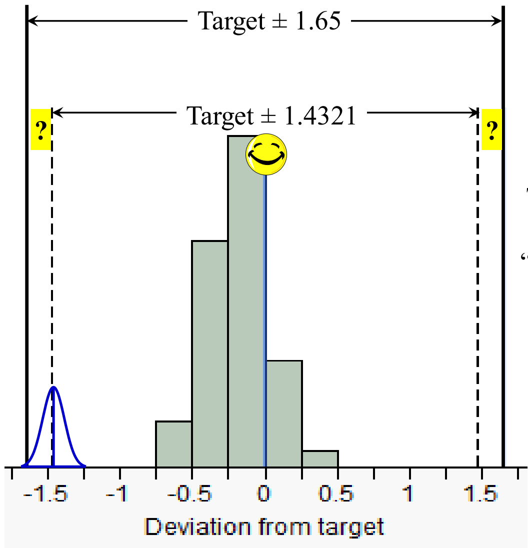
Interpreting $3\sigma_{ms}$

392

- In this example, $3\sigma_{ms} = 0.2179$
- For a given measurement m, the true value lies in the interval
  $$m \pm 0.2179$$
  with 99.7% confidence
- The tolerance for drop velocity is $\pm$ 1.65 (Given on previous slide)
- $1.65 - 0.2179 = 1.4321$
- To be confident that a drop velocity is in spec, it must be within 1.4321 of the target value (see next slide)

Interpreting $3\sigma_{ms}$ (cont'd)

393



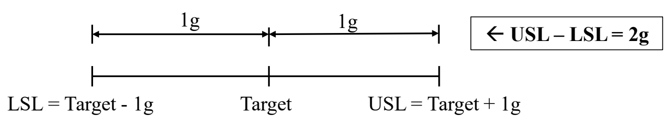
These are also known as "Guard Bands"

Exercise 20.1

394

Open *Data Sets* → *msa weight*. Three operators weighed 10 samples 3 times each, all using the same scale.

(a) The tolerance for the weight is *target* ± 1g. Find $3\sigma_{ms}$ and calculate the *% Tolerance* metric. Classify the measurement system as excellent, good, acceptable, or unacceptable. (*Target* is another word for *center of the spec*.)



(b) Create a line chart of the operator columns. If this is not informative, create a tab titled *with avg* to mimic the calculations in *msa velocity gage with charts.* Create a plot of the weights with the part averages subtracted out. What seems to be the problem here? (It might help to use *Session* as the X-axis variable.)

Exercise 20.2

395

Open *Data Sets* → *msa calipers*. These are dimensional inspections of PVC extrusions made with a hand held digital caliper.

(a) The tolerance for this dimension is Target ± 0.020 inch (which is the same as saying USL-LSL = 0.04). Find $3\sigma_{ms}$ and calculate the *% Tolerance* metric. Classify the measurement system as excellent, good, acceptable, or unacceptable.

(b) Create a line chart of the operator columns with the data sorted by Sample (this will be the format you used for ANOVA). Who seems to be the greatest opportunity for improvement? To investigate further, make a second line chart with the data sorted by Session.

Exercise 20.3

396

Open *Data Sets* → *msa gloss*. These are measurements of % gloss on 7 sheets of photographic paper (the "parts") by 9 technicians. MSAs were conducted at 3 different angles of view to determine the effect of angle on measurement variation.

a) Find the measurement error ($3\sigma_{ms}$) at 20 deg. Identify the dominant component of σ_{ms}.

b) Find the measurement error ($3\sigma_{ms}$) at 60 deg. Identify the dominant component of σ_{ms}.

c) Find the measurement error ($3\sigma_{ms}$) at 85 deg. Identify the dominant component of σ_{ms}.

d) What is the effect of angle of view on measurement variation?

Exercise 20.4

397

Each team is to conduct an MSA involving coins of different diameters. Every team member will be an appraiser in the study. Each appraiser will measure the diameter of each coin twice (S = 2). Each team is to do the following:

a) Develop a procedure for measuring the diameter.

b) Determine the number of coins needed for the study.

c) Create an appropriately formatted Excel worksheet for data collection.

d) Follow the guidelines for conducting a quantitative MSA.

e) Collect and enter the data. Give the $3\sigma_{ms}$ value and calculate the *% Tolerance* metric. (The tolerance for all diameters is *target* ± 0.050 inches or $\pm$ 1.27 mm))

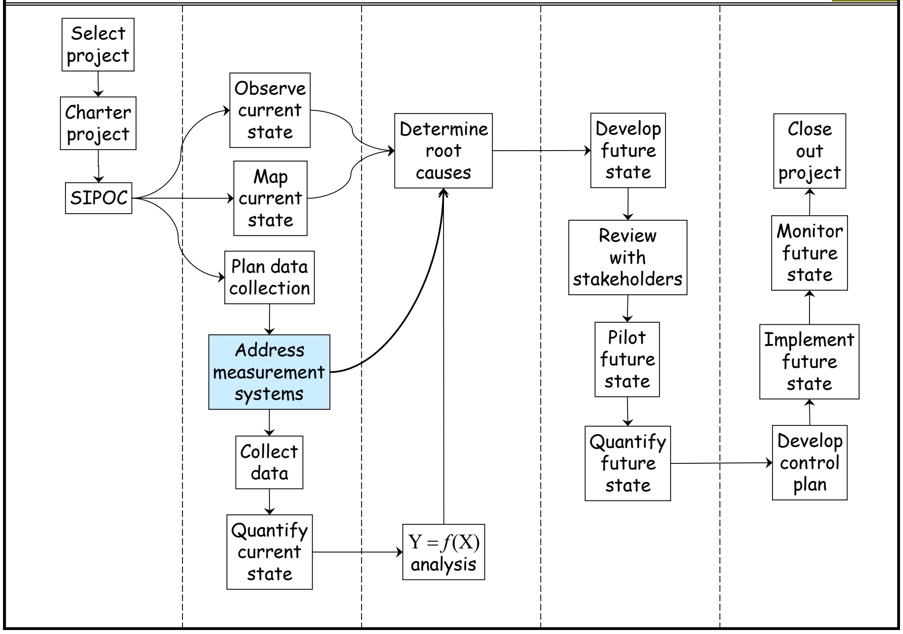
f) Is the measurement system excellent, good, acceptable or unacceptable?

Notes

398

21 Categorical MSA

399



399

Categorical MSA

400

- Also known as *Attribute Gage Study*
- Applied most often to pass/fail inspections
- The terms *repeatability* and *reproducibility* are not used in this context
- In this section we assume that the study is based on *standards* (items for which we know the true value)
- Primary objective in this case:

Determine the % agreement with standard
(Also known as % correct)

400

Impact of measurement variation for categorical MSA

401

Action taken

Standard		Pass	Fail
	Good		*"False alarm"*
	Bad	*"Escape"*	

Which type of error is more costly? For which is the cost easier to quantify?

401

Notes

402

402

Designing a categorical MSA

403

1. Choose at least 10 items (parts, samples, documents…) to be inspected. There should be roughly equal numbers of items that are clearly passing, borderline passing, borderline failing and clearly failing. Choose an expert appraiser to function as the reference standard.

2. If the measurement system has only a few appraisers, include them all in the study. If there are many appraisers, include as large a representative sample as possible.

3. Let I = the number of items, A = the number of appraisers, and S = the number of measurements per item per appraiser.

   - The quantity IA(S – 1) is the number of independent opportunities for appraisers to agree *with themselves*. It should be at least 60.

   - The quantity I(A – 1) is the number of independent opportunities for appraisers to agree *with each other*. It should be at least 60.

   It is best to satisfy these requirements by increasing A with I = 10 and S = 2. If this is not possible, increase I.

403

Designing a categorical MSA (cont'd)

404

4. If the measurements are taken by devices, and operators have no influence on the results, the devices are the appraisers.

5. If devices are used to aid human inspection, combinations of devices and human inspectors should be treated as the appraisers. The ideal is to use all possible combinations of human inspectors and devices. If this is not possible, a DOE matrix with an acceptable number of combinations should be created.

404

Examples of step 3

405

Open *Student Files* → *calculator - sample size* → *MSA* sheet

Number of items	30
Number of appraisers	3
Number of sessions	2
# Opportunities for appraiser self-agreement	90
# Opportunities for appraiser cross-agreement	60
Total sample size	180

These should be at least 30 for quantitative data, at least 60 for categorical data.

Best plan if there are only 3 appraisers

405

Examples of step 3

406

Number of items	10
Number of appraisers	7
Number of sessions	2
# Opportunities for appraiser self-agreement	70
# Opportunities for appraiser cross-agreement	60
Total sample size	140

These should be at least 30 for quantitative data, at least 60 for categorical data.

Best plan if there are 7 appraisers

406

Conducting a categorical MSA*

407

1. Perform this sequence for each session:

First appraiser measures all items once

Second appraiser measures all items once

.
.
.

Last appraiser measures all items once.

2. The order in which the items are measured should be reversed each time the appraiser changes.

3. The full measurement set-up process must be repeated each time a measurement is taken.

4. Allow some time separation between sessions to represent variation in operating conditions, and for human appraisers to “forget” the parts.

*Same as for quantitative MSA

407

Analyzing a categorical MSA

408

- Open *Data Sets \ msa passfail*
- I = 50, A = 3, S = 3
- Did they follow the best plan for 3 appraisers? If not, what would be better?
- P = pass, F = fail
- *Standard* gives the correct answer for each part inspected
- The analysis is based on % agreement with the standard

	A	B	C	D	E	F
1	Session	Part	Standard	Insp A	Insp B	Insp C
2	1	1	P	P	P	P
3	1	2	P	P	P	P
4	1	3	F	F	F	F
5	1	4	F	F	F	F
6	1	5	F	F	F	F
7	1	6	P	P	P	P
8	1	7	P	P	P	P
9	1	8	P	P	P	P
10	1	9	F	F	F	F
11	1	10	P	P	P	P
12	1	11	P	P	P	P
13	1	12	F	F	F	F
14	1	13	P	P	P	P
15	1	14	P	P	P	P
16	1	15	P	P	P	P
17	1	16	P	P	P	P
18	1	17	P	P	P	P
19	1	18	P	P	P	P
20	1	19	P	P	P	P
21	1	20	P	P	P	P
22	1	21	P	P	P	F
23	1	22	F	F	F	P
24	1	23	P	P	P	P
25	1	24	P	P	P	P
26	1	25	F	F	F	F
27	1	26	F	F	F	F
28	1	27	P	P	P	P
29	1	28	P	P	P	P
30	1	29	P	P	P	P

408

Worked example

409

The first step is to define new columns indicating whether A, B, and C agree or disagree with *Standard* in each case (1 = agree, 0 = disagree)

G2 =IF(D2=$C2,1,0)

	A	B	C	D	E	F	G	H	I
1	**Session**	**Part**	**Standard**	**Insp A**	**Insp B**	**Insp C**	**A**	**B**	**C**
2	1	1	P	P	P	P	1		
3	1	2	P	P	P	P			
4	1	3	F	F	F	F			
5	1	4	F	F	F	F			
6	1	5	F	F	F	F			

Drag

I2 =IF(F2=$C2,1,0)

	A	B	C	D	E	F	G	H	I
1	**Session**	**Part**	**Standard**	**Insp A**	**Insp B**	**Insp C**	**A**	**B**	**C**
2	1	1	P	P	P	P	1	1	1
3	1	2	P	P	P	P			
4	1	3	F	F	F	F			
5	1	4	F	F	F	F			
6	1	5	F	F	F	F			

Double click

409

Example (cont'd)

410

- Use the *Average* function on the *AutoSum* button to get the % agreement with standard for each inspector (cells G152 through I152)
- Use it again to get the overall % agreement with standard (cell J152)
- If improvement is needed, Inspector C is the greatest opportunity

J152 =AVERAGE(G152:I152)

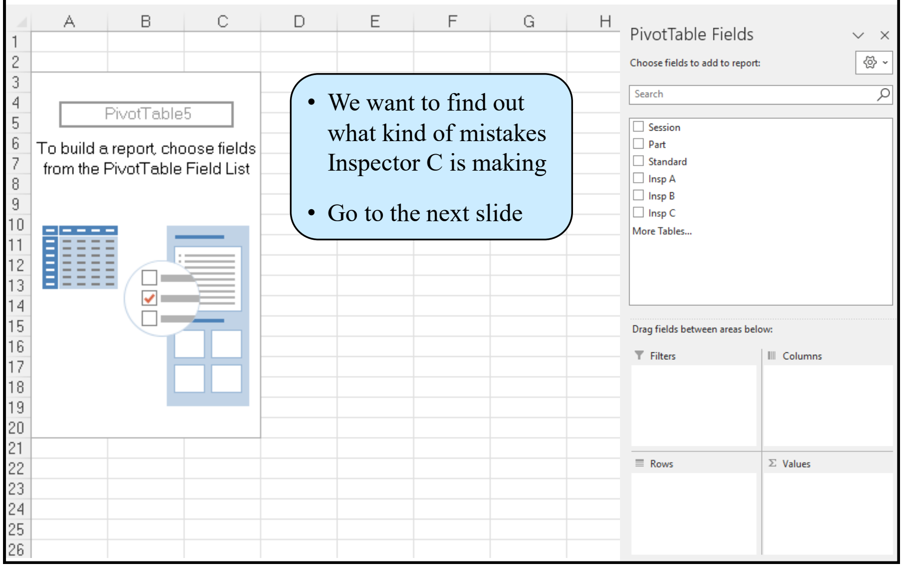
	A	B	C	D	E	F	G	H	I	J
1	**Session**	**Part**	**Standard**	**Insp A**	**Insp B**	**Insp C**	**A**	**B**	**C**	
143	3	42	F	F	F	F	1	1	1	
144	3	43	P	P	P	F	1	1	0	
145	3	44	P	P	P	P	1	1	1	
146	3	45	F	F	F	F	1	1	1	
147	3	46	P	P	P	P	1	1	1	
148	3	47	P	P	P	P	1	1	1	
149	3	48	F	F	F	F	1	1	1	
150	3	49	P	P	P	P	1	1	1	
151	3	50	F	F	F	F	1	1	1	
152							94.7%	96.7%	90.0%	93.8%
153										

410

Example (cont'd)

411

Highlight columns A-F only! → select the *Insert* ribbon → select *PivotTable* → OK

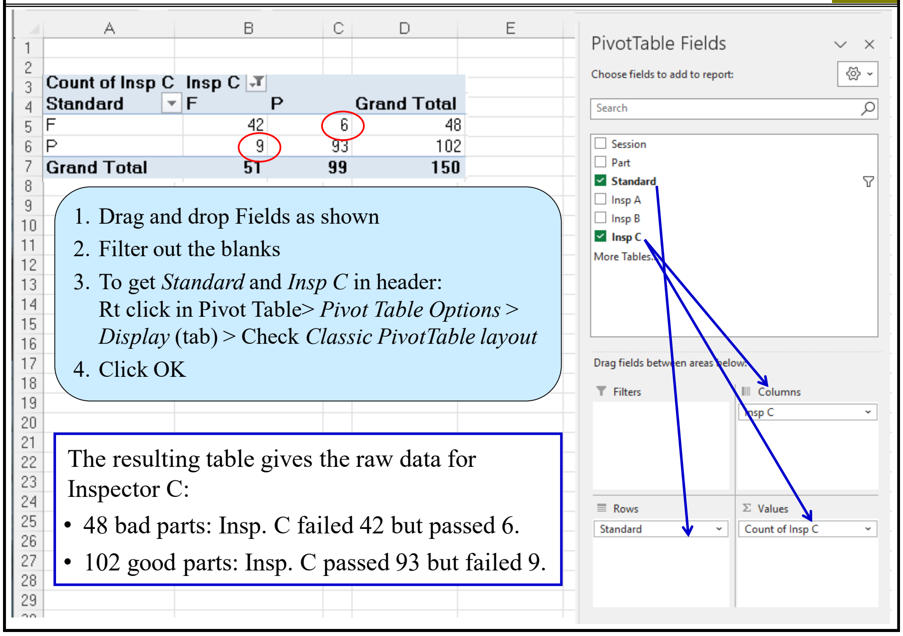


- We want to find out what kind of mistakes Inspector C is making
- Go to the next slide

411

Example (cont'd)

412



Count of Insp C	Insp C		
Standard	F	P	Grand Total
F	42	6	48
P	9	93	102
Grand Total	51	99	150

1. Drag and drop Fields as shown
2. Filter out the blanks
3. To get *Standard* and *Insp C* in header: Rt click in Pivot Table> *Pivot Table Options* > *Display* (tab) > Check *Classic PivotTable layout*
4. Click OK

The resulting table gives the raw data for Inspector C:

- 48 bad parts: Insp. C failed 42 but passed 6.
- 102 good parts: Insp. C passed 93 but failed 9.

412

Example (cont'd)

413

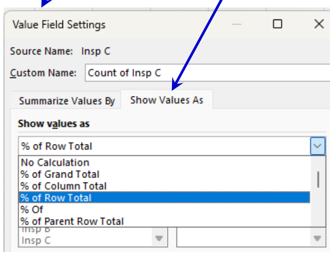
Count of Insp C	Insp C		
Standard	F	P	Grand Total
F	87.50%	12.50%	100.00%
P	8.82%	91.18%	100.00%
Grand Total	34.00%	66.00%	100.00%

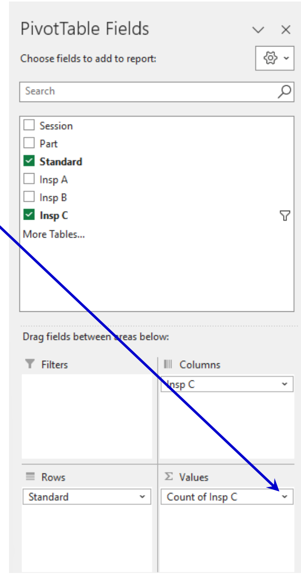
- Inspector C passed 12.5% of the bad parts
- and failed 8.8% of the good parts
- Inspector C needs further training to reduce both types of errors

Click dropdown on *Count of Insp C >*

Value Field Settings >

Show Values As >
% of row total





413

Exercise 21.1

414

Open *Data Sets* → *msa print samples 1*. These are visual inspections of print samples by 3 inspectors. The standards were determined by a committee of experienced print quality evaluators.

(a) Calculate the % agreement with standard by inspector and overall.

(b) Which inspector offers the greatest opportunity for improvement? Make a pivot table to determine whether the main problem is passing bad samples, failing good ones, or both.

(c) Save your work.

414

Exercise 21.2

415

Open *Data Sets* → *msa print samples 2*. These are visual inspections of new print samples by the same 3 inspectors after additional training.

(a) Calculate the % agreement with standard by inspector and overall. Have we improved?

(b) There is something interesting about the data for sample 18 (not row 18). What are the possible explanations? (Sorting by sample number will help.)

(c) It turns out the standard for sample 18 was wrong. Reclassify the standard for sample 18 as passing. What is the % agreement now?

(d) Save your work.

Exercise 21.3

416

Open *Data Sets* → *msa ratings.* Each of 15 employment applications was rated twice on a five point scale (1 = worst, 5 = best) by each of five appraisers.

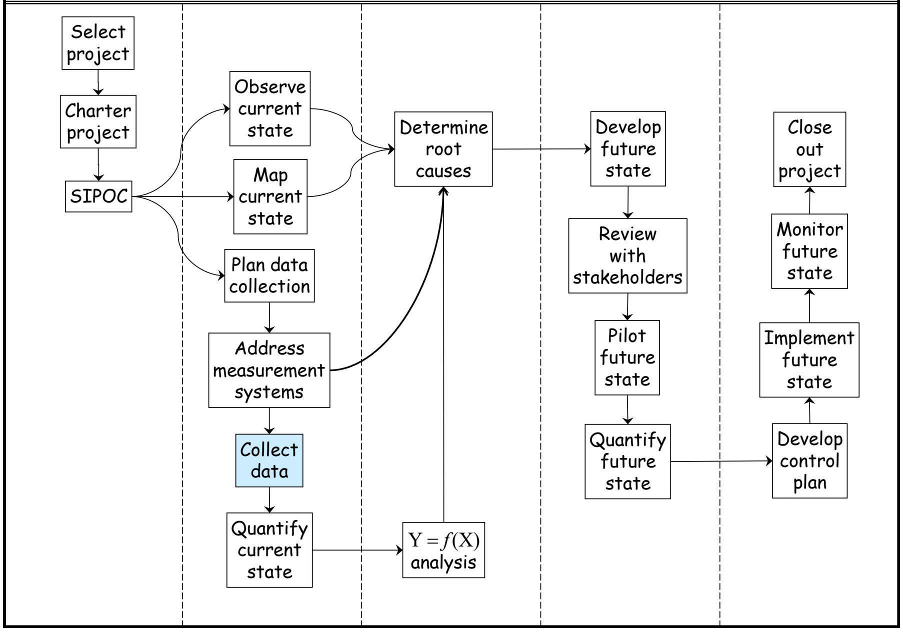
a) Calculate the % agreement by appraiser and overall.

b) Which inspector offers the greatest opportunity for improvement? Make a pivot table to determine the particular error this inspector often makes.
Use format of ***Show Values as Count***; it will be easier to discern any pattern this way.

c) Save your work.

22 Data Collection

417



417

Purposes of data collection

418

- Calculate project metrics for the current state
- Pareto analysis of defect types, error types, failure reasons, etc.
- Comparisons within the current state (stratification analysis)
- Correlation of X and Y variables
- Use analysis results to help identify root causes

418

Population sampling

419

Population	• A specified collection of people or things
Sample	• A subset of a population • Usually relatively small • Intended to represent the population

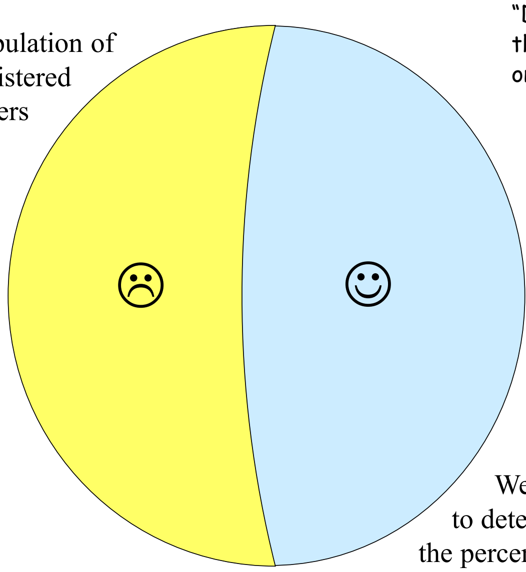
419

Example: opinion poll

420

Population of registered voters

"Do you support the current policy on _____ ?"

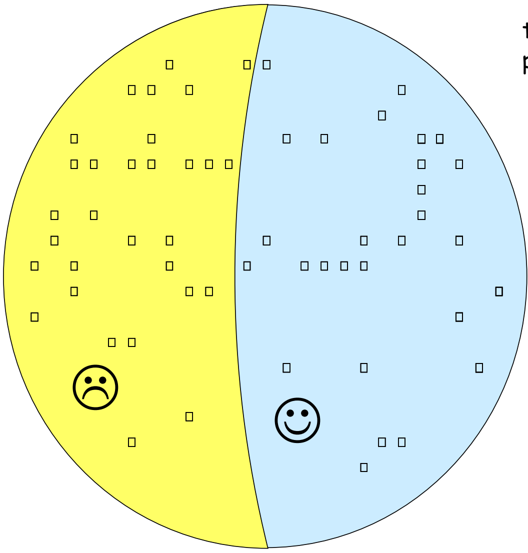


We want to determine the percentages

420

The sample must be representative

421



"Do you support the current policy on _____ ?"

421

Representative sampling (cont'd)

422

- Examples of obvious biases: sample includes only
  - ✓ Democrats
  - ✓ Republicans
  - ✓ Men
  - ✓ Women
  - ✓ Residents of Wyoming
  - ✓ Convicted white collar criminals
  - ✓ Relatives of elected government officials
- Standard survey sampling technique
  - ✓ All counties are categorized into something like 30 groups ("strata") according to population density
  - ✓ Each stratum (group of counties with similar population density) is randomly sampled in proportion to its population
- This is an example of *stratified random sampling*

422

Exercise 22.1

423

Decide whether or not the proposed sample in each case below will be representative of the population. If not, note obvious or possible biases on the next slide.

Population	Purpose	Proposed sample
(a) Former Enron employees	Opinion on culpability of top Enron executives	Those with the largest retirement accounts, comprising 85% of lost value
(b) A year, make, and model of car	Surreptitiously determine % with a given defect	Offer a free _____ until 100 cars have been inspected at each US dealership
(c) ER patients at a hospital last year	Customer satisfaction survey	Those whose last names begin with the letter M
(d) Lambs born in New Zealand last year	Determine % with "mad lamb" disease	Random sample of each ranch in NZ, proportional to # of lambs
(e) Registered voters	Opinion on a candidate	Generate telephone numbers at random, call those people

423

Exercise 22.1 (cont'd)

424

(a)

(b)

(c)

(d)

(e)

424

Incorrect interpretation of survey data

425

"Do you support the current policy on _____ ?"

☐ 51% of the people responding to the survey say "yes"

Click Bait Reporting
"According to a recent survey, the majority of registered voters support the current policy."

Interpretation of survey data (cont'd)

426

- Suppose the sampling plan was perfectly representative of the population
- Still, we cannot say that what is true in the sample is true in the population
- The sample data does *not* prove that 51% of registered voters agree with the current policy

Must quantify the uncertainty

427

"Do you support the current policy on _____ ?"

Accurate Reporting

"51% of sampled voters supported the current policy. The margin of error is ±3 percentage points, so the survey is inconclusive."

Quantifying uncertainty (cont'd)

428

- "Margin of error" (MOE) is how we quantify our uncertainty about the population in light of the sample data
- The most we can say: "The percentage of registered voters agreeing with the current policy is between 48% and 54%"
- The data fails to demonstrate a majority on *either* side of the question

Process sampling

429

Process — A predetermined sequence of actions and decisions intended to produce a desired outcome. (A way of doing something.)

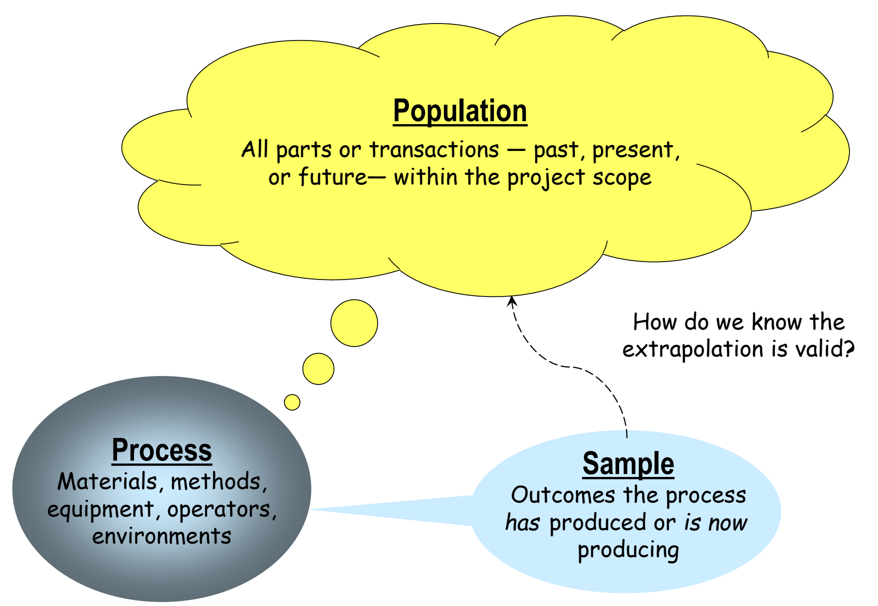
- ✓ Manufacturing process
- ✓ Service process
- ✓ Business process
- ✓ Transactional process
- ✓ Decision process
- ✓ Design process

For any process, there is an associated *population*

429

Process sampling (cont'd)

430



430

Process sampling for LSS projects

431

- 100% sampling for a period of time, is the most common method
- What are some situations where 100% sampling is not possible?
- The sample must cover a representative time period
- The sample must capture all *typical sources of variation* (see next slide)

Typical sources of variation

432

Process participants

"Identical" pieces of equipment

Time of day, week or month

Batches or lots of raw material or components

Different suppliers

Production lots, work orders, . . .

Different locations

Changing environmental conditions

Inconsistent practices/procedures

Multiple measurement systems

⇩

In summary, the "6 M's"

"Less than 100%" sampling methods

433

Random	Items are selected by a random number generator
Systematic	Items are selected at regular intervals
Stratified random*	Items are sampled from homogeneous subpopulations, in proportion to subpopulation size
Judgment	Items are selected using knowledge of the process
Convenience	Items are selected based on cost or ease of access

*Usually considered to be the most representative sampling method.

433

Exercise 22.2

434

Check the sampling methods that apply in each case based on the given information.

	Random	Systematic	Stratified	Judgment	Convenience
(a) Pulled 10 parts off the high volume production line at the top of each hour					
(b) Reviewed Enron electricity trades during periods of highest demand					
(c) Used random numbers to select 10% of patient charts for the past year					
(d) Monitored every 1000th customer service call					
(e) Downloaded invoices with numbers ending in 0 or 5					
(f) Inspected the first 3 parts from each production lot					
(g) Took a sample from the top of each barrel on the top layer of the stack					

434

Sample size

435

- Amount of data: more is better than less
- Time period: longer is better than shorter*
- Capturing all typical sources of variation usually gives an adequate sample size
- You should do a sample size calculation just to make sure

*But beware of old data that is no longer relevant to your current state.

435

Sample size calculation: opinion poll example

436

ϕ	The fraction (proportion) of people in the population who would say yes to the survey question if asked. We don't know, and will never know, the exact value of ϕ. However, we can get an accurate estimate of ϕ if we collect enough data.
Sample	The people who respond to the survey. Usually, this is a very small subset of the population.
ϕ_{sample}	The fraction (proportion) of the respondents who say yes to the survey question. This is our estimate of ϕ. We don't know this now, but we will after we get the data.
MOE	Margin of error: the amount by which ϕ_{sample} could differ from ϕ, based on an established statistical standard of evidence. MOE is always a +/– value. The most common standard of evidence is called "95% confidence."
N	The number of people who respond to the survey — the *sample size*. The required sample size depends on ϕ_{sample} and the desired MOE.

436

Sample size (cont'd)

437

In most opinion polls, ϕ_{sample} is assumed to be close to 0.5 when determining sample size. This gives the largest sample size needed to achieve the desired margin of error (MOE). If ϕ_{sample} is not 0.5, the MOE will be smaller, which is desirable. The approximate formula for the MOE (with 95% confidence) is:

$$MOE = 1.96\sqrt{\frac{\phi_{sample}\left(1-\phi_{sample}\right)}{N}} = 1.96\sqrt{\frac{0.5\,(0.5)}{N}} = \frac{0.98}{\sqrt{N}}$$

We can solve this equation for N:

$$N = (0.98 / MOE)^2$$

MOE for ϕ = 0.5	N
0.05	384
0.04	600
0.03	1067
0.02	2401
0.01	9604

Sample size calculation: process applications for pass/fail Y

438

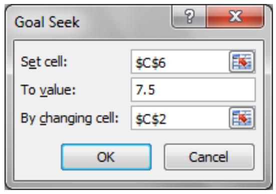
- In process applications (as opposed to survey data), ϕ represents the fraction defective
- In this case, the margin of error on the high side is of greatest interest:

$$\boxed{\phi_{sample} + MOE_{upper} = \text{Upper bound on } \phi \text{ (with 95\% confidence)}}$$

- To do a sample size calculation, we must provide two inputs:
  - a) A guess for ϕ_{sample}
  - b) An acceptable upper bound on ϕ (giving the desired MOE, which is the difference between this upper bound and ϕ_{sample})
- Open *Student Files* → *calculator - sample size* → *% Defective*

Example *calculator - sample size* $\rightarrow$ *% Defective* 439

- We think ϕ_{sample} will be close to 0.05 (5% defective)
- If this turns out to be true, we want to be able to say (with 95% confidence) that ϕ is no larger than 0.075 (7.5% defective)
- Enter 1 in cell C2, 5 in C3, and 7.5 in C5
- We want to set cell C6 to 7.5 by changing cell C2
- Select *Data* $\rightarrow$ *What If Analysis* $\rightarrow$ *Goal Seek* $\rightarrow$ set up as shown to the right $\rightarrow$ click OK



	A	B	C	D	E
1					
2		Sample size (N)	319		
3		Guess for sample % defective	5		
4		Defectives in the sample	16		
5		Desired upper bound on population % defective	7.5		
6		Actual upper bound on population % defective	7.50	95	% Confidence level

439

Exercise 22.3 440

We want to get an accurate estimate of the population % defective. Use *calculator - sample size* $\rightarrow$ *% Defective* to find the required sample size in the following scenarios:

	Guess for sample % defective	Desired upper bound on population % defective	Sample size
(a)	10	20	
(b)	10	15	
(c)	10	13	
(d)	1	4	
(e)	1	3	
(f)	1	2	

440

Finite population sampling for pass/fail Y

441

Open *Student Files → calculator - sample size → Finite population sampling*

- We want to determine the % defective in a finite population of size 2000
- Enter the values shown below in cells C4, C6, and C7
- We want to set cell C9 to 3 by changing C10

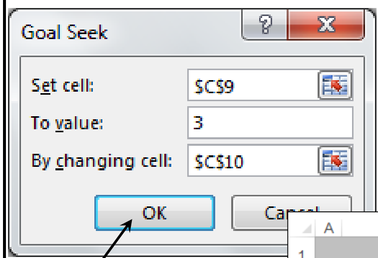
	A	B	C	D
1				
2		**Finite population sampling**		
3				
4		Population size	2,000	
5				
6		Guess for sample % defective	30	
7		Desired MOE for population % defective	3	
9		Actual MOE for population % defective	89.817	
10		Sample size (N)	1	
11				
12		95	% Confidence level	
13				
14		1.9600	z-value for the given confidence level	

Data
↓
What If Analysis
↓
Goal Seek
↓
Set up as shown on the next slide

441

Finite population sampling for pass/fail Y (cont'd)

442



	A	B	C	D	E
1					
2		**Finite population sampling**			
3					
4		Population size	2,000		
5					
6		Guess for sample % defective	30		
7		Desired MOE for population % defective	3		
9		Actual MOE for population % defective	3.000		
10		Sample size (N)	619		
11					
12		95	% Confidence level		
13					
14		1.9600	z-value for the given confidence level		

442

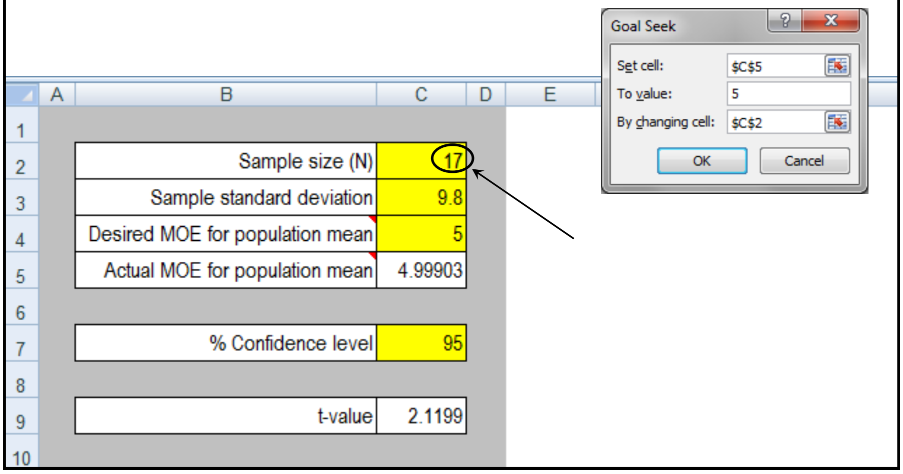
Sample size for estimating a population mean (quantitative Y) 443

- Open *Student Files* → *calculator - sample size* → *Pop. mean for quant. Y*
- Requires an estimate of the standard deviation
- Common practice:
  - ✓ Collect a small amount of data, calculate the standard deviation
  - ✓ Do a sample size calculation to see how much more you need
  - ✓ You can also get a rough estimate of the mean from this data
- Suppose our rough estimates are $\mu = 50.4$ and $\sigma = 9.8$
- We want our MOE to be 10% of the mean → MOE = .1 * 50.4 = 5
- Enter the value 2 in cell C2, 9.8 in C3, and 5 in C4
- Select *Data* → *What If Analysis* → *Goal Seek*

443

Sample size for population mean (quantitative Y) (cont'd) 444

- We want to set cell C5 to 5 by changing cell C2
- Set *Goal Seek* up as shown here, click OK



444

Exercise 22.4

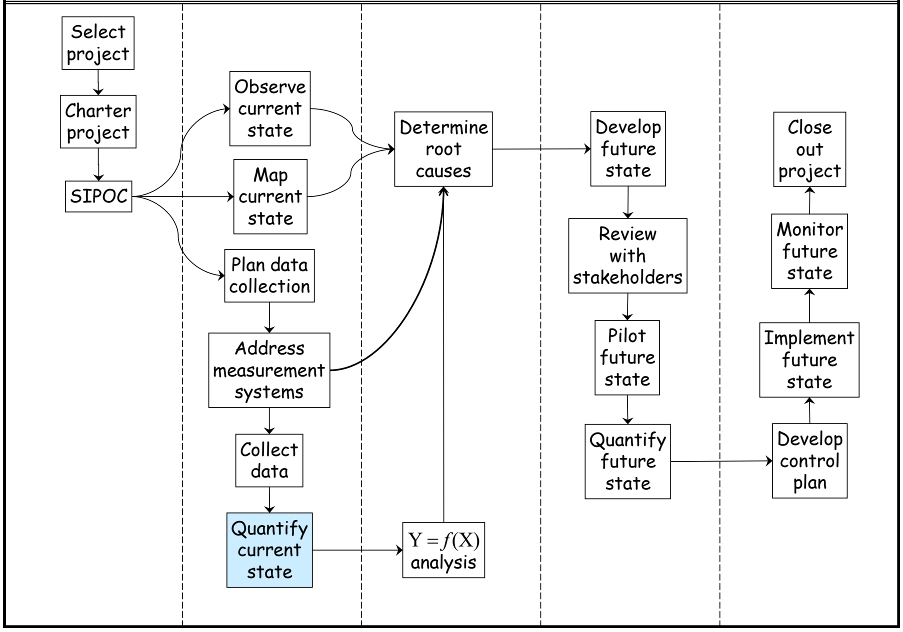
a) For the previous example, use *calculator - sample size → Pop. mean for quant. Y* to calculate the sample size assuming we want our MOE to be 5% of the mean instead of 10%.

b) Use *calculator - sample size → Pop. mean for quant. Y* to calculate the sample size assuming we want MOE to be 1% of the mean.

Notes

23 Establishing Baselines — Pass/fail Y

447



Topics

448

- Calculating % defective from “raw” pass/fail data
- Pareto analysis of failure reasons from “raw” failure/defect data
- Calculating % defective from tabulated pass/fail data
- Pareto analysis from tabulated failure/defect data

% Defective from "raw" pass/fail data

449

Open *Data Sets* → *ATE Mar & Apr*

	A	B	C	D	E	F
1	Date & Time	P/N	S/N	Tester	Result	Failure Reason
2	3/1/06 6:02 AM	690	3457456	3	Pass	
3	3/1/06 6:03 AM	692	4499441	1	Pass	
4	3/1/06 6:05 AM	690	3457457	3	Fail	Backlight-LCD
5	3/1/06 6:06 AM	690	3457458	3	Pass	
6	3/1/06 6:12 AM	690	3457442	3	Pass	
7	3/1/06 6:12 AM	692	4499442	1	Pass	
8	3/1/06 6:13 AM	692	4500377	2	Pass	
9	3/1/06 6:15 AM	690	3457443	3	Fail	Op curr out of range
10	3/1/06 6:17 AM	692	4500378	2	Pass	
11	3/1/06 6:18 AM	690	3457444	3	Fail	Backlight-LCD
12	3/1/06 6:18 AM					
13	3/1/06 6:19 A					
14	3/1/06 6:20 A					
15	3/1/06 6:21 A					
16	3/1/06 6:22 A					
17	3/1/06 6:22 A					
18	3/1/06 6:24 A					
19	3/1/06 6:24 A					
20	3/1/06 6:25 A					
21	3/1/06 6:27 A					
22	3/1/06 6:27 A					
23	3/1/06 6:27 AM					
24	3/1/06 6:30 AM	690	3457451	3	Pass	
25	3/1/06 6:30 AM	692	4499448	1	Pass	

- Medical devices are tested for 20 or so failure modes by automated test equipment (ATE)
- Part level data (not tabulated)
- Y variables = *Result, Failure Reason*
- X variables = *Date, Time, P/N, Tester*

449

% Defective (cont'd)

450

	A	B	C	D	E	F	G
1	Date & Time	P/N	S/N	Tester	Result	Failure Reason	
2	3/1/06 6:02 AM	690	3457456	3	Pass		
3	3/1/06 6:03 AM	692	4499441	1	Pass		
4	3/1/06 6:05 AM	690	3457457	3	Fail	Backlight-LCD	
5	3/1/06 6:06 AM	690	3457458	3	Pass		
6	3/1/06 6:12 AM	690	3457442	3	Pass		
7	3/1/06 6:12 AM	692	4499442	1	Pass		
8	3/1/06 6:13 AM	692	4500377	2	Pass		
9	3/1/06 6:15 AM	690	3457443	3	Fail	Op curr out of range	
10	3/1/06 6:17 AM	692	4500378	2	Pass		
11	3/1/06 6:18 AM	690	3457444	3	Fail	Backlight-LCD	
12	3/1/06 6:18 AM	690	3457445	3	Fail	Op curr out of range	
13	3/1/06 6:19 AM	692	4499443	1	Pass		
14	3/1/06 6:20 AM	690	3457439	3	Pass		
15	3/1/06 6:21 AM	692	4500379	2	Pass		
16	3/1/06 6:22 AM	690	3457447	3	Pass		
17	3/1/06 6:22 AM	692	4499444	1	Pass		
18	3/1/06 6:24 AM	692	4499445	1	Fail	Slp curr out of range	
19	3/1/06 6:24 AM	690	3457448	3	Fail	Switch Test	
20	3/1/06 6:25 AM	692	4500380	2	Pass		
21	3/1/06 6:27 AM	692	4499446	1	Fail	Slp curr out of range	
22	3/1/06 6:27 AM	690	3457449	3	Fail	Switch Test	
23	3/1/06 6:27 AM	692	4500381	2	Pass		
24	3/1/06 6:30 AM	690	3457451	3	Pass		
25	3/1/06 6:30 AM	692	4499448	1	Pass		
26	3/1/06 6:30 AM	692	4500382	2	Pass		
27	3/1/06 6:32 AM	690	3457452	3	Pass		
28	3/1/06 6:32 AM	692	4499449	1	Pass		
29	3/1/06 6:33 AM	692	4500383	2	Fail	Switch Test	
30	3/1/06 6:34 AM	690	3457453	3	Pass		
31	3/1/06 6:34 AM	692	4499450	1	Pass		
32	3/1/06 6:35 AM	692	4500387	2	Pass		

1. Select columns A-F
2. Insert → Pivot Table → OK
3. Go to the next slide.

450

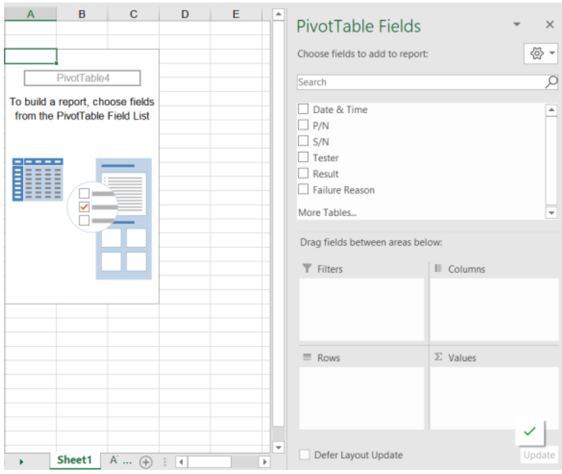
% Defective (cont’d)

451

4. Drag/drop *Result* into the *Columns* box

5. Drag/drop *Result* into the *Values* box

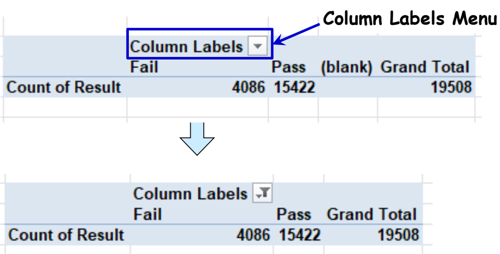
6. Go to the next slide.



451

% Defective (cont’d)

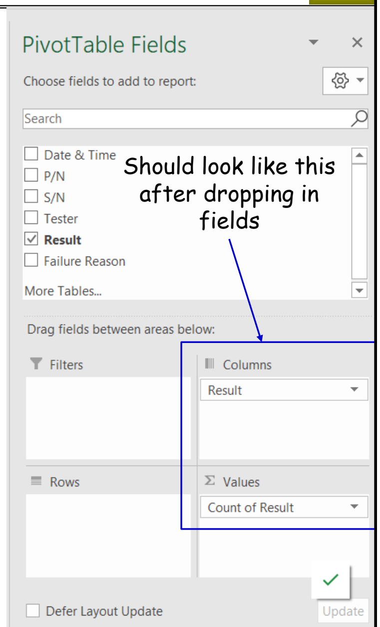
452



7. Pull down the *Column Labels* menu (shown above)

8. Uncheck *(blank)* on that menu, select OK

9. Go to the next slide.

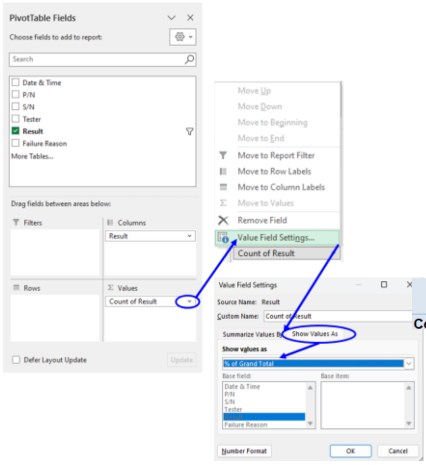


452

% Defective (cont'd)

453

Next, we'll format the data as a percentage for reporting purposes.



1. Right-click drop down on *Count of Result*
2. Choose *Value Field Settings*
3. Select *Show Values As*, then *% of Grand Total*.

	Column Labels		
	Fail	Pass	Grand Total
Count of Result	20.9%	79.1%	100.0%

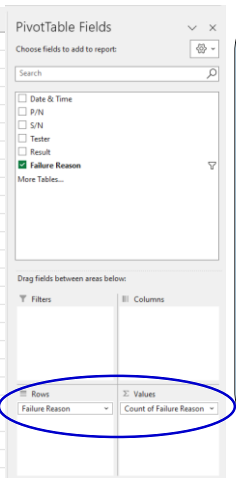
Format for reporting:

Project metric	% Defective
Baseline value	20.95%

Pareto analysis of failure reasons

454

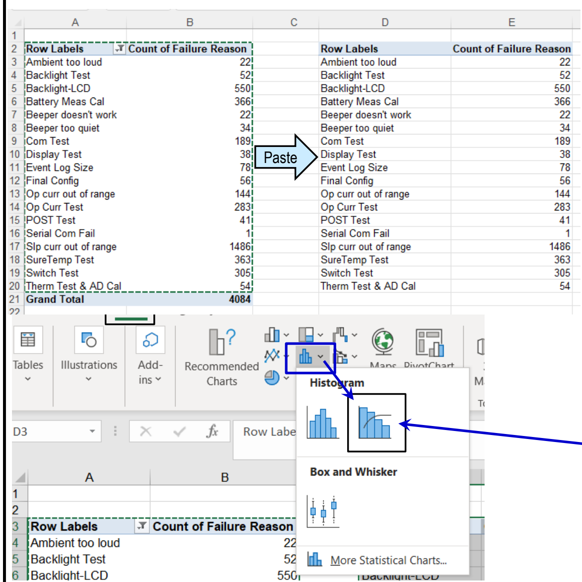
	A	B
1		
2		Menu
3	Row Labels	Count of Failure Reason
4	Ambient too loud	22
5	Backlight Test	52
6	Backlight-LCD	550
7	Battery Meas Cal	366
8	Beeper doesn't work	22
9	Beeper too quiet	34
10	Com Test	189
11	Display Test	38
12	Event Log Size	78
13	Final Config	56
14	Op curr out of range	144
15	Op Curr Test	283
16	POST Test	41
17	Serial Com Fail	1
18	Slp curr out of range	1486
19	SureTemp Test	363
20	Switch Test	305
21	Therm Test & AD Cal	54
22	Grand Total	4084
23		
24		
25		



1. Go back to the data sheet, launch a new *PivotTable*
2. Drag/drop *Failure Reason* to *Rows* and to *Values*
3. Uncheck *(blank)* on the *Row Labels* menu as needed
4. Go to the next slide

Pareto analysis of failure reasons (cont'd)

455

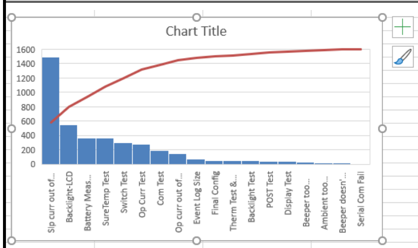


Row Labels	Count of Failure Reason
Ambient too loud	22
Backlight Test	52
Backlight-LCD	550
Battery Meas Cal	366
Beeper doesn't work	22
Beeper too quiet	34
Com Test	189
Display Test	38
Event Log Size	78
Final Config	56
Op curr out of range	144
Op Curr Test	283
POST Test	41
Serial Com Fail	1
Slp curr out of range	1486
SureTemp Test	363
Switch Test	305
Therm Test & AD Cal	54
Grand Total	4084

5. Copy Pivot table except for the Grand Total
6. Paste one column to the right
7. Highlight entire table you just pasted
8. Select *Insert* > Charts Section > *Insert Statistic Chart* dropdown > *Pareto*
9. Go to the next slide

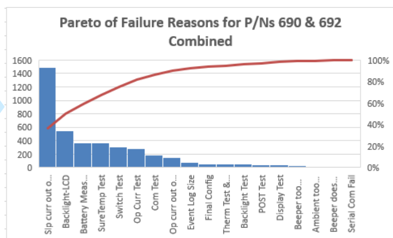
Pareto analysis of failure reasons (cont'd)

456



Click the "+" button to edit chart elements

Select and edit desired elements including Chart Title, Axes Titles, and Secondary Axis



Exercise 23.1

457

All files are in the *Data Sets* folder.

a) Open *lot sampling.* Find the % failing. Save your work.

b) Open *old cars.* Assume that each row represents one automotive product recall, and the *make* column lists the brand of car involved in the recall. Create a Pareto chart of *make* by frequency of occurrence. Save your work.

Exercise 23.1 (cont'd)

458

c) Open *supplier comparison.* Find the % failing. Save your work.

d) Open *unplanned downtime log.* Each row represents a downtime event in a manufacturing process. Create a Pareto chart of *Problem area* by frequency of occurrence. Save your work.

% Defective from tabulated pass/fail data

459

- Open *Data Sets → ATE failure occurrence tabulated*
- Daily summaries, not part level data

	A	B	C	D	E
1	Date	P/N	Tester	Tested	Failed
2	3/1/2006	690	3	166	12
3	3/1/2006	692	1	142	13
4	3/1/2006	692	2	183	34
5	3/1/2006	692	3	1	0
6	3/2/2006	690	1	155	20
7	3/2/2006	690	2	168	12
8	3/2/2006	690	3	24	4
9	3/2/2006	692	3	107	14
10	3/3/2006	690	1	87	10
11	3/3/2006	690	2	19	9
12	3/3/2006	690	3	5	2
13	3/3/2006	692	2	54	8
14	3/3/2006	692	3	63	16
15	3/6/2006	690	1	109	24
16	3/6/2006	690	2	28	10
17	3/6/2006	690	3	152	42
18	3/6/2006	692	1	75	18
19	3/6/2006	692	2	125	23
20	3/7/2006	690	1	82	12
21	3/7/2006	690	3	138	50
22	3/7/2006	692	1	77	13
23	3/7/2006	692	2	164	29
24	3/7/2006	692	3	2	2
25	3/8/2006	690	1	194	37
26	3/8/2006	690	2	77	13
27	3/8/2006	690	3	59	13
28	3/8/2006	692	1	2	0
29	3/8/2006	692	2	100	16
30	3/9/2006	690	1	1	0
31	3/9/2006	690	2	162	22
32	3/9/2006	690	3	125	34
33	3/9/2006	692	1	136	12

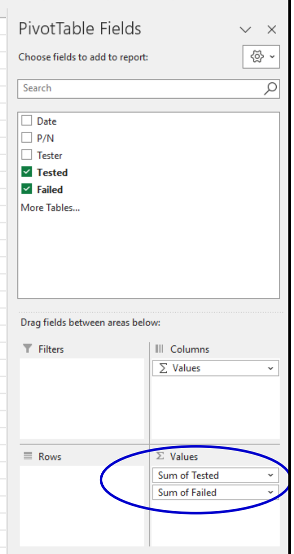
459

% Defective from tabulated data (cont'd)

460

- Insert a pivot table
- Set up as shown here
- Calculate the % defective
  (Do 'manually' with a formula since *Value Field Settings* won't work due to the tabulated data.)

	A	B	C	D
3	Sum of Tested	Sum of Failed		
4	19509	4087		
5				
6	% Defective=	20.9%		



460

Pareto analysis from tabulated data

461

- Open *Data Sets → ATE failure reasons tabulated*
- Daily summaries, not part level data
- *Freq* = number of failures for each day, P/N, tester, and failure reason
- The total number of tests for each day, P/N, and tester is not given
- This situation is very common in tabulated failure/defect data

	A	B	C	D	E
1	Date	P/N	Tester	Failure Reason	Freq
2	3/1/2006	690	3	Backlight-LCD	4
3	3/1/2006	690	3	Op curr out of range	2
4	3/1/2006	692	1	Backlight Test	3
5	3/1/2006	692	2	Backlight-LCD	10
6	3/1/2006	692	1	Battery Meas Cal	1
7	3/1/2006	692	2	Battery Meas Cal	1
8	3/1/2006	692	1	Com Test	1
9	3/1/2006	692	2	Com Test	2
10	3/1/2006	692	2	Final Config	1
11	3/1/2006	692	2	Op curr out of range	7
12	3/1/2006	692	1	Op Curr Test	1
13	3/1/2006	692	1	Slp curr out of range	4
14	3/1/2006	692	2	SureTemp Test	5
15	3/2/2006	690	1	Backlight-LCD	1
16	3/2/2006	690	2	Backlight-LCD	2
17	3/2/2006	690	1	Battery Meas Cal	2
18	3/2/2006	690	2	Battery Meas Cal	1
19	3/2/2006	690	1	Com Test	1
20	3/2/2006	690	3	Com Test	1
21	3/2/2006	690	1	Op curr out of range	5
22	3/2/2006	690	2	Op curr out of range	2
23	3/2/2006	690	1	Op Curr Test	4
24	3/2/2006	690	2	Op Curr Test	4
25	3/2/2006	690	2	Slp curr out of range	1
26	3/2/2006	690	1	SureTemp Test	5
27	3/2/2006	690	2	SureTemp Test	1
28	3/2/2006	690	3	SureTemp Test	3
29	3/2/2006	692	3	Backlight Test	1
30	3/2/2006	692	3	Backlight-LCD	7
31	3/2/2006	692	3	Battery Meas Cal	1

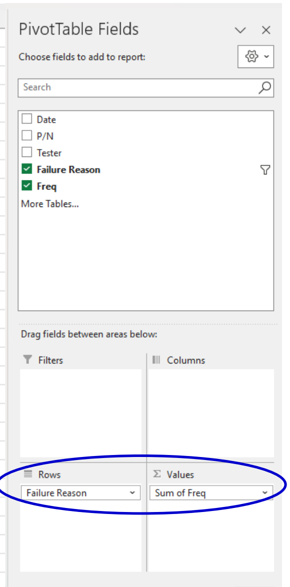
461

Pareto from tabulated data (cont'd)

462

- Insert a pivot table
- Set it up as shown here
- Failure reasons can be sorted in descending order by number of occurrences in the Pivot Table, but this step is not necessary when creating a Pareto with Excel
- The Pareto chart will turn out the same as the one generated from the "raw" data

	A	B	C
1			
2			
3	Row Labels	Sum of Freq	
4	Slp curr out of range	1486	
5	Backlight-LCD	550	
6	Battery Meas Cal	366	
7	SureTemp Test	363	
8	Op Curr Test	283	
9	Com Test	189	
10	Op curr out of range	144	
11	Event Log Size	78	
12	Final Config	56	
13	Backlight Test	52	
14	POST Test	41	
15	Display Test	38	
16	Beeper too quiet	34	
17	Ambient too loud	22	
18	Beeper doesn't work	22	
19	Serial No & Model	1	
20	Serial Com Fail	1	
21	Grand Total	3726	



462

Exercise 23.2

463

All files are in the *Data Sets* folder.

a) Open *parts inspected & defective.* Find the % defective. Save your work.

b) Open *defects & types.* Create a Pareto chart of defect types by frequency of occurrence. Is it possible to obtain % defective from this data set? Explain your answer. Save your work.

c) Open *out of box failures.* The data represent results of a customer's incoming inspection of purchased components. Find the % failing. Save your work.

Exercise 23.2 (cont'd)

464

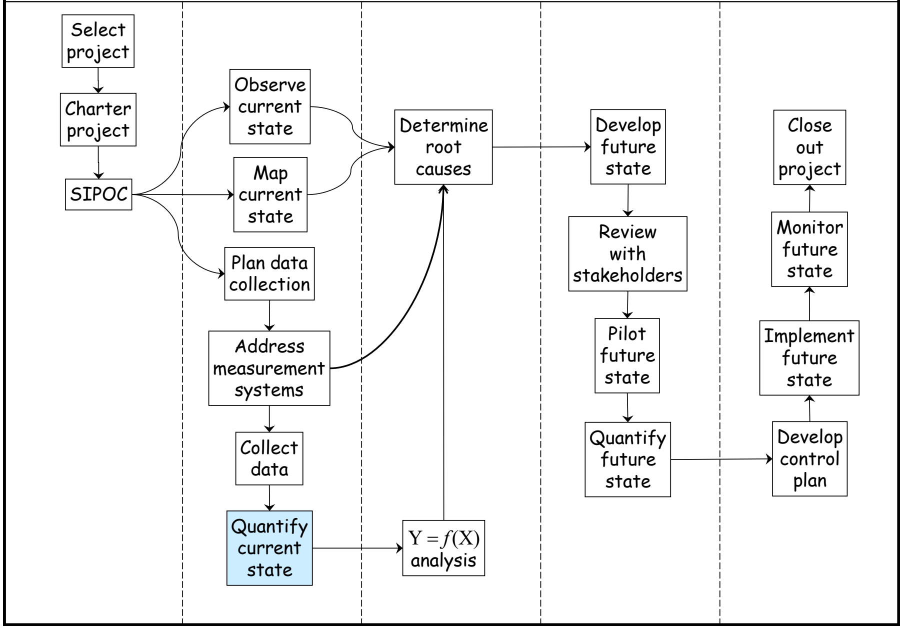
d) Open *unplanned downtime log.* Create a Pareto chart of *Problem area* by total downtime. Save your work.

e) Open *scrap quantity and cost.* Create a Pareto chart of scrap category by *quantity* scrapped. Is it possible to obtain scrap as a % of total production from this data set? Explain your answer.

f) Create a Pareto chart of scrap category by total *cost* of scrap. (You will have to create a new data column defined by a formula.) Compare this to the chart in (e). Save your work.

24 Establishing Baselines — Quantitative Y

465



465

Topics

466

- Basic statistical summary
- Frequency histogram
- Calculating % defective from quantitative data

466

Basic statistical summary

467

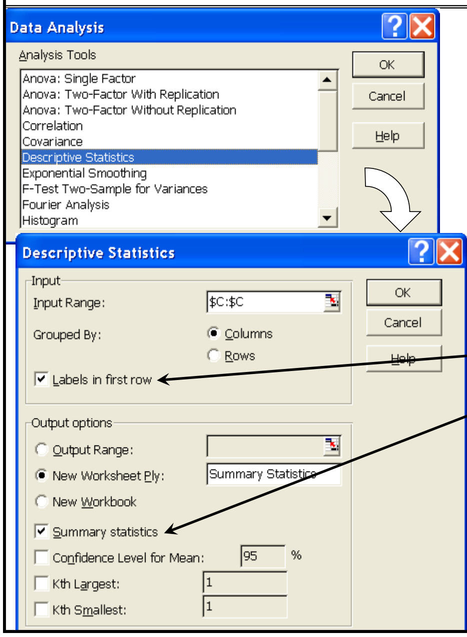
- Open *Data Sets* → *DI water*
- Measurements of de-ionized water used in machining and cutting operations taken 3 times an hour for 8 days
- Y variable = *Resist* (higher is better)
- X variables = *Day, Hour*

	A	B	C	D	E
1	Day	Hour	Resist		
2	1-Tu	10	1608.5		
3	1-Tu	10	1832.0		
4	1-Tu	10	1808.0		
5	1-Tu	11	1714.0		
6	1-Tu	11	1846.0		
7	1-Tu	11	1686.0		
8	1-Tu	12	1558.5		
9	1-Tu	12	1888.0		
10	1-Tu	13	1592.0		
11	1-Tu	13	1752.0		
12	1-Tu	13	1784.0		
13	1-Tu	14	1442.5		
14	1-Tu	14	1502.0		
15	1-Tu	14	1700.0		
16	1-Tu	15	1500.0		
17	1-Tu	15	1674.5		
18	1-Tu	15	1707.0		
19	1-Tu	16	1660.5		
20	1-Tu	16	1804.0		
21	1-Tu	16	1672.0		
22	1-Tu	17	1728.0		
23	1-Tu	17	1969.0		
24	1-Tu	17	1606.0		
25	1-Tu	18	1718.0		
26	1-Tu	18	1824.5		
27	1-Tu	18	1662.0		
28	1-Tu	19	1830.0		
29	1-Tu	19	1703.0		
30	1-Tu	20	1717.0		

467

Basic statistical summary (cont'd)

468



1. Select the *Data* ribbon
2. Select *Data Analysis*
3. Select *Descriptive Statistics*
4. Click OK
5. For *Input Range* select all of column C (click on the column header)
6. Select *Labels in first row*
7. Select *Summary statistics*
8. Click OK

468

Basic statistical summary (cont'd)

469

	A	B
1	*Resist*	
2		
3	Mean	1628.758439
4	Standard Error	6.562900877
5	Median	1625
6	Mode	1454
7	Standard Deviation	142.8844659
8	Sample Variance	20415.97059
9	Kurtosis	-0.241369475
10	Skewness	0.153084191
11	Range	733
12	Minimum	1267
13	Maximum	2000
14	Sum	772031.5
15	Count	474

- Stretch column A to avoid using the wrong standard deviation
- Edit down to the "vital few"
- Correct the default numerical formats

	A	B
1	*Resist*	
2		
3	Mean	1628.8
4	Standard Deviation	142.9
5	Minimum	1267
6	Maximum	2000
7	Count	474
8		
9		
10		
11		
12		
13		
14		
15		

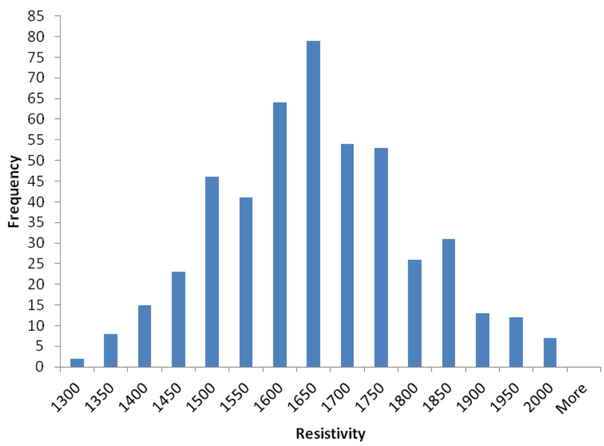
Project metric	Average Resistivity
Baseline value	1628.8

469

Frequency histogram

470

A statistical graphic for displaying variation in quantitative data



470

Histogram (cont'd)

471

- Shows variation without plotting the data over time
  - Heights of bars show the number of data points in each bin
  - Bin widths are equal, and are a range of numbers
- Histograms and time plots are complementary — they can reveal different aspects of the data
- We will discuss time plots later

471

Histogram (cont'd)

472

Excel path to create Histogram:

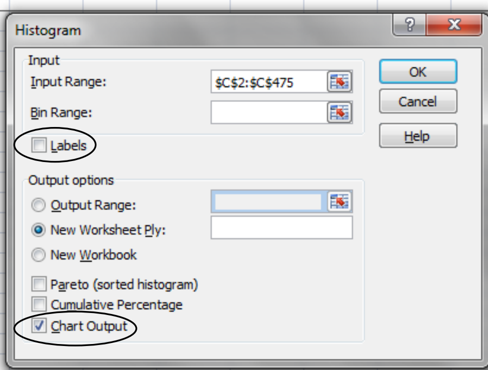
Data → *Data Analysis* → *Histogram*

472

Histogram Setup: *Data → Data Analysis → Histogram*

473

Day	Hour	Resist
1-Tu	10	1608.5
1-Tu	10	1832.0
1-Tu	10	1808.0
1-Tu	11	1714.0
1-Tu	11	1846.0
1-Tu	11	1686.0
1-Tu	12	1558.5
1-Tu	12	1888.0
1-Tu	13	1592.0
1-Tu	13	1752.0
1-Tu	13	1784.0
1-Tu	14	1442.5
1-Tu	14	1502.0
1-Tu	14	1700.0
1-Tu	15	1500.0
1-Tu	15	1674.5
1-Tu	15	1707.0
1-Tu	16	1660.5
1-Tu	16	1804.0
1-Tu	16	1672.0
1-Tu	17	1728.0
1-Tu	17	1969.0
1-Tu	17	1606.0
1-Tu	18	1718.0
1-Tu	18	1824.5
1-Tu	18	1662.0
1-Tu	19	1830.0
1-Tu	19	1703.0
1-Tu	20	1717.0



Select the data range only

Click in *C2* and press *Ctrl-Shift-↓* to grab whole column of data

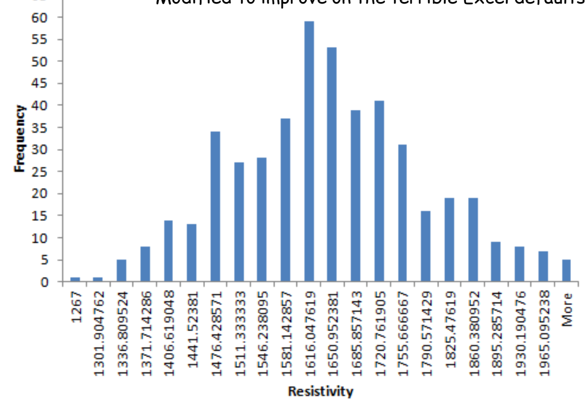
473

Histogram output*

474

Bin	*Frequency*
1267	1
1301.905	1
1336.81	5
1371.714	8
1406.619	14
1441.524	13
1476.429	34
1511.333	27
1546.238	28
1581.143	37
1616.048	59
1650.952	53
1685.857	39
1720.762	41
1755.667	31
1790.571	16
1825.476	19
1860.381	19
1895.286	9
1930.19	8
1965.095	7
More	5

*Modified to improve on the terrible Excel defaults



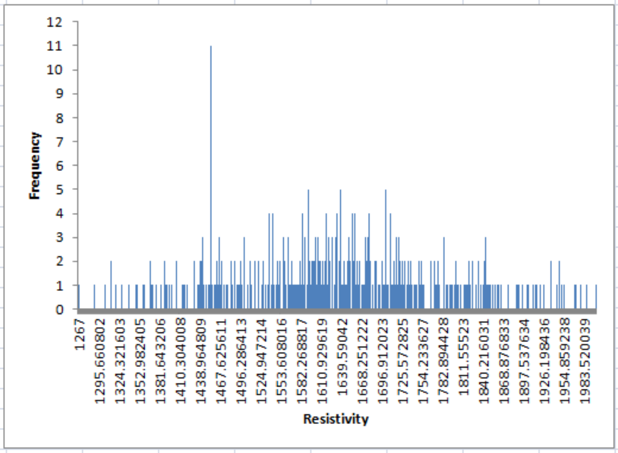
The numeric format for the bin endpoints should not vary

474

Histogram output that you don't want

475

	A	B
1	*Bin*	*Frequency*
2	1267	1
3	1267.717	0
4	1268.433	0
5	1269.15	0
6	1269.866	0
7	1270.583	0
8	1271.299	0
9	1272.016	0
10	1272.732	0
11	1273.449	0
12	1274.165	0
13	1274.882	0
14	1275.598	0
15	1276.315	0
16	1277.031	0
17	1277.748	0
18	1278.464	0
19	1279.181	0
20	1279.897	0
21	1280.614	0
22	1281.33	0
23	1282.047	0
24	1282.763	0
25	1283.48	0
26	1284.196	0
27	1284.913	0
28	1285.63	0
29	1286.346	0
30	1287.063	0



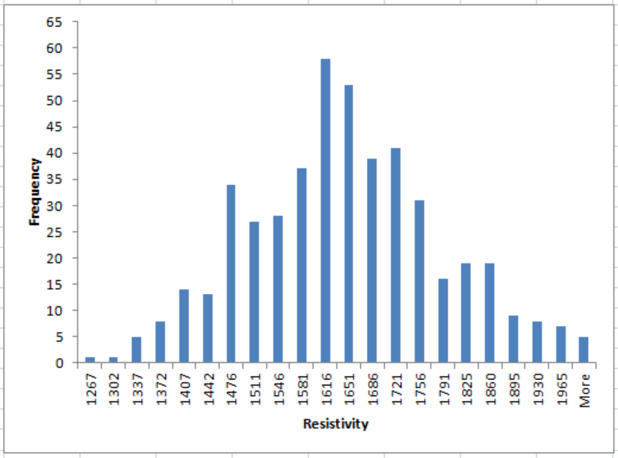
If you get a graph that looks like this, you selected the entire column, not just the data.

475

Histogram (cont'd)

476

	A	B
1	*Bin*	*Frequency*
2	1267	1
3	1302	1
4	1337	5
5	1372	8
6	1407	14
7	1442	13
8	1476	34
9	1511	27
10	1546	28
11	1581	37
12	1616	58
13	1651	53
14	1686	39
15	1721	41
16	1756	31
17	1791	16
18	1825	19
19	1860	19
20	1895	9
21	1930	8
22	1965	7
23	More	5



It looks better if we format the bin endpoints (A2:A22) to an appropriate number of significant digits

476

% Defective from quantitative data

477

	A	B	C	D	E
1	Day	Hour	Resist		
2	1-Tu	10	1608.5		
3	1-Tu	10	1832.0		
4	1-Tu	10	1808.0		
5	1-Tu	11	1714.0		
6	1-Tu	11	1846.0		
7	1-Tu	11	1686.0		
8	1-Tu	12	1558.5		
9	1-Tu	12	1888.0		
10	1-Tu	13	1592.0		
11	1-Tu	13	1752.0		
12	1-Tu	13	1784.0		
13	1-Tu	14	1442.5		
14	1-Tu	14	1502.0		
15	1-Tu	14	1700.0		
16	1-Tu	15	1500.0		
17	1-Tu	15	1674.5		
18	1-Tu	15	1707.0		
19	1-Tu	16	1660.5		
20	1-Tu	16	1804.0		
21	1-Tu	16	1672.0		
22	1-Tu	17	1728.0		
23	1-Tu	17	1969.0		
24	1-Tu	17	1606.0		
25	1-Tu	18	1718.0		
26	1-Tu	18	1824.5		
27	1-Tu	18	1662.0		
28	1-Tu	19	1830.0		
29	1-Tu	19	1703.0		
30	1-Tu	20	1717.0		
31	1-Tu	20	1801.0		
32	1-Tu	20	1453.5		
33	1-Tu	21	1350.0		

- Averages are common project metrics for quantitative Y variables
- Averages are useful for statistical comparisons
- However, customers feel the *variation*, not the average
- The best metric for customer dissatisfaction is the % of parts or transactions that do not meet a requirement or expectation

Percent less than 1500

478

D2 | =IF(C2>=1500,"Pass","Fail")

	A	B	C	D	E	F	G
1	Day	Hour	Resist	R>=1500			
2	1-Tu	10	1608.5	Pass			
3	1-Tu	10	1832.0				
4	1-Tu	10	1808.0				
5	1-Tu	11	1714.0				
6	1-Tu	11	1846.0				
7	1-Tu	11	1686.0				
8	1-Tu	12	1558.5				
9	1-Tu	12	1888.0				
10	1-Tu	13	1592.0				
11	1-Tu	13	1752.0				
12	1-Tu	13	1784.0				
13	1-Tu	14	1442.5				
14	1-Tu	14	1502.0				
15	1-Tu	14	1700.0				
16	1-Tu	15	1500.0				
17	1-Tu	15	1674.5				
18	1-Tu	15	1707.0				
19	1-Tu	16	1660.5				
20	1-Tu	16	1804.0				
21	1-Tu	16	1672.0				
22	1-Tu	17	1728.0				
23	1-Tu	17	1969.0				
24	1-Tu	17	1606.0				

- Let's say the lower spec limit (LSL) for *Resist* is 1500.
- Use the requirement to be met as the name for a new column (cell D1)
- We want the new column to say "Pass" when *Resist* ≥ 1500 and "Fail" when *Resist* < 1500
- Enter the corresponding IF statement into cell D2

=IF(C2 >= 1500,"Pass","Fail")

Percent less than 1500 (cont'd)

479

D2 =IF(C2>=1500,"Pass","Fail")

	A	B	C	D	E	F
1	Day	Hour	Resist	R>=1500		
2	1-Tu	10	1608.5	Pass		
3	1-Tu	10	1832.0	Pass		
4	1-Tu	10	1808.0	Pass		
5	1-Tu	11	1714.0	Pass		
6	1-Tu	11	1846.0	Pass		
7	1-Tu	11	1686.0	Pass		
8	1-Tu	12	1558.5	Pass		
9	1-Tu	12	1888.0	Pass		
10	1-Tu	13	1592.0	Pass		
11	1-Tu	13	1752.0	Pass		
12	1-Tu	13	1784.0	Pass		
13	1-Tu	14	1442.5	Fail		
14	1-Tu	14	1502.0	Pass		
15	1-Tu	14	1700.0	Pass		
16	1-Tu	15	1500.0	Pass		
17	1-Tu	15	1674.5	Pass		
18	1-Tu	15	1707.0	Pass		
19	1-Tu	16	1660.5	Pass		
20	1-Tu	16	1804.0	Pass		
21	1-Tu	16	1672.0	Pass		
22	1-Tu	17	1728.0	Pass		
23	1-Tu	17	1969.0	Pass		
24	1-Tu	17	1606.0	Pass		
25	1-Tu	18	1718.0	Pass		

Now we need to copy the formula down to end of the column:

- Click on D2
- Double-click on the lower right-hand corner of D2
- If there are blank cells, repeat this process until you get down to the last row of data

Percent less than 1500 (cont'd)

480

- Run a pivot table on the new column: highlight columns A-F, Insert → Pivot Table → OK, drag R>=1500 to Columns and Values
- Calculate the % less than 1500

	Column Labels		
	Fail	Pass	Grand Total
Count of R>=1500	92	382	474

- Use Value Field Settings to format as a percentage

	Column Labels		
	Fail	Pass	Grand Total
Count of R>=1500	19.4%	80.6%	100.0%

Format for reporting:

Project metric	% < 1500
Baseline value	19.4%

Percent greater than 1800

481

E2 =IF(C2<=1800,"Pass","Fail")

	A	B	C	D	E	F
1	Day	Hour	Resist	R>=1500	R <= 1800	
2	1-Tu	10	1608.5	Pass	Pass	
3	1-Tu	10	1832.0	Pass	Fail	
4	1-Tu	10	1808.0	Pass	Fail	
5	1-Tu	11	1714.0	Pass	Pass	
6	1-Tu	11	1846.0	Pass	Fail	
7	1-Tu	11	1686.0	Pass	Pass	
8	1-Tu	12	1558.5	Pass	Pass	
9	1-Tu	12	1888.0	Pass	Fail	
10	1-Tu	13	1592.0	Pass	Pass	
11	1-Tu	13	1752.0	Pass	Pass	
12	1-Tu	13	1784.0	Pass	Pass	
13	1-Tu	14	1442.5	Fail	Pass	
14	1-Tu	14	1502.0	Pass	Pass	
15	1-Tu	14	1700.0	Pass	Pass	
16	1-Tu	15	1500.0	Pass	Pass	
17	1-Tu	15	1674.5	Pass	Pass	
18	1-Tu	15	1707.0	Pass	Pass	
19	1-Tu	16	1660.5	Pass	Pass	
20	1-Tu	16	1804.0	Pass	Fail	
21	1-Tu	16	1672.0	Pass	Pass	
22	1-Tu	17	1728.0	Pass	Pass	
23	1-Tu	17	1969.0	Pass	Fail	
24	1-Tu	17	1606.0	Pass	Pass	
25	1-Tu	18	1718.0	Pass	Pass	

- Let's pretend *Resist* has a USL at 1800
- Use the requirement to be met as the name for a new column (cell E1)
- We want the new column to say "Pass" when *Resist* ≤ 1800 and "Fail" when *Resist* > 1800
- Enter the corresponding IF statement into cell E2
- Copy the formula down to the end of the data set

481

Percent greater than 1800 (cont'd)

482

- Run a pivot table on the new column
- Calculate the % greater than 1800
- The total % defective would be 19.4 + 13.3 = 32.7%
- Save your work

	Column Labels		
	Fail	Pass	Grand Total
Count of R<=1800	63	411	474

	Column Labels		
	Fail	Pass	Grand Total
Count of R<=1800	13.3%	86.7%	100.0%

Format for reporting:

Project Metric:	%>1800
Baseline Value:	13.3%

Project Metric:	Total % Defective
Baseline Value:	32.7%

482

Exercise 24.1

483

Open *Data Sets* → *number & size of defects*. *Max size* is the area of the largest weld repair on a casting.

(a) Create a basic statistical summary for *Max size*.

(b) Create a frequency histogram for *Max size*.

(c) The customer will accept a casting only if *Max size* is less than or equal to 15. Find the percentage of castings that exceed 15.

(d) Save your work.

483

Exercise 24.2

484

Open *Student Files* → *Case Studies* → *quotation process* → *quotation process current state*. TAT is the turnaround time in business days for each quote.

(a) Create a basic statistical summary of TAT. Update the charter* by entering the baseline average TAT. Enter 1.5 days as the goal for that metric.

(b) Create a frequency histogram of TAT.

(c) Customers have been told quotes will be turned around in 3 days or less. Find the percentage of quotes that do not satisfy this expectation. Update the charter by entering this as the baseline value. Enter 10% as the goal for that metric.

(d) Calculate the purchase order hit rate (% Yes in the PO column). Update the charter by entering this as the baseline value. Enter 95% as the goal for that metric.

(e) Save your work.

* *Student Files* → *Case Studies* → *quotation process* → *quotation process charter*

484

Exercise 24.3

485

Open *Student Files → Case Studies → MBDP → MBDP current state*.

a) Create a basic statistical summary of PO-PD. Update the charter* by entering the average PO-PD as the baseline value.

b) Create a frequency histogram of PO-PD.

c) Find the % of orders for which PO-PD exceeds 30 days. Update the charter by entering this as the baseline value.

d) Find the % of orders for which MFG is not happy. Update the charter by entering this as the baseline value.

e) Save your work.

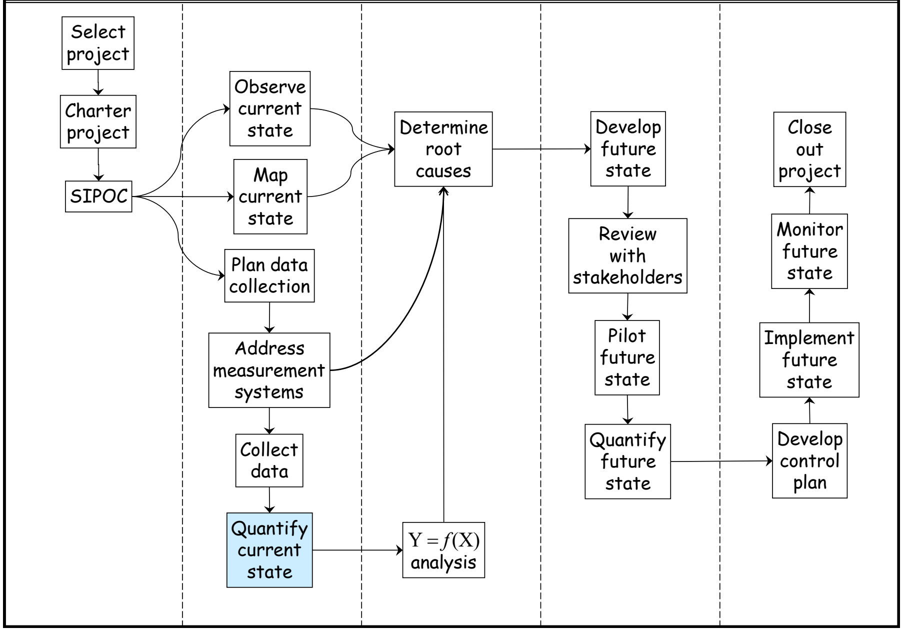
* *Student Files → Case Studies → MBDP →MBDP charter*

Notes

486

25 Plotting Data Over Time

487



Why plot data over time?

488

By plotting data in time sequence, we can see how the process is performing over time. We can quickly see:

- the amount of variation and whether it changes over time
- upward or downward trends
- unusual data points
- cycles or other patterns in the data

Example 1: Plotting quantitative data

489

Open *Data Sets* → *DI water*

- De–ionized water is used in machining and cutting operations
- Y = electrical resistivity (*Resist*)
- Want lower conductivity, so higher Y is better
- Baseline data was collected over 8 days, 3 measurements per hour
- Want to make a time plot

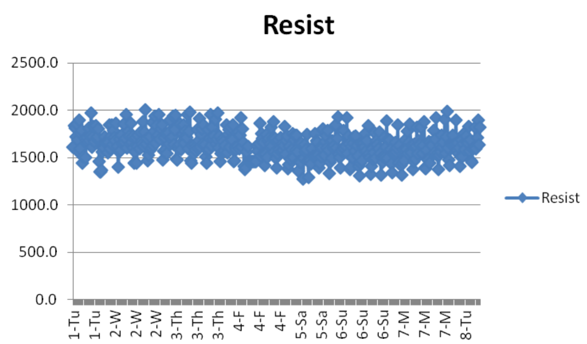
	A	B	C	D
1	**Day**	**Hour**	**Resist**	
2	1-Tu	10	1608.5	
3	1-Tu	10	1832.0	
4	1-Tu	10	1808.0	
5	1-Tu	11	1714.0	
6	1-Tu	11	1846.0	
7	1-Tu	11	1686.0	
8	1-Tu	12	1558.5	
9	1-Tu	12	1888.0	
10	1-Tu	13	1592.0	
11	1-Tu	13	1752.0	
12	1-Tu	13	1784.0	
13	1-Tu	14	1442.5	
14	1-Tu	14	1502.0	
15	1-Tu	14	1700.0	
16	1-Tu	15	1500.0	
17	1-Tu	15	1674.5	
18	1-Tu	15	1707.0	
19	1-Tu	16	1660.5	
20	1-Tu	16	1804.0	
21	1-Tu	16	1672.0	
22	1-Tu	17	1728.0	
23	1-Tu	17	1969.0	
24	1-Tu	17	1606.0	
25	1-Tu	18	1718.0	
26	1-Tu	18	1824.5	
27	1-Tu	18	1662.0	
28	1-Tu	19	1830.0	
29	1-Tu	19	1703.0	
30	1-Tu	20	1717.0	
31	1-Tu	20	1801.0	
32	1-Tu	20	1453.5	
33	1-Tu	21	1350.0	

489

Example 1 (cont'd)

490

1. Select column C, then select column A while holding down the **Ctrl** key
2. Insert a line chart ("Line with Markers")
3. Behold: your typically terrible default Excel chart
4. Desperately needs "graphical 5S"

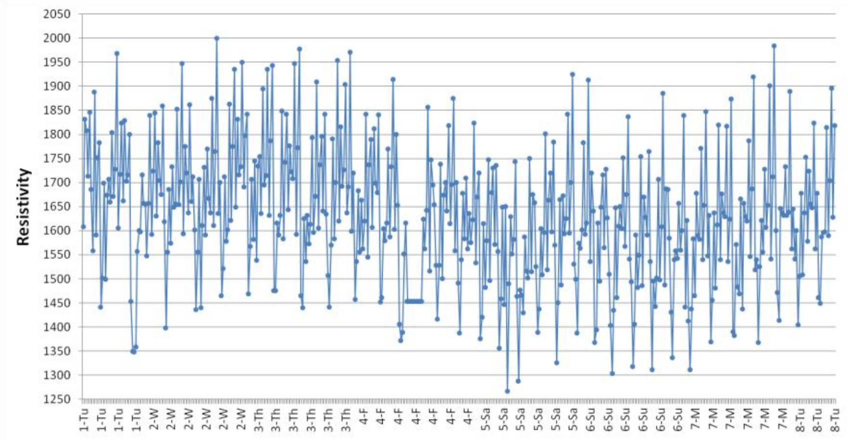


490

Example 1 (cont'd)

491

5. With a single data series the legend is pointless — delete it
6. Format the vertical axis as shown below: more data, less empty space
7. Format the data series to reduce the size of the markers and lines



Example 1 (cont'd)

492

- Good graphics are "lean" graphics
- General principle for lean graphics:

Reduce the ink-to-data ratio!

- There are a couple of interesting observations about the data plotted in the previous slide — what are they?

Example 2: Plotting quantitative data

493

Open *Student Files* → *Case Studies* → *quotation process* → *quotation process current state*

	A	B	C	D	E	F	G	H	I	J
1	Quote Num	AcctMgr	BU	Initial RFQ	Month	RFQ Cycles	Finance review	TAT	TAT<=3	PO
2	6250012	19	6	02-Jun-03	2003.06	1	Yes	2	Pass	Yes
3	7250022	5	7	02-Jun-03	2003.06	1	Yes	1	Pass	Yes
4	7250023	5	7	02-Jun-03	2003.06	1	No	2	Pass	Yes
5	5250039	8	5	03-Jun-03	2003.06	2	No	3	Pass	Yes
6	5250040	8	5	03-Jun-03	2003.06	2	No	3	Pass	Yes
7	7250011	10	7	03-Jun-03	2003.06	1	No	1	Pass	Yes
8	6250014	19	6	04-Jun-03	2003.06	1	No	2	Pass	Yes
9	6250015	15	6	04-Jun-03	2003.06	1	No	2	Pass	Yes
10	7250025	14	7	04-Jun-03	2003.06	1	No	6	Fail	Yes
11	5250044	8	5	05-Jun-03	2003.06	2	Yes	4	Fail	Yes
12	3250033	3	3	06-Jun-03	2003.06	1	Yes	2	Pass	No
13	3250035	3	3	09-Jun-03	2003.06	1	Yes	1	Pass	No
14	7250024	15	7	09-Jun-03	2003.06	1	No	2	Pass	Yes
15	5250045	8	5	10-Jun-03	2003.06	3	Yes	2	Pass	No
16	8250009	11	8	10-Jun-03	2003.06	1	No	1	Pass	Yes
17	8250010	12	8	10-Jun-03	2003.06	1	No	1	Pass	Yes
18	8250011	11	8	10-Jun-03	2003.06	1	No	1	Pass	Yes
19	8250012	12	8	10-Jun-03	2003.06	1	No	1	Pass	Yes

=YEAR(D2)+MONTH(D2)/100

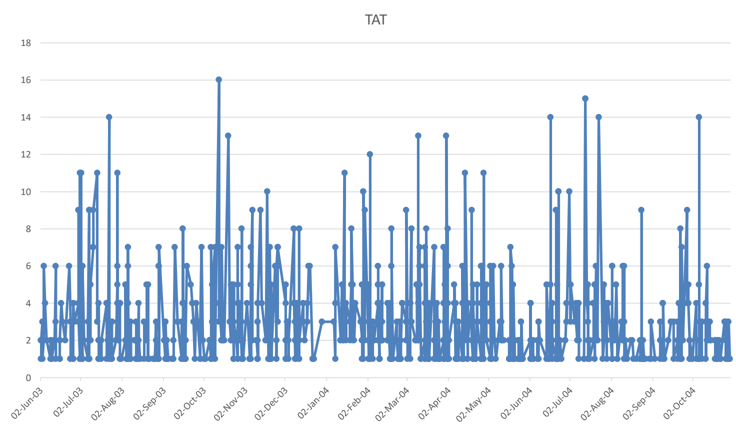
=IF(H2>3,"Fail","Pass")

493

Example 2 (cont'd)

494

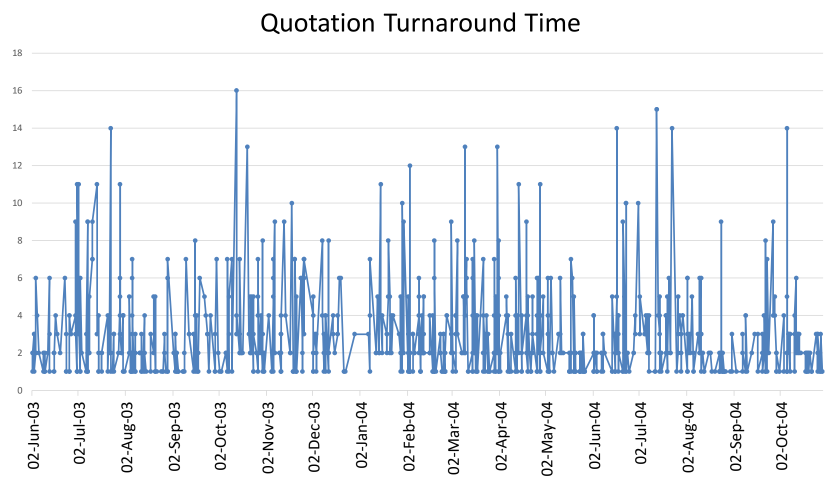
1. Select column H, then select column D while holding down the **Ctrl** key
2. Insert a line chart ("Line with Markers")



494

Example 2 (cont'd)

495



Changes in variation, no discernable changes in the mean

Example 3: Plotting pass/fail data

496

Open *Data Sets* → *ATE Mar & Apr*

	A	B	C	D	E	F
1	Date & Time	P/N	S/N	Tester	Result	Failure Reason
2	3/1/06 6:02 AM	690	3457456	3	Pass	
3	3/1/06 6:03 AM	692	4499441	1	Pass	
4	3/1/06 6:05 AM	690	3457457	3	Fail	Backlight-LCD
5	3/1/06 6:06 AM	690	3457458	3	Pass	
6	3/1/06 6:12 AM	690	3457442	3	Pass	
7	3/1/06 6:12 AM	692	4499442	1	Pass	
8	3/1/06 6:13 AM	692	4500377	2	Pass	
9	3/1/06 6:15 AM	690	3457443	3	Fail	Op curr out of range
10	3/1/06 6:17 AM					
11	3/1/06 6:18 A					Backlight-LCD
12	3/1/06 6:18 A					Op curr out of range
13	3/1/06 6:19 A					
14	3/1/06 6:20 A					
15	3/1/06 6:21 A					
16	3/1/06 6:22 AM					
17	3/1/06 6:22 AM	692	4499444	1	Pass	
18	3/1/06 6:24 AM	692	4499445	1	Fail	Slp curr out of range
19	3/1/06 6:24 AM	690	3457448	3	Fail	Switch Test
20	3/1/06 6:25 AM	692	4500380	2	Pass	
21	3/1/06 6:27 AM	692	4499446	1	Fail	Slp curr out of range
22	3/1/06 6:27 AM	690	3457449	3	Fail	Switch Test

- Part level data (not tabulated)
- Y variables = *Result, Failure Reason*
- X variables = *Date, Time, P/N, Tester*

Example 3 (cont'd)

497

- Medical devices are tested for 20 or so failure modes by automated test equipment (ATE)
- Every time a unit is tested, a new record is added to the database
- This is part level data — one part for each row
- Let's say we want plot the daily % failing

497

Example 3: (cont'd)

498

	A	B	C	D	E	F
1	**Date & Time**	**P/N**	**S/N**	**Tester**	**Result**	**Failure Reason**
2	3/1/06 6:02 AM	690	3457456	3	Pass	
3	3/1/06 6:03 AM	692	4499441	1	Pass	
4	3/1/06 6:05 AM	690	3457457	3	Fail	Backlight-LCD
5	3/1/06 6:06 AM	690	3457458	3	Pass	
6	3/1/06 6:12 AM	690	3457442	3	Pass	
7	3/1/06 6:12 AM	692	4499442	1	Pass	
8	3/1/06 6:13 AM	692	4500377	2	Pass	
9	3/1/06 6:15 AM	690	3457443	3	Fail	Op curr out of range
10	3/1/06 6:17 AM	692	4500378	2	Pass	
11	3/1/06 6:18 AM	690	3457444	3	Fail	Backlight-LCD
12	3/1/06 6:18 A	[illegible]	[illegible]	[illegible]	Fail	Op curr out of range
13	3/1/06 6:19 A	[illegible]	[illegible]	[illegible]	Pass	
14	3/1/06 6:20 A	[illegible]	[illegible]	[illegible]	Pass	
15	3/1/06 6:21 AM	692	4500379	2	Pass	
16	3/1/06 6:22 AM	690	3457447	3	Pass	
17	3/1/06 6:22 AM	692	4499444	1	Pass	
18	3/1/06 6:24 AM	692	4499445	1	Fail	Slp curr out of range
19	3/1/06 6:24 AM	690	3457448	3	Fail	Switch Test
20	3/1/06 6:25 AM	692	4500380	2	Pass	
21	3/1/06 6:27 AM	692	4499446	1	Fail	Slp curr out of range
22	3/1/06 6:27 AM	690	3457449	3	Fail	Switch Test

1. Select columns A-F
2. Insert a *PivotTable* (see next slide)

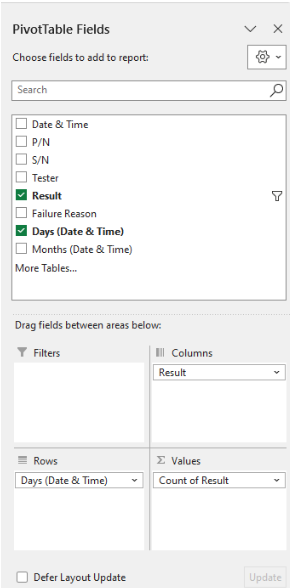
498

Example 3 (cont'd)

499

Count of Resul	Column Label		
Row Labels	**Fail**	**Pass**	**Grand Total**
1-Mar	59	433	492
2-Mar	50	404	454
3-Mar	45	183	228
6-Mar	116	372	488
7-Mar	106	357	463
8-Mar	79	353	432
9-Mar	80	386	466
10-Mar	42	320	362
13-Mar	77	356	433
14-Mar	155	346	501
15-Mar	91	376	467
16-Mar	141	430	571
17-Mar	109	346	455
18-Mar			
20-Mar			
21-Mar			
22-Mar			
23-Mar	74	398	472
24-Mar	104	363	467
27-Mar	73	351	424
28-Mar	63	392	455
29-Mar	92	369	461
30-Mar	113	460	573
31-Mar	150	326	476
1-Apr	71	134	205
3-Apr	124	384	508
4-Apr	146	432	578
5-Apr	105	419	524

3. Set up as shown here
4. Go to the next slide



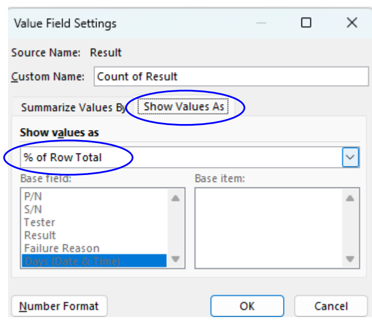
499

Example 3 (cont'd)

500

Count of Result	Column Labels		
Row Labels	**Fail**	**Pass**	**Grand Total**
1-Mar	11.99%	88.01%	100.00%
2-Mar	11.01%	88.99%	100.00%
3-Mar	19.74%	80.26%	100.00%
6-Mar	23.77%	76.23%	100.00%
7-Mar	22.89%	77.11%	100.00%
8-Mar	18.29%	81.71%	100.00%
9-Mar	17.17%	82.83%	100.00%
10-Mar	11.60%	88.40%	100.00%
13-Mar	17.78%	82.22%	100.00%
14-Mar	30.94%	69.06%	100.00%
15-Mar	19.49%	80.51%	100.00%
16-Mar	24.69%	75.31%	100.00%
17-Mar	23.96%	76.04%	100.00%
18-Mar	66.67%	33.33%	100.00%
20-Mar	27.22%	72.78%	100.00%
21-Mar	27.01%	72.99%	100.00%
22-Mar	30.25%	69.75%	100.00%
23-Mar	15.68%	84.32%	100.00%
24-Mar	22.27%	77.73%	100.00%
27-Mar	17.22%	82.78%	100.00%
28-Mar	13.85%	86.15%	100.00%
29-Mar	19.96%	80.04%	100.00%
30-Mar	19.72%	80.28%	100.00%
31-Mar	31.51%	68.49%	100.00%
1-Apr	34.63%	65.37%	100.00%
3-Apr	24.41%	75.59%	100.00%
4-Apr	25.26%	74.74%	100.00%
5-Apr	20.04%	79.96%	100.00%
6-Apr	16.76%	83.24%	100.00%
7-Apr	23.33%	76.67%	100.00%
8-Apr	17.95%	82.05%	100.00%
10-Apr	21.88%	78.13%	100.00%
11-Apr	20.04%	79.96%	100.00%

5. Format the data as percentages using *Value Field Settings*
6. Because we are using individual samples (rows) of data, we need to calculate the percentage based on the row total
7. Go to the next slide



500

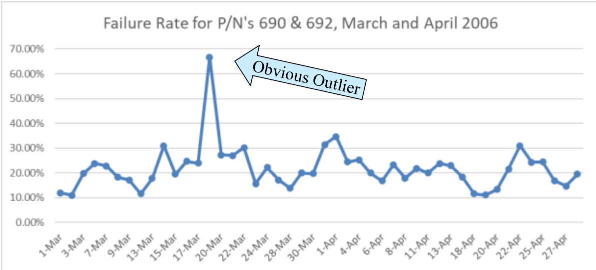
Example 3 (cont'd)

501

Count of Result	Column Labels
Row Labels	Fail
1-Mar	11.99%
2-Mar	11.01%
3-Mar	19.74%
6-Mar	23.77%
7-Mar	22.89%
8-Mar	18.29%
9-Mar	17.17%
10-Mar	11.60%
13-Mar	17.78%
14-Mar	30.94%
15-Mar	19.49%
16-Mar	24.69%
17-Mar	23.96%
18-Mar	66.67%
20-Mar	27.22%
21-Mar	27.01%
22-Mar	30.25%
23-Mar	15.68%
24-Mar	22.27%
27-Mar	17.22%
28-Mar	13.85%
29-Mar	19.96%
30-Mar	19.72%
31-Mar	31.51%
1-Apr	34.63%
3-Apr	24.41%
4-Apr	25.26%
5-Apr	20.04%
6-Apr	16.76%
7-Apr	23.33%
8-Apr	17.95%

8. Next, *Copy* and *Paste* the *Count of Result Row Labels* and the *Fail %* columns to a blank area of the worksheet.

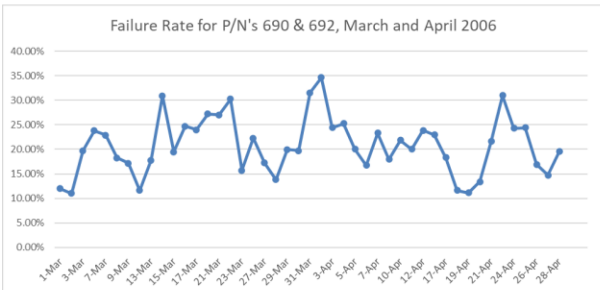
9. Click in any *Fail* data cell and *Insert* a *Line Chart with Markers*



Example 3 (cont'd)

502

- The outlier is 3/18/06, a Saturday
- The plant is closed on weekends — an engineer came in to troubleshoot one of the testers
- De-select 3/18/2006 in the original pivot table and redo the Line chart.
- Looks like steady variation around a mean of about 20%.
- Close and save the data set



Example 4: Plotting summary statistics

503

Open *Data Sets* → *DI water*

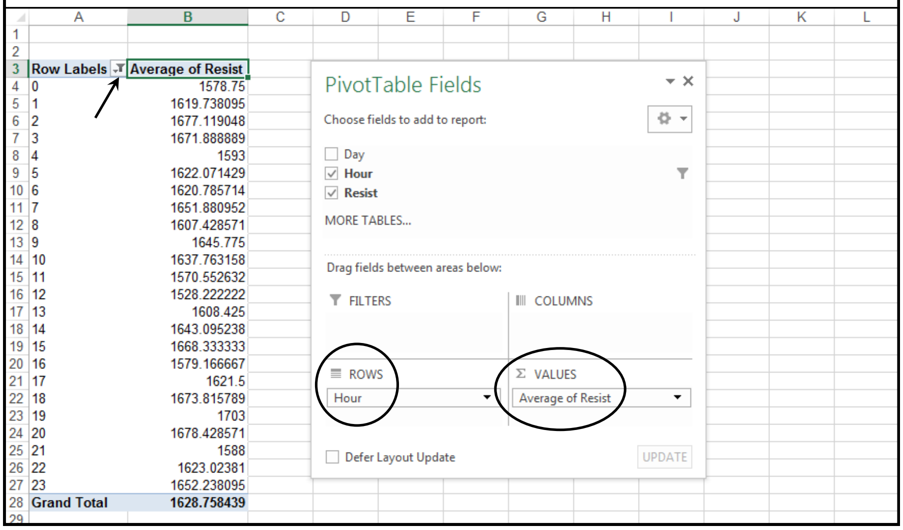
- Can also plot *summary statistics* by time period
- Average, % too high, % too low, etc.
- May give a clearer picture of certain patterns of variation

503

Example 4 (cont'd)

504

1. Let's plot average resistivity by hour of day
2. Insert a pivot table, set it up as shown below



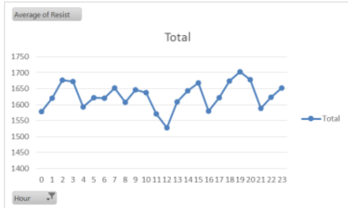
Row Labels	Average of Resist
0	1578.75
1	1619.738095
2	1677.119048
3	1671.888889
4	1593
5	1622.071429
6	1620.785714
7	1651.880952
8	1607.428571
9	1645.775
10	1637.763158
11	1570.552632
12	1528.222222
13	1608.425
14	1643.095238
15	1668.333333
16	1579.166667
17	1621.5
18	1673.815789
19	1703
20	1678.428571
21	1588
22	1623.02381
23	1652.238095
Grand Total	1628.758439

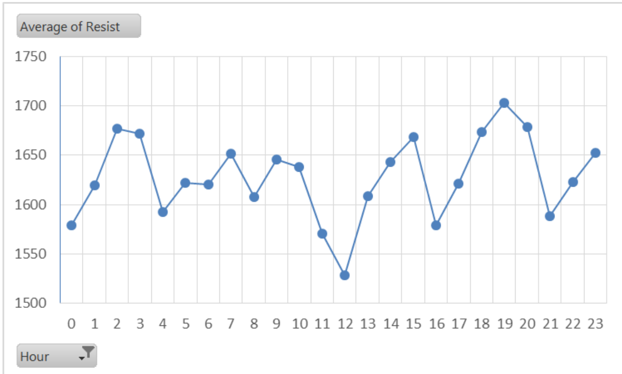
504

Example 4 (cont’d)

505

Click on any data cell in the Pivot Table (the *Pivot Table Fields* dialog will be showing), select *Insert* ribbon → *Line Chart*





- There was a cyclical daily pattern, most pronounced from noon to midnight
- It was caused by everyone taking lunch and breaks at the same time

505

Exercise 25.1

506

Open *Student Files* → *Case Studies* → *quotation process* → *quotation process current state*. Create the following charts. Make them look the way they should.

a) Monthly % TAT > 3.

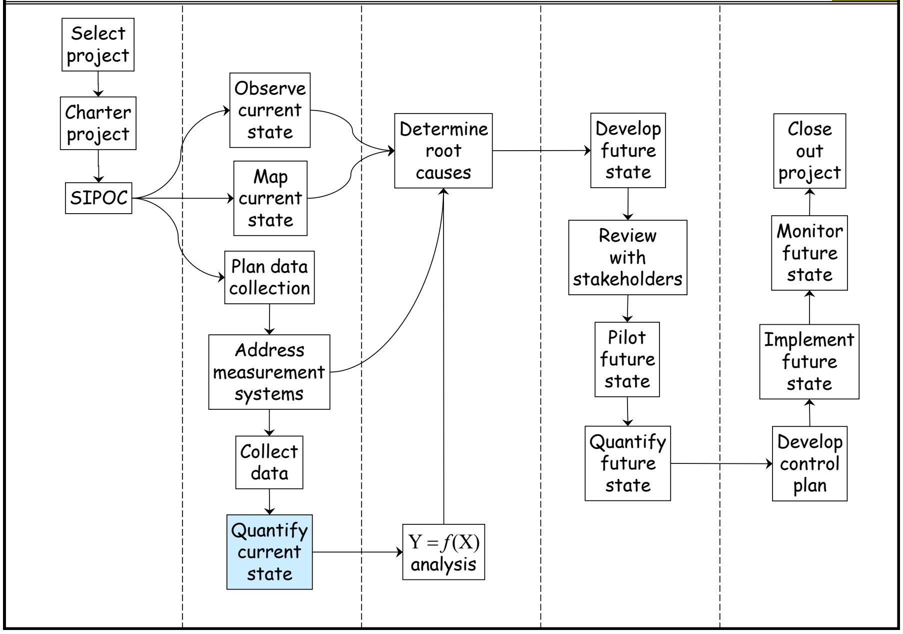
b) Monthly PO hit rate (% Yes).

c) Close and save the data set.

506

26 Process Capability Indices

507



507

Topics

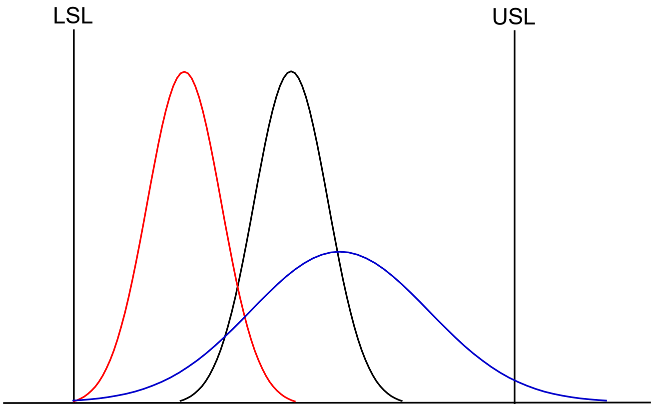
508

- Purpose of Process Capability Indices
- Commonly used indices
- Important assumptions for validity

508

Process capability indices

509



- Some industries focus on “capability indices” instead of DPPM or DPMO
- These are calculated from the specification limit(s) and a fitted distribution
- Back in the day, the distribution was always assumed to be Normal

509

Process capability indices (cont’d)

510

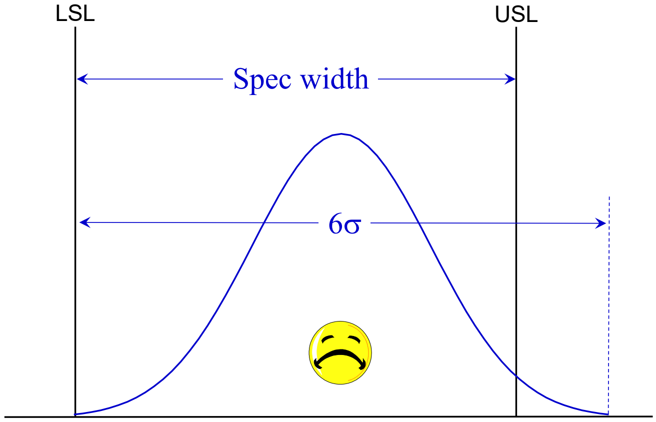
- Do your organization’s external customers ask for process capability reporting?
- Are there internal requirements or needs for process capability reporting?

510

C_p index

511

$$C_p = \frac{\text{Spec width}}{6\sigma} = \frac{USL - LSL}{6\sigma}$$



In this case, C_p is less than 1

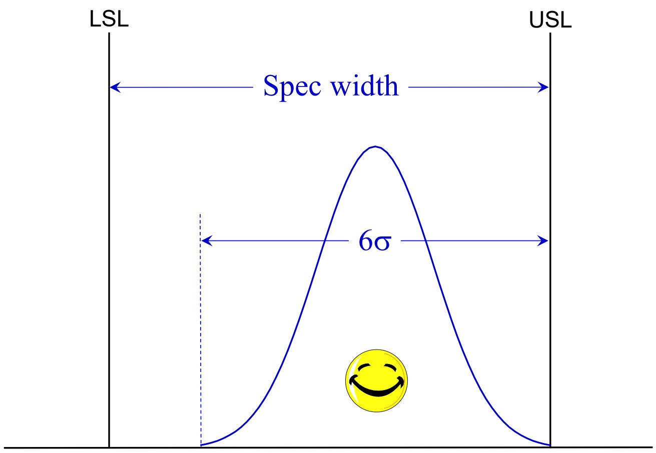
C_p index (cont'd)

512

- The C_p index was historically the first to be used.
- It is defined as the specification width (USL – LSL) divided by the process spread (6σ).
- It set the precedent for capability indices to be defined so that "higher is better."
- In the example above, the process spread is greater than the spec width, so C_p is less than 1.
- It is common for customers to push suppliers to achieve index values of 1.33 or higher for key Y variables.

C_p (cont'd)

513



In this case, C_p is greater than 1, but what's a potential problem here?

513

C_p (cont'd)

514

- In the example shown in the previous slide, the process spread is less than the spec width, so C_p is greater than 1.
- The limitation of C_p is that it doesn't depend on the process mean.
  - If the process mean is equal to the midpoint of the specification range, then C_p is directly related to first pass yield.
  - If the process mean does not equal the midpoint of the specification range, C_p represents the capability that could be attained by moving the process mean to the midpoint.

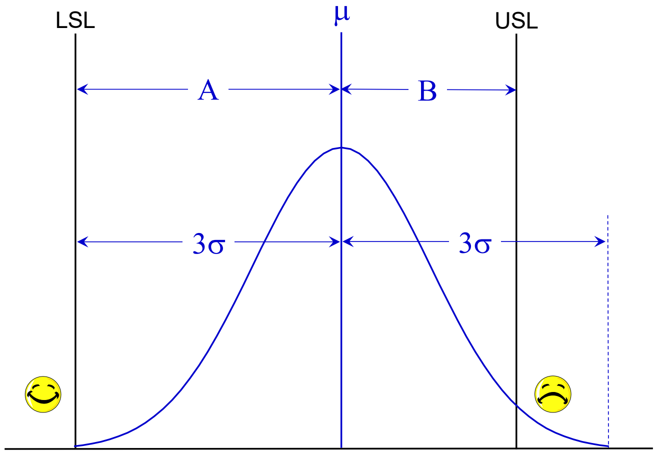
514

C_{pl} and C_{pu} and C_{pk} indices

515

$$C_{pl} = \text{"}C_p \text{ lower"} = \frac{A}{3\sigma}$$

$$C_{pu} = \text{"}C_p \text{ upper"} = \frac{B}{3\sigma}$$



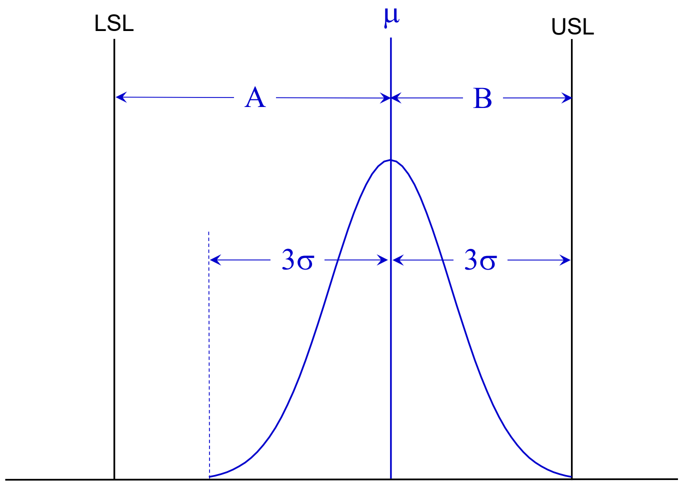
C_{pl} and C_{pu} and C_{pk} indices (cont'd)

516

- The indices C_{pl} and C_{pu}, pronounced "C_p lower" and "C_p upper", were introduced to overcome the deficiency of C_p.
- They depend on both the mean and standard deviation of the process. If we know both C_{pl} and C_{pu} we can determine the first pass yield of the process.
- C_{pk} is the final index reported from C_{pl} and C_{pu} ; it is the lower of the two indices, i.e., the worst-case scenario.
- Like the C_p index, C_{pl}, C_{pu} , and C_{pk} are defined so that "higher is better."
- In the example shown above, the main problem is on the high side, with C_{pk} less than 1.

C_{pl} and C_{pu} and C_{pk} indices (cont'd)

517



C_{pl} is greater than 1, C_{pu} is equal to 1

C_{pl} and C_{pu} and C_{pk} indices (cont'd)

518

- C_{pk} is equal to 1 in the example shown in the previous slide. The improvement opportunity is on the high side.
- We've used "A" and "B" to conceptually represent the comparison of each half of the Spec width to the associated half of the process spread.
- How would you write the actual formulas for C_{pl} and C_{pu}?

Process Capability Formulas (Normal distribution)

519

$$C_p = \frac{USL - LSL}{6\sigma}$$

$$C_{pl} = \frac{\mu - LSL}{3\sigma} \qquad C_{pu} = \frac{USL - \mu}{3\sigma}$$

$$C_{pk} = \min\left(C_{pl}, C_{pu}\right)$$

Many people have asked what the *k* in C_{pk} stands for. To everyone's great disappointment, the *k* seems to have been chosen arbitrarily and may not stand for anything.

There is, however, a bit of historical trivia that may give us a clue:

- C_{pk} was first popularized by a man named Victor Kane.
- Is it possible Victor simply used the first letter of his last name?

519

Guidelines for Process Capability Indices

520

- Use C_{pl} if you have only a lower spec limit
- Use C_{pu} if you have only an upper spec limit
- Use C_{pk} (smaller of C_{pl} and C_{pu}) if you have both lower and upper spec limits
- As noted previously, C_p indicates what C_{pk} would be if the process mean were equal to the midpoint of the spec range.
  - If this is not the case, C_p represents a potential capability.
  - Centering a process at this midpoint may not always be desirable.

520

Important assumptions in Process Capability

521

For Process Capability indices to be valid, the following must be true:

- The process is in statistical control (we will discuss this topic in the Control phase)
- The measurement data is normally distributed*
- The sampling method used is representative of day-to-day process operation

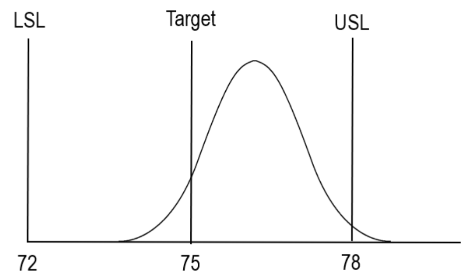
There are times when we want to calculate process capability before the process is under control, for example to set an initial baseline or make a rough prediction.

- The purpose of a process capability study should always be communicated along with the numbers.

**Handling situations when the data is not normally distributed is beyond the scope of this course. Some statistical software packages offer options for calculating Process Capability for non-Normal distributions, along with indices for other special cases.*

Exercise 26.1 Calculating Process Capability indices

522



- For this distribution, the mean = 76 and the standard deviation = 1.
- We will calculate the Process Capability Indices together, writing out each fraction in detail to better visualize the Spec Width vs Process Spread.

$$C_p = \frac{USL - LSL}{6\sigma} = \frac{\quad}{\quad} = \frac{\quad}{\quad} =$$

$$C_{pl} = \frac{\mu - LSL}{3\sigma} = \frac{\quad}{\quad} = \frac{\quad}{\quad} =$$

$$C_{pu} = \frac{USL - \mu}{3\sigma} = \frac{\quad}{\quad} = \frac{\quad}{\quad} =$$

$$C_{pk} = \min(C_{pu}, C_{pl}) =$$

Exercise 26.2

(a) Calculate C_p and C_{pk} for a process with mean = 55, standard deviation = 1, USL = 60 and LSL = 50.

Sketch the distribution.

(b) Calculate C_p and C_{pk} for a process with mean = 100.20, standard deviation = 0.20, USL = 101.00 and LSL = 100.00.

Sketch the distribution.

What is "good" process capability?

Capability	How good is this?	Sigma Level
$C_p = 1.0$	Marginally capable	3 sigma
$C_p = 1.33$	Good	4 sigma
$C_p = 2.0$	World-class	6 sigma

The indices C_p and C_{pk} are assumed to be measures of the long-term capability of the process. Therefore,

- the data needs to be gathered over a long enough period of time to capture all regular contributors to process variation,
- *and* a sample size of at least 70 is needed, with 100 preferred.

Predicting defects

525

C_p, C_{pk} Value	C_p Fallout (centered)	C_{pk} Fallout (not centered)
.5	133,620 PPM	66,810 PPM
.6	71,860	35,930
.7	35,720	17,860
.8	16,400	8,200
.9	6,940	3,470
1.0	2,700	1,350
1.1	966	483
1.2	318	159
1.3	96	48
1.33	66	33
1.4	26	13
1.5	7	3
1.6	2	800 PPB
1.7	340 PPB	170
1.8	60	30
1.9	12	6
2.0	2	1

PPM = Parts Per Million
PPB = Parts Per Billion
Note: 1%=10,000 PPM

525

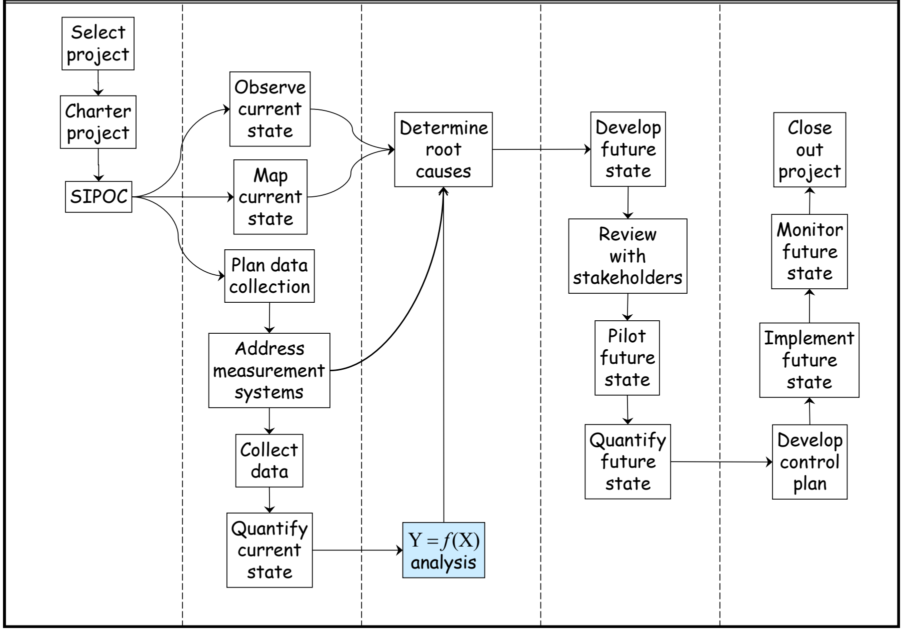
Notes

526

526

27 Testing for Statistical Significance

527



527

Topics

528

- Comparing populations with quantitative Y
- Comparing populations with categorical (pass/fail) Y
- Correlating quantitative X and Y variables

528

Comparing populations with quantitative Y

529

Example	Is there a difference between molding machines A and B with respect to average diameter of molded parts?
Required data	Diameters for representative samples of parts molded on machines A and B.
Y variable	Diameter — quantitative
X variable	Machine (A or B)

529

Comparing populations with categorical (pass/fail) Y

530

Example	Is there a difference between molding machines A and B with respect to the percentage of parts with cosmetic defects?
Required data	Defective (yes/no) for representative samples of parts molded on machines A and B.
Y variable	Defective (yes/no)
X variable	Machine (A or B)

530

Correlating quantitative Y and X variables

531

Example	If we reduce our billing lead time, will we get paid sooner?
Required data	Days in accounts receivable and billing lead times for a representative sample of invoices.
Y variable	Days in accounts receivable
X variable	Billing lead time

531

The role of the X variable in significance testing

532

X data type	Analysis type	The X column contains . . .
Categorical	Comparing populations	• Labels identifying logical subgroups (strata) within the current state data, or • Labels distinguishing the current state data from the future state pilot data • Each group must contain multiple rows (Y data values)
Quantitative	Correlating variables	• Quantitative measurements • The data consists of (X, Y) pairs (values in the same row) • Don't need to have multiple Y values for each X value

532

Excel tools for significance testing

X data type	Y data type	Excel tool
Categorical	Quantitative	Data Analysis ↓ Anova: Single Factor
	Categorical (Pass/fail)	Student Files ↓ calculator - chi square test
Quantitative	Quantitative	Data Analysis ↓ Regression
	Categorical (Pass/fail)	Logistic Regression (Not an Excel option and not covered in this course)

Exercise 27.1

For questions (a) through (g) on the next three slides, identify the X and Y variables and their data types, then write the letter in the appropriate box.

X data type	Y data type	Questions	Analysis tool
Categorical	Quantitative		Data Analysis ↓ Anova: Single Factor
	Categorical (Pass/fail)		Student Files ↓ calculator - chi square test
Quantitative	Quantitative		Data Analysis ↓ Regression

Exercise 27.1 (cont'd)

(a) We applied a functional test to circuit boards from the standard process and our new lead-free process. We counted the number that passed and failed for both processes and want to know if the failure rate is the same.

(b) We sealed potato chip bags using various bonding pressures, then measured the bond strengths. Is bond strength correlated with pressure?

(c) We conducted a Kaizen event in order processing. We measured lead times before and after the event. Is average lead time after the event shorter than it was before the event?

Exercise 27.1 (cont'd)

(d) For each customer support call we record the wait time and a customer satisfaction score on a scale from 1 to 10. Is customer dissatisfaction correlated with wait time?

(e) Measuring the fat content of milk by chemical analysis is very accurate, but it takes too long and costs too much to use in production. We need a faster, cheaper method. For a set of milk samples, we have the fat content based on chemical analysis, as well as a different kind of measurement based on infrared (IR) spectroscopy of the milk sample. Is fat content correlated with the IR measurement?

Exercise 27.1 (cont'd)

537

f) Engineers complete change orders which are then sent back to the customer for approval. Each change order has been counted as being complete and accurate or not based on the customer's approval. Are there differences among the engineers in their change orders' "complete and accurate" rate?

g) We use several different machines to seal potato chip bags. Do the machines give the same average bond strength?

Significance testing: example 1 ANOVA

538

Comparing samples with quantitative Y

Standard data matrix format ↓ Data format required for ANOVA: Single Factor ↓

	A	B	C	D	E	F	G	H
1	**Molding machine**	**Part diams**			**A**	**B**		
2	A	27.5			27.5	31.0		
3	A	29.0			29.0	29.0		
4	A	28.0			28.0	31.5		
5	A	29.5			29.5	30.0		
6	B	31.0						
7	B	29.0						
8	B	31.5						
9	B	30.0						
10								

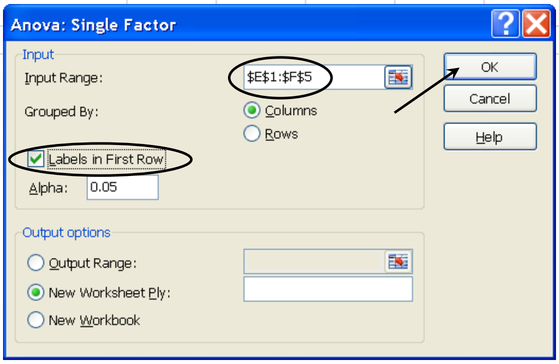
- Open *Data Sets* → *significance testing examples*
- We want to determine whether or not there a significant difference between machines A and B.
- Reformat the data into columns A and B, as shown, to perform ANOVA.

Significance testing: example 1 ANOVA (cont'd)

539

	A	B	C	D	E	F	G	H
1	Molding machine	Part diams			A	B		
2	A	27.5			27.5	31.0		
3	A	29.0			29.0	29.0		
4	A	28.0			28.0	31.5		
5	A	29.5			29.5	30.0		
6	B	31.0						
7	B	29.0						
8	B	31.5						
9	B	30.0						
10								

Data
↓
Data Analysis
↓
Anova: Single Factor
↓
Set up as shown
↓
OK



539

Significance testing: example 1 ANOVA (cont'd)

540

Default Excel output

	A	B	C	D	E	F	G	H
1	Anova: Single Factor							
2								
3	SUMMARY							
4	*Groups*	*Count*	*Sum*	*Average*	*Variance*			
5	A	4	114	28.5	0.833333			
6	B	4	121.5	30.375	1.229167			
7								
8								
9	ANOVA							
10	*ce of Varic*	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	
11	Between (	7.03125	1	7.03125	6.818182	0.040058	5.987378	
12	Within Gr	6.1875	6	1.03125				
13								
14	Total	13.21875	7					

Go to the next slide

540

Significance testing: example 1 ANOVA (cont'd)

541

Cleaned up Excel output

	A	B	C	D	E	F	G	H
1	Anova: Single Factor							
2								
3	SUMMARY							
4	Groups	Count	**Average**					
5	A	4	**28.5**					
6	B	4	**30.4**					
7								
8								
9	ANOVA							
10	Source of Variation	SS	df	MS	F	**P-value**	←	
11	Between Groups	7.03	1	7.03	6.82	**0.0401**		
12	Within Groups	6.19	6	1.03				

P value	The probability that there is no difference between the populations.
	The probability that there is no difference in average diameter between machines A and B. The sample is used to infer a difference in the machines' performance.

541

Interpreting P values - "Statistical Standard of Evidence"

542

Probability of NO difference or correlation (P value)	Level of evidence that samples ARE different or variables ARE correlated	Confidence level (CL) for difference/correlation
1.00 – 0.15	None	None
0.15 – 0.05	Some	85% ≤ CL < 95%
0.05 – 0.01	Strong	95% ≤ CL < 99%
0.01 & lower toward zero	Very Strong	CL ≥ 99%

542

Significance testing: example 1 ANOVA (cont'd)

543

	A	B	C	D	E	F	G	H
1	Anova: Single Factor							
2								
3	SUMMARY							
4	Groups	Count	**Average**					
5	A	4	**28.5**	←				
6	B	4	**30.4**					
7								
8								
9	ANOVA							
10	Source of Variation	SS	df	MS	F	**P-value**		
11	Between Groups	7.03	1	7.03	6.82	**0.0401**	←	
12	Within Groups	6.19	6	1.03				
13								

- In this example, the P value is 0.0401
- There is *strong evidence* of a difference between the samples
- Based on this analysis, we expect that parts molded on machine B will have larger diameters than parts molded on machine A

543

Notes on p-values, confidence, and false-positives

544

It may seem odd that P values are defined in relation to hypotheses of *no* difference or *no* correlation. This practice evolved from an emphasis in applied scientific research on preventing false positives (i.e., concluding there is a difference or correlation when there really isn't).

When communicating significance testing results to those unfamiliar with P values, it can be less confusing to express the evidence supporting differences or correlations in terms of confidence levels. The levels shown on the P value interpretation chart are also analogous to legal standards of evidence used in court trials: Some — a preponderance of evidence; Strong — clear and convincing evidence; Very strong — beyond a reasonable doubt.

In process development and improvement, we are concerned about false positives, but we should also be concerned about false negatives (i.e., concluding there is no difference or correlation when there really is). False negatives are missed opportunities. Allowing the "preponderance of evidence" standard in our decision-making reduces the chance of missed opportunities when large sample sizes are not feasible (although performing a sample size calculation is *always* recommended). We'll circle back to this topic in the Improve phase.

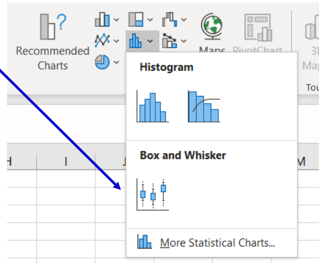
544

Displaying the data graphically using Box and Whisker Plots

545

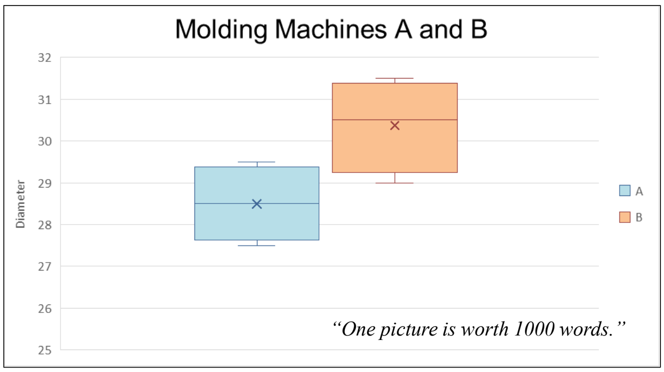
1. Highlight the two columns for molding Machines A&B
2. Navigate to the Insert Ribbon and then the Charts section
3. Choose the Insert Statistics Chart dropdown and then the Box and Whisker plot

E	F
A	B
27.5	31.0
29.0	29.0
28.0	31.5
29.5	30.0



Displaying the data graphically Using Box and Whisker Plots (cont'd)

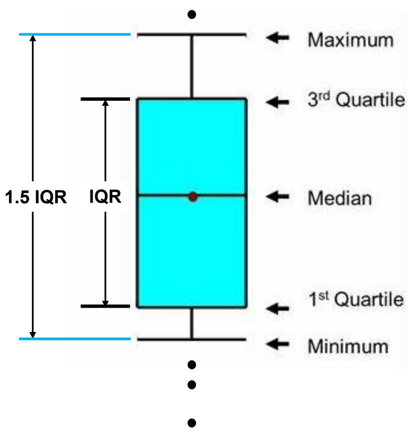
546



- Edit legends, titles, etc. as desired.
- Rule of thumb – if the median line for one data set is outside of the box of the other data set, then the two samples are significantly different
- If we wanted to reduce the overall variation in diameter, would we focus on within or between machine variation first? What follow up action is needed here?

Anatomy of a Box and Whisker Plot

547



- Box and Whisker plots display data distributions based on Quartiles.
- The data is divided in four equal parts, with the Box drawn from Q1 (25%) to Q3 (75%).
- The Median line is drawn at Q2 (50%).
- The Mean (aka Average) may also be marked (with a dot, x, etc.).
- The Inner Quartile Range (IQR) provides a robust measure of spread.
- The Min/Max Whiskers are drawn at the lowest/highest of the *actual* data points inside (1.5)IQR.
- Outliers are defined as data falling outside the range Q1 – (1.5)IQR and Q3 + (1.5)IQR.

547

Exercise 27.2

548

Open *Data Sets* → *number & size of defects*. Is there a significant difference in *Max size* between welders A and B?

a) Identify the data types for the X and Y variables, then perform the appropriate analysis.

b) Give the P value and its interpretation in terms of standards of evidence.

c) Create an appropriate chart to illustrate the analysis.

d) Describe an appropriate follow-up to this analysis.

e) Close and save the data set.

548

Significance testing: example 2 Chi Square

549

Comparing samples with pass/fail Y

• During process observation, a suspicion was raised that the defect rate at ATE* had decreased in the last month.

• Based on the data, it looks like this could be the case.

• But is it a statistically significant difference?

Process	Sample size	No. Failed	% Defective
March	10760	2277	21.16
April	8748	1809	20.68

*from *Data Sets \ ATE Mar & Apr*

549

Significance testing: example 2 Chi Square (cont'd)

550

• Open *Student Files* → *calculator - chi square test*

• Fill out the *2 groups* sheet as shown

Note that the Group Labels can be changed

Columns F-J are hidden

	A	B	C	D	E	K
1		Defective?		Sample size		
2	Group labels	Yes	No		% Defective	P-value
3	March	2277	8483	10760	21.16	**0.4099**
4	April	1809	6939	8748	20.68	
5	Totals	4086	15422	19508		

P value	
	The probability that there is no difference between the populations.
	The probability that that there is no difference in the defect rate between March and April.

550

Interpreting P values - “Statistical Standard of Evidence”

551

Probability of NO difference or correlation (P value)	Level of evidence that samples ARE different or variables ARE correlated	Confidence level (CL) for difference/correlation
1.00 – 0.15	None	None
0.15 – 0.05	Some	85% ≤ CL < 95%
0.05 – 0.01	Strong	95% ≤ CL < 99%
0.01 & lower toward zero	Very Strong	CL ≥ 99%

551

Significance testing: example 2 Chi Square (cont’d)

552

- In this example for ATE defect rate, the P value is 0.4099
- There is *no evidence* of a difference between the samples
- Based on this analysis, the team should not investigate differences based on month any further but should test other X variables for significant differences.

552

Exercise 27.3

553

Open *Data Sets* → *supplier comparison*. This file contains defect data for raw material lots from suppliers A and B. Is there a significant difference between these suppliers?

a) Identify the data types for the X and Y variables, then perform the appropriate analysis.

b) Give the P value and its interpretation in terms of standards of evidence.

c) There is something in this data set that casts doubt on your conclusion in (b). Make a pivot table with *Supplier* as the *Column Label*, *Inspector* as the *Row label*, and Result in the *Values* area. What is the potential issue?

d) Close and save the data set.

Notes

554

Significance testing: example 3 Regression

555

Correlating quantitative X and Y variables

If we reduce our billing lead time, will we get paid sooner?

1. Open *Data Sets → significance testing examples*
2. Highlight column B

	A	B	C
1	**Billing LT (days)**	**Avg. Days in AR**	
2	1	58.9	
3	2	59.6	
4	3	59.1	
5	4	59.7	
6			

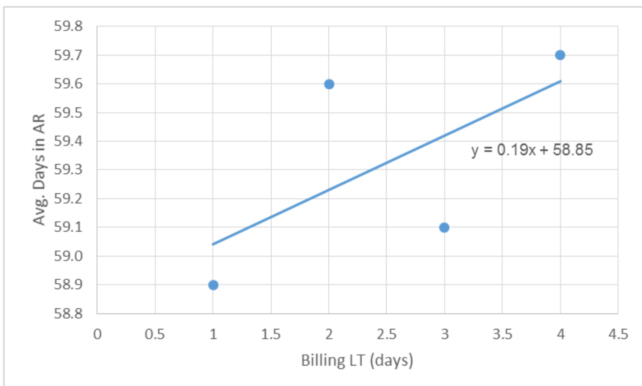
3. Highlight column A while holding down the **Shift** key
4. **Insert → Scatter plot**
5. Right click on a data point → **Add Trendline** → **Fill & Line** (looks like a bucket) → Solid line → Dash type → Solid → **Trendline Options** (looks like a bar chart) → Display equation on chart
6. See next slide

Significance testing: example 3 Regression (cont'd)

556

7. Click on the graph, select **Chart Tools → Design**
8. Select **Add Chart Element → Axis Titles → Primary Horizontal** and **Primary Vertical**

- It looks like there may be a correlation, but appearances can be deceiving!
- We need to calculate the P value before we know for sure



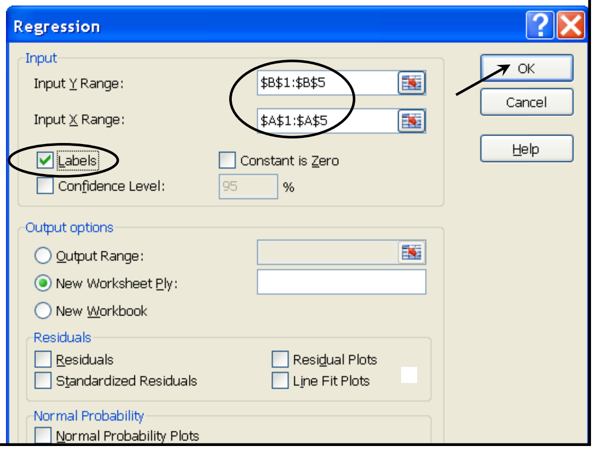
Significance testing: example 3 Regression (cont'd)

557

	A	B
1	Billing LT (days)	Avg. Days in AR
2	1	58.9
3	2	59.6
4	3	59.1
5	4	59.7
6		

Select the labels & data only (not whole column).
Columns must be contiguous.

Data
↓
Data Analysis
↓
Regression
↓
set up as shown
↓
OK



Significance testing: example 3 Regression (cont'd)

558

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.63509996
R Square	0.40335196
Adjusted R Square	0.10502793
Standard Error	0.36537652
Observations	4

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.1805	0.1805	1.35206	0.364900043
Residual	2	0.267	0.1335		same
Total	3	0.4475			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	58.85	0.447493017	131.51	5.8E-05	56.92459295	60.77540705	56.92459295	60.77540705
Billing Lead Time	0.19	0.163401346	1.16278	0.3649	-0.513059249	0.893059249	-0.513059249	0.893059249

P value	
	The probability that there is no correlation between X and Y.
	The probability of no correlation between billing lead time and days in accounts receivable

Interpreting P values - “Statistical Standard of Evidence”

559

Probability of NO difference or correlation (P value)	Level of evidence that samples ARE different or variables ARE correlated	Confidence level (CL) for difference/correlation
1.00 – 0.15	None	None
0.15 – 0.05	Some	85% ≤ CL < 95%
0.05 – 0.01	Strong	95% ≤ CL < 99%
0.01 & lower toward zero	Very Strong	CL ≥ 99%

559

Interpreting P values (and other stuff) for correlation

560

SUMMARY OUTPUT

Regression Statistics	
Adjusted R Square	**0.1050**
Standard Error	**0.3654**
Observations	4

- In this example, only 10.5% of the variation in Y is caused by variation in X
- This is one standard deviation of the data variation above and below the trend line

ANOVA

	df	*SS*	*MS*	*F*	***P-value***
Regression	1	0.1805	0.1805	1.35206	**0.3649**
Residual	2	0.267	0.1335		
Total	3	0.4475			

- The P value is 0.3649
- There is no evidence of a correlation between billing lead time and days in AR
- The trend line is of no use when there is no evidence of a correlation

560

Exercise 27.4

561

Open *Data Sets* → *DPPM vs dwell time*. Is DPPM correlated with *dwell time*?

a) Identify the data types for the X and Y variables, then perform the appropriate analysis.

b) Give the P value and its interpretation in terms of standards of evidence.

c) Create an appropriate chart to illustrate the analysis.

d) Describe an appropriate follow-up to this analysis.

e) Close and save the data set.

Exercise 27.5

562

Open *Data Sets* → *number & size of defects*. Someone hypothesizes that *Max size* (the size of the largest weld repair area) depends on *# Defects* (the number of weld repair areas).

a) Identify the data types for the X and Y variables, then perform the appropriate analysis.

b) Give the P value and its interpretation in terms of standards of evidence.

c) Create an appropriate chart to illustrate the analysis.

d) Describe an appropriate follow-up to this analysis.

e) Close and save the data set.

Exercise 27.6

563

Open *Data Sets* → *computer chips*. Is Y correlated with X?

a) Identify the data types for the X and Y variables, then perform the appropriate analysis.

b) Give the P value and its interpretation in terms of standards of evidence.

c) Create an appropriate chart to illustrate the analysis.

d) Describe an appropriate follow-up to this analysis.

e) Close and save the data set.

563

Notes

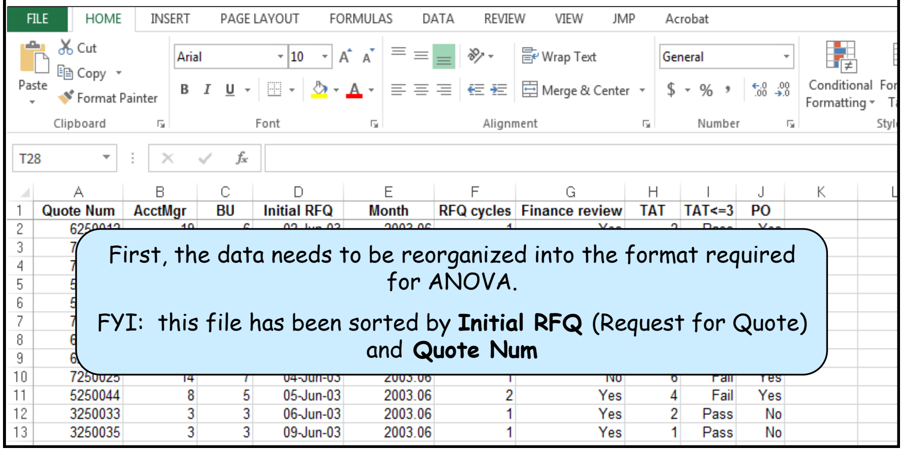
564

564

28 Stratification Analysis — Quantitative Y

Open *Student Files* → *Case Studies* → *quotation process* → *unstacked quotation process current state*

We want to test for significant differences among the business units (BUs) with respect to turnaround time (TAT)



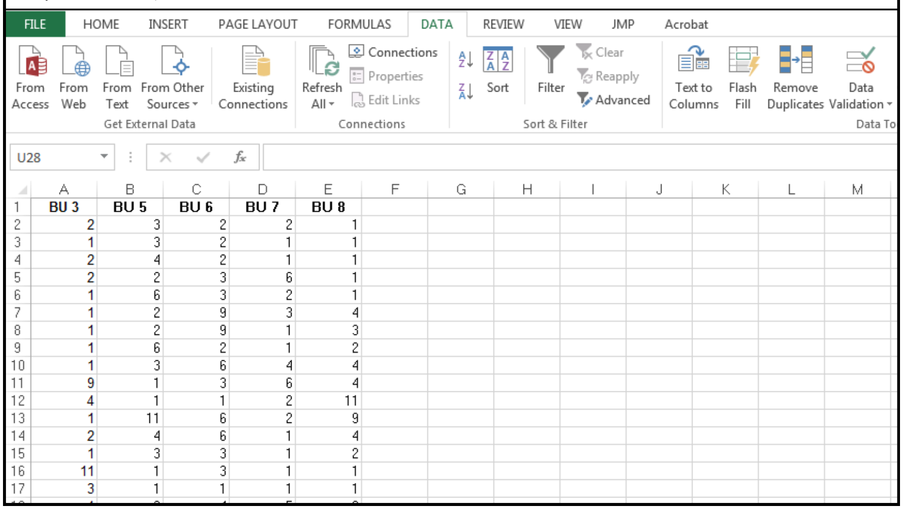
Quote Num	AcctMgr	BU	Initial RFQ	Month	RFQ cycles	Finance review	TAT	TAT<=3	PO
7250025	14	7	04-Jun-03	2003.06	1	No	6	Fail	Yes
5250044	8	5	05-Jun-03	2003.06	2	Yes	4	Fail	Yes
3250033	3	3	06-Jun-03	2003.06	1	Yes	2	Pass	No
3250035	3	3	09-Jun-03	2003.06	1	Yes	1	Pass	No

First, the data needs to be reorganized into the format required for ANOVA.

FYI: this file has been sorted by **Initial RFQ** (Request for Quote) and **Quote Num**

Stratification with quantitative Y (cont'd)

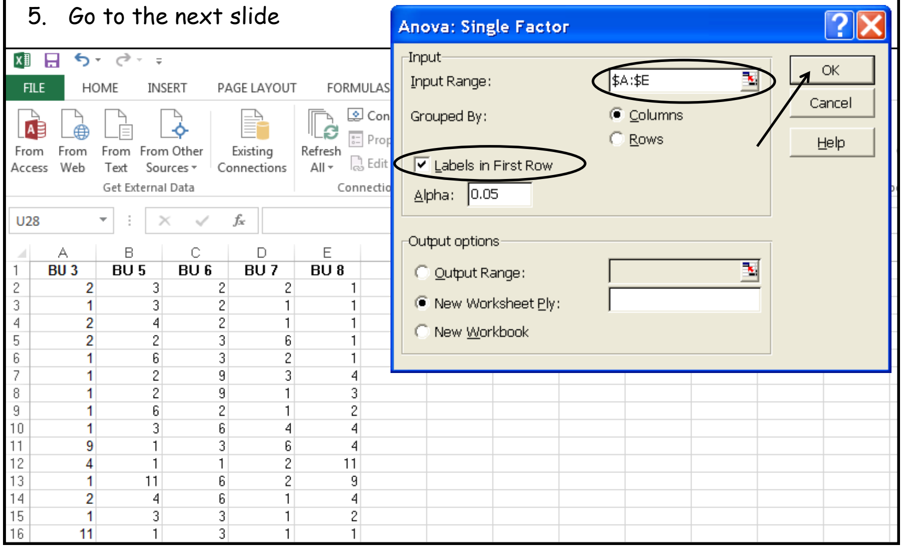
1. Click on tab "TAT by BU" to find this worksheet of reorganized data. (For your reference, instructions for creating this worksheet can be found at the end of this section.)
2. Go to the next slide



BU 3	BU 5	BU 6	BU 7	BU 8
2	3	2	2	1
1	3	2	1	1
2	4	2	1	1
2	2	3	6	1
1	6	3	2	1
1	2	9	3	4
1	2	9	1	3
1	6	2	1	2
1	3	6	4	4
9	1	3	6	4
4	1	1	2	11
1	11	6	2	9
2	4	6	1	4
1	3	3	1	2
11	1	3	1	1
3	1	1	1	1

Stratification with quantitative Y (cont'd) 567

3. Go to the **Data** ribbon, select **Data Analysis**, select **Anova: Single Factor**
4. Fill out as shown here, click OK
5. Go to the next slide

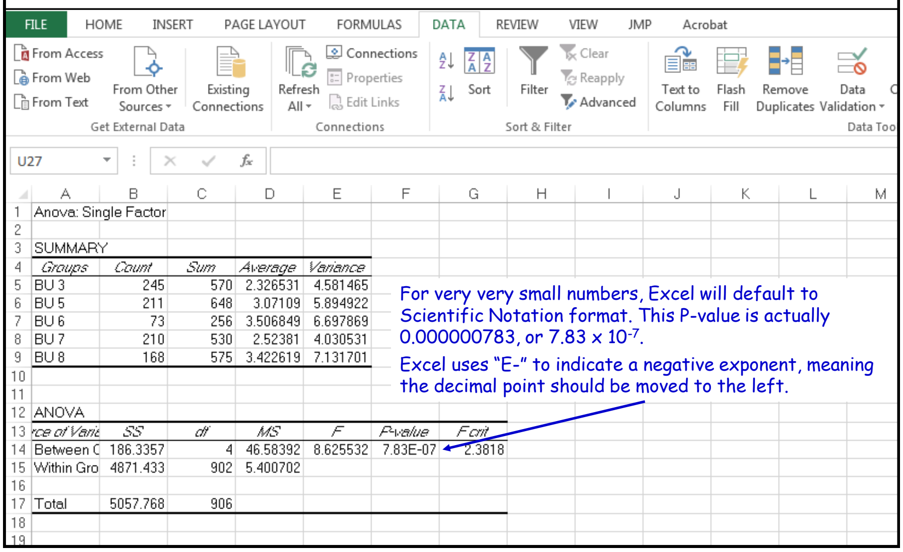


	A	B	C	D	E
1	BU 3	BU 5	BU 6	BU 7	BU 8
2	2	3	2	2	1
3	1	3	2	1	1
4	2	4	2	1	1
5	2	2	3	6	1
6	1	6	3	2	1
7	1	2	9	3	4
8	1	2	9	1	3
9	1	6	2	1	2
10	1	3	6	4	4
11	9	1	3	6	4
12	4	1	1	2	11
13	1	11	6	2	9
14	2	4	6	1	4
15	1	3	3	1	2
16	11	1	3	1	1

567

Stratification with quantitative Y (cont'd) 568

6. Here is the unedited default output
7. Go to the next slide for the cleaned-up output



	A	B	C	D	E	F	G
1	Anova: Single Factor						
2							
3	SUMMARY						
4	*Groups*	*Count*	*Sum*	*Average*	*Variance*		
5	BU 3	245	570	2.326531	4.581465		
6	BU 5	211	648	3.07109	5.894922		
7	BU 6	73	256	3.506849	6.697869		
8	BU 7	210	530	2.52381	4.030531		
9	BU 8	168	575	3.422619	7.131701		
10							
11							
12	ANOVA						
13	*rce of Varia*	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
14	Between G	186.3357	4	46.58392	8.625532	7.83E-07	2.3818
15	Within Gro	4871.433	902	5.400702			
16							
17	Total	5057.768	906				

For very very small numbers, Excel will default to Scientific Notation format. This P-value is actually 0.000000783, or 7.83×10^{-7}.

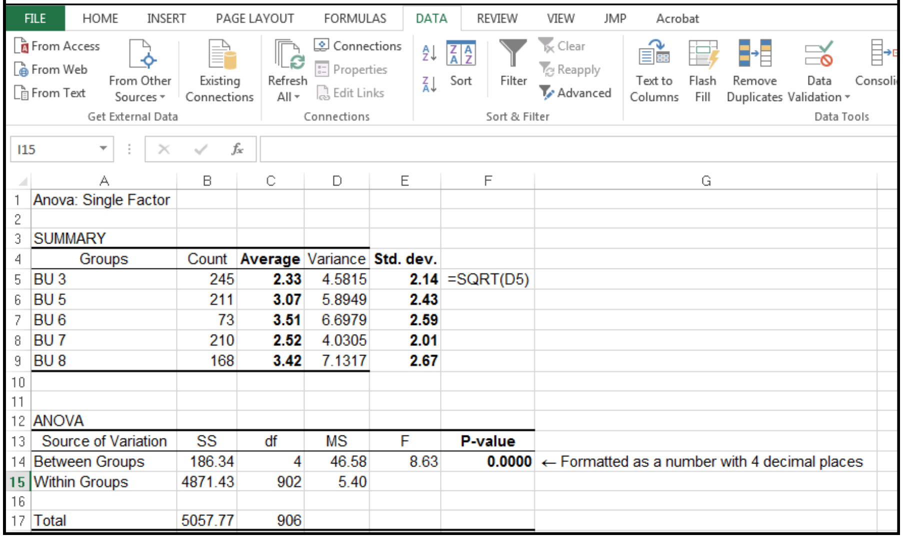
Excel uses "E-" to indicate a negative exponent, meaning the decimal point should be moved to the left.

568

Stratification with quantitative Y (cont'd)

569

8. Very strong evidence of differences among the five BUs with respect to TAT
9. See next slide for a column chart of the averages



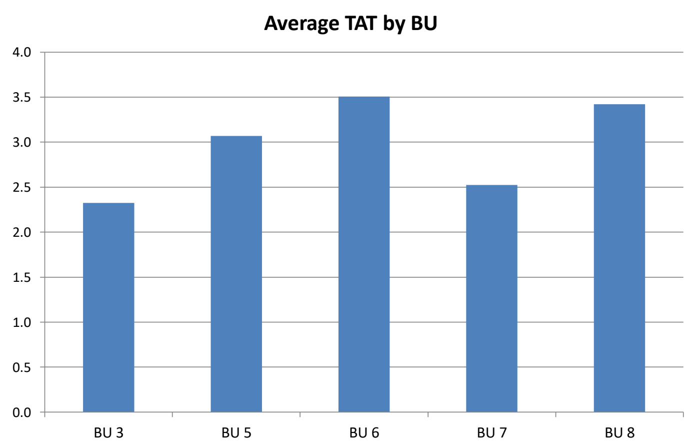
	A	B	C	D	E	F	G
1	Anova: Single Factor						
2							
3	SUMMARY						
4	Groups	Count	**Average**	Variance	**Std. dev.**		
5	BU 3	245	**2.33**	4.5815	**2.14**	=SQRT(D5)	
6	BU 5	211	**3.07**	5.8949	**2.43**		
7	BU 6	73	**3.51**	6.6979	**2.59**		
8	BU 7	210	**2.52**	4.0305	**2.01**		
9	BU 8	168	**3.42**	7.1317	**2.67**		
10							
11							
12	ANOVA						
13	Source of Variation	SS	df	MS	F	**P-value**	
14	Between Groups	186.34	4	46.58	8.63	**0.0000**	← Formatted as a number with 4 decimal places
15	Within Groups	4871.43	902	5.40			
16							
17	Total	5057.77	906				

569

Stratification with quantitative Y (cont'd)

570

10. BUs 3 and 7 represent best practice. Follow up: find out what they are doing and make it the standard for all BUs.
11. Close and save your workbook .



570

Exercise 28.1

571

Open *Data Sets* → *alignment process*. Three alignment tools of the same type are used to attach orifice plates to chips. We want to know if there are significant differences among the three tools in terms of radial alignment error *R dev*.

(a) Test for significant differences in average *R dev* among the 3 aligners. (Data is arranged for ANOVA under tab *R dev by Aligner*.) Give the P value and its interpretation in terms of standards of evidence.

(b) Smaller *R dev* is better. Which aligner represents best practice? Describe the appropriate follow up action.

(c) Create an appropriate chart to illustrate the analysis.

(d) Close and save the data set.

571

Exercise 28.2

572

Open *Data Sets* → *casting dimensions*. Metal parts are cast from wax patterns molded on machines A or B. We want to know if there is a significant difference in average casting dimensions depending on which machine molded the pattern.

a) Test for a significant difference in average *length* between machines A and B. Give the P value and its interpretation in terms of standards of evidence.

b) The target value for *length* is 600. Which machine is closer to target?

c) Create an appropriate chart to illustrate the *length* analysis.

572

Exercise 28.2 (cont'd)

573

d) Test for a significant difference in average *diam* between machines A and B. Give the P value and its interpretation in terms of standards of evidence.

e) The target value for *diam* is 50. Which machine is closer to target?

f) Create an appropriate chart to illustrate the *diam* analysis.

g) Describe an appropriate follow up action.

h) Close and save the data set.

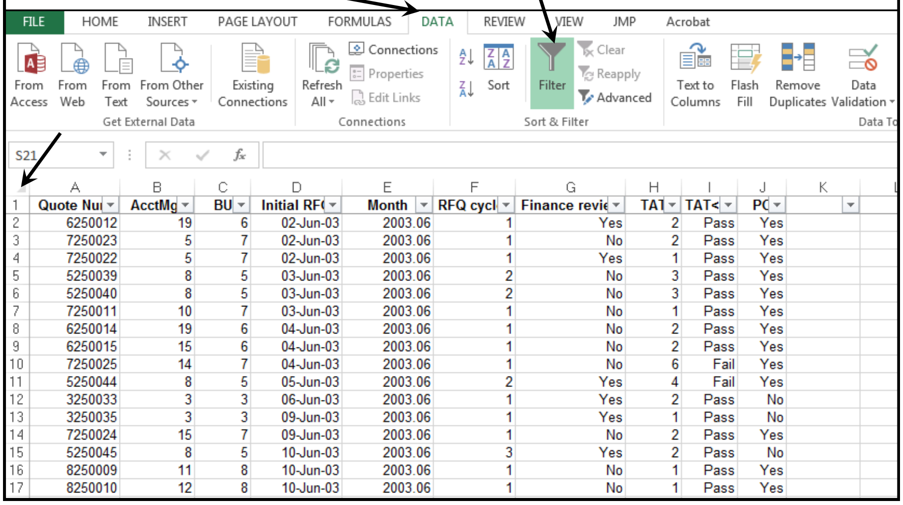
573

Example: Unstacking Data using Filtering

574

<u>For reference only:</u>

1. Highlight BU column
2. Select the **Data** ribbon
3. Select **Filter**
4. Go to the next slide



	Quote Nu	AcctMg	BU	Initial RF(	Month	RFQ cycl	Finance revie	TAT	TAT<	PC
2	6250012	19	6	02-Jun-03	2003.06	1	Yes	2	Pass	Yes
3	7250023	5	7	02-Jun-03	2003.06	1	No	2	Pass	Yes
4	7250022	5	7	02-Jun-03	2003.06	1	Yes	1	Pass	Yes
5	5250039	8	5	03-Jun-03	2003.06	2	No	3	Pass	Yes
6	5250040	8	5	03-Jun-03	2003.06	2	No	3	Pass	Yes
7	7250011	10	7	03-Jun-03	2003.06	1	No	1	Pass	Yes
8	6250014	19	6	04-Jun-03	2003.06	1	No	2	Pass	Yes
9	6250015	15	6	04-Jun-03	2003.06	1	No	2	Pass	Yes
10	7250025	14	7	04-Jun-03	2003.06	1	No	6	Fail	Yes
11	5250044	8	5	05-Jun-03	2003.06	2	Yes	4	Fail	Yes
12	3250033	3	3	06-Jun-03	2003.06	1	Yes	2	Pass	No
13	3250035	3	3	09-Jun-03	2003.06	1	Yes	1	Pass	No
14	7250024	15	7	09-Jun-03	2003.06	1	No	2	Pass	Yes
15	5250045	8	5	10-Jun-03	2003.06	3	Yes	2	Pass	No
16	8250009	11	8	10-Jun-03	2003.06	1	No	1	Pass	Yes
17	8250010	12	8	10-Jun-03	2003.06	1	No	1	Pass	Yes

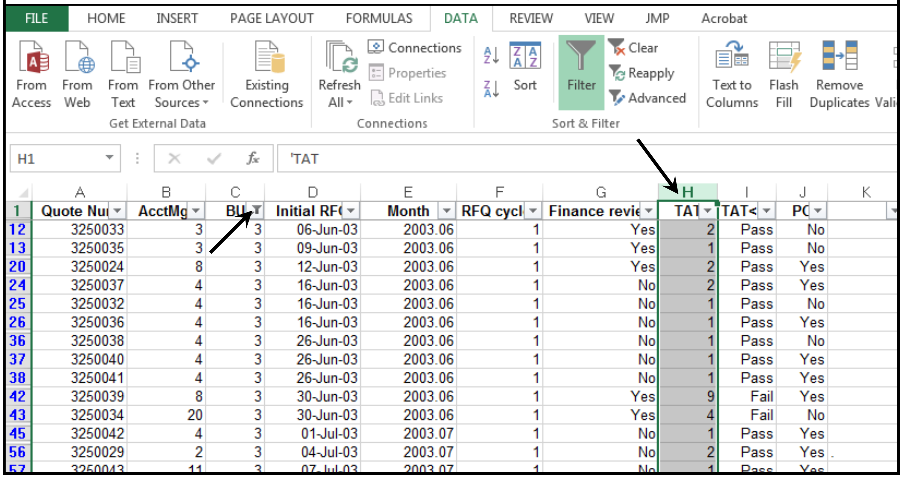
574

Example: Unstacking Data using Filtering (cont'd)

575

For reference only:

5. Highlight the TAT column (H)
6. Click on the arrowhead next to the BU header in column C
7. Deselect all but BU 3 → OK
8. Right click on the TAT column
9. Select **Copy**
10. Go to the next slide



	Quote Nu	AcctMg	BU	Initial RF	Month	RFQ cycl	Finance revie	TAT	TAT<	PC
12	3250033	3	3	06-Jun-03	2003.06	1	Yes	2	Pass	No
13	3250035	3	3	09-Jun-03	2003.06	1	Yes	1	Pass	No
20	3250024	8	3	12-Jun-03	2003.06	1	Yes	2	Pass	Yes
24	3250037	4	3	16-Jun-03	2003.06	1	No	2	Pass	Yes
25	3250032	4	3	16-Jun-03	2003.06	1	No	1	Pass	No
26	3250036	4	3	16-Jun-03	2003.06	1	No	1	Pass	Yes
36	3250038	4	3	26-Jun-03	2003.06	1	No	1	Pass	No
37	3250040	4	3	26-Jun-03	2003.06	1	No	1	Pass	Yes
38	3250041	4	3	26-Jun-03	2003.06	1	No	1	Pass	Yes
42	3250039	8	3	30-Jun-03	2003.06	1	Yes	9	Fail	Yes
43	3250034	20	3	30-Jun-03	2003.06	1	Yes	4	Fail	No
45	3250042	4	3	01-Jul-03	2003.07	1	No	1	Pass	Yes
56	3250029	2	3	04-Jul-03	2003.07	1	No	2	Pass	Yes
57	3250043	11	3	07-Jul-03	2003.07	1	No	[illegible]	Pass	Yes

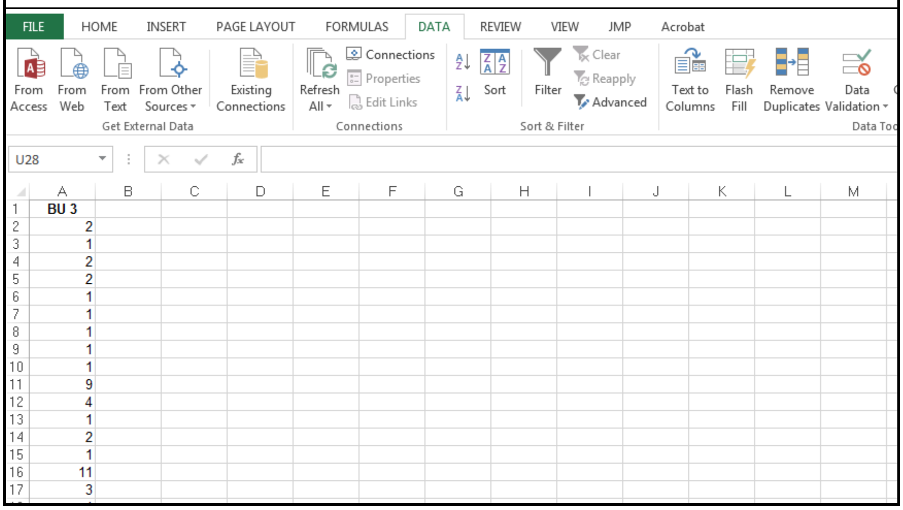
575

Example: Unstacking Data using Filtering (cont'd)

576

For reference only:

11. Create a blank worksheet, **Paste** in cell A1
12. Change the header in cell A1 as shown below
13. Repeat steps 7 through 12 for BUs 5, 6, 7, and 8



	A
1	BU 3
2	2
3	1
4	2
5	2
6	1
7	1
8	1
9	1
10	1
11	9
12	4
13	1
14	2
15	1
16	11
17	3

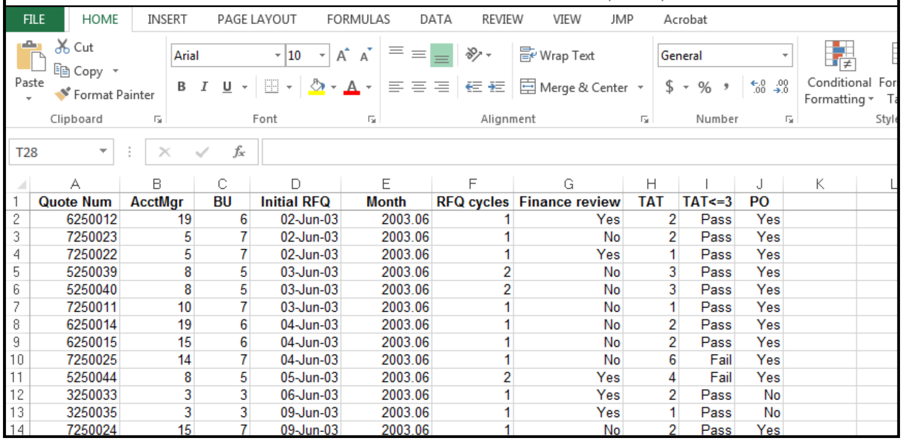
576

29 Stratification Analysis — Pass/Fail Y

577

Open *Student Files → Case Studies → quotation process → quotation process current state*

We want to test for significant differences among the business units (BUs) with respect to PO hit rate



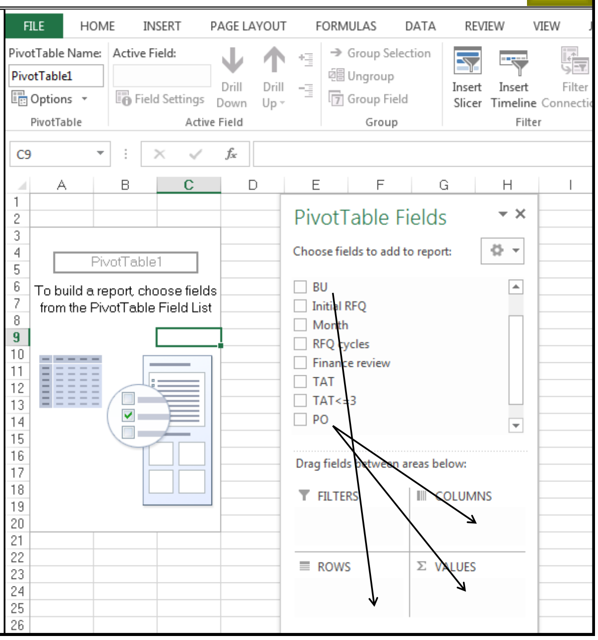
	Quote Num	AcctMgr	BU	Initial RFQ	Month	RFQ cycles	Finance review	TAT	TAT<=3	PO
2	6250012	19	6	02-Jun-03	2003.06	1	Yes	2	Pass	Yes
3	7250023	5	7	02-Jun-03	2003.06	1	No	2	Pass	Yes
4	7250022	5	7	02-Jun-03	2003.06	1	Yes	1	Pass	Yes
5	5250039	8	5	03-Jun-03	2003.06	2	No	3	Pass	Yes
6	5250040	8	5	03-Jun-03	2003.06	2	No	3	Pass	Yes
7	7250011	10	7	03-Jun-03	2003.06	1	No	1	Pass	Yes
8	6250014	19	6	04-Jun-03	2003.06	1	No	2	Pass	Yes
9	6250015	15	6	04-Jun-03	2003.06	1	No	2	Pass	Yes
10	7250025	14	7	04-Jun-03	2003.06	1	No	6	Fail	Yes
11	5250044	8	5	05-Jun-03	2003.06	2	Yes	4	Fail	Yes
12	3250033	3	3	06-Jun-03	2003.06	1	Yes	2	Pass	No
13	3250035	3	3	09-Jun-03	2003.06	1	Yes	1	Pass	No
14	7250024	15	7	09-Jun-03	2003.06	1	No	2	Pass	Yes

577

Stratification with pass/fail Y (cont'd)

578

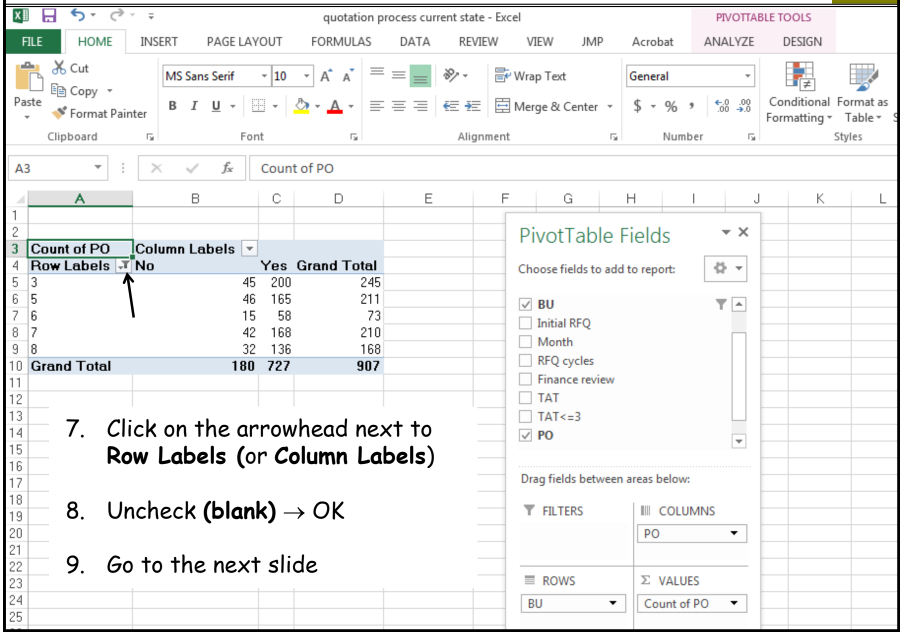
1. Highlight all columns
2. Insert → PivotTable → OK
3. Drag/drop **BU** to the **Rows** area
4. Drag/drop **PO** to the **Columns** area
5. Drag/drop **PO** to the **Values** area
6. Go to the next slide



578

Stratification with pass/fail Y (cont'd)

579



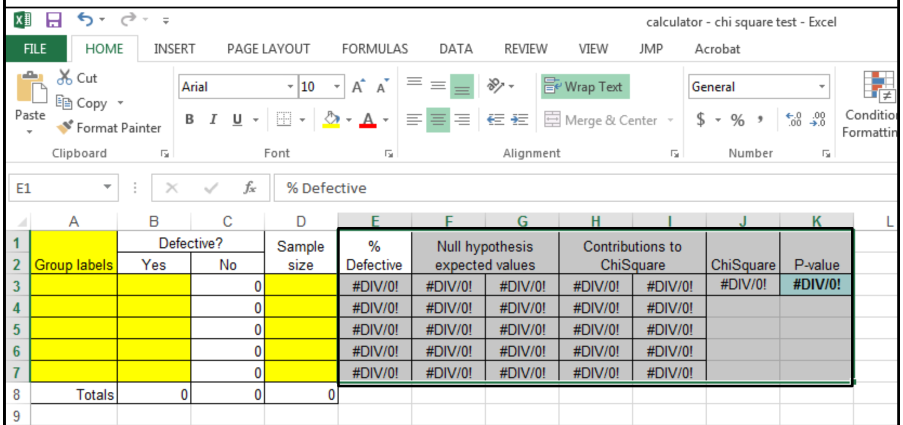
7. Click on the arrowhead next to **Row Labels** (or **Column Labels**)
8. Uncheck **(blank)** → OK
9. Go to the next slide

579

Stratification with pass/fail Y (cont'd)

580

10. Open ***Student Files → calculator - chi square test***
11. Select the **5 groups** sheet, select and copy the cell range shown below



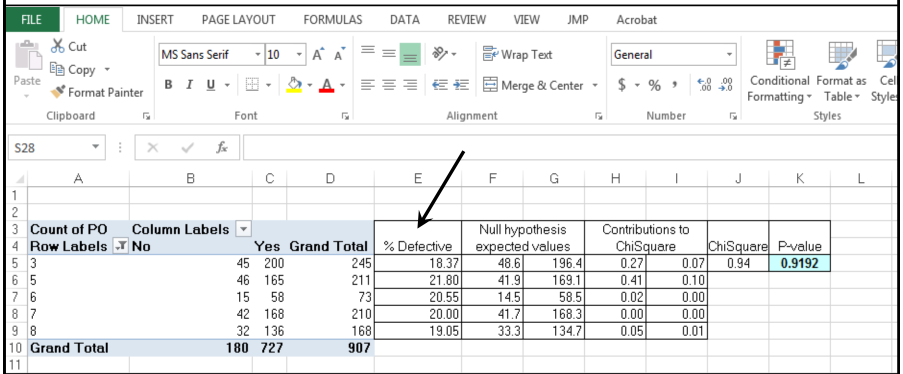
12. Go to the worksheet containing your pivot table
13. Go to the next slide

580

Stratification with pass/fail Y (cont'd)

14. Paste in cell **E3**

15. The P value is 0.9192. There is no evidence of differences among the BUs with respect to PO hit rate.



Count of PO	Column Labels				Null hypothesis expected values		Contributions to ChiSquare			
Row Labels	No	Yes	Grand Total	% Defective					ChiSquare	P-value
3	45	200	245	18.37	48.6	196.4	0.27	0.07	0.94	0.9192
5	46	165	211	21.80	41.9	169.1	0.41	0.10		
6	15	58	73	20.55	14.5	58.5	0.02	0.00		
7	42	168	210	20.00	41.7	168.3	0.00	0.00		
8	32	136	168	19.05	33.3	134.7	0.05	0.01		
Grand Total	180	727	907							

16. Note: for this calculator to work, your pivot table has to contain raw counts, **not** percentages of row totals.

17. Close and save your workbook.

Exercise 29.1

Open *Data Sets* → *ATE Mar & Apr*.

a) Test for significant differences in the Fail Result (aka % Defective) among the four test stations. Give the P value and its interpretation in terms of standards of evidence.

b) Based on the Fail Result for each test station, which pairs of stations appear to be statistically similar? Which pairs appear to be statistically different? Describe an appropriate follow up action.

c) Test for a significant difference between the two part numbers (P/N). Give the P value and its interpretation in terms of standards of evidence. Describe an appropriate follow up action.

d) Close and save the data set.

Exercise 29.2 (Read all instructions carefully!)

583

Open *Data Sets* → *out of box failures*. This file has tabulated pass/fail data of a customer's incoming inspection of purchased components. Set up your pivot table as shown on the **next slide**, then enter the values into the appropriate cells in *calculator – chi square test*. **(Pasting from the calculator to the pivot table won't work in this case because we're using sums.)**

a) Compare processes A, B, and C in terms of % failing. Give the P value and its interpretation in terms of standards of evidence.

b) Is there a significant difference between processes B and C? Give the P value and its interpretation in terms of standards of evidence. Describe an appropriate follow up action.

c) Create an appropriate chart to illustrate the *diam* analysis.

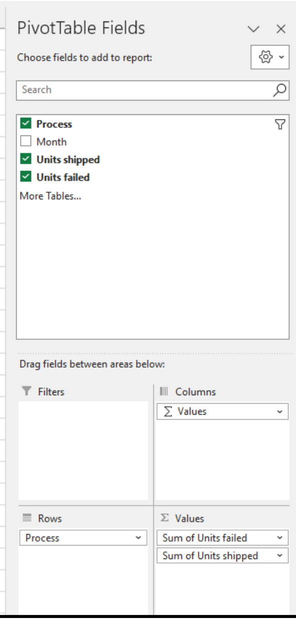
d) Close and save the data set.

583

Exercise 29.2 (cont'd)

584

Row Labels	Sum of Units failed	Sum of Units shipped
A	758	26344
B	418	31642
C	154	16824
Grand Total	**1330**	**74810**



584

Exercise 29.3 --Small group exercise

585

Open *Student Files → Case Studies → MBDP→ unstacked MBDP current state*. In your group, perform the stratification tests indicated in the table on the next slide:

a) Determine the type of Y data (PO-PD and MFG happy)

b) Determine the type of analysis for each. Find examples to follow.

c) Do the first one, the Sales row, together. Make sure everyone in the group knows how to do the analysis for the two types of data.

d) Assign one of the remaining rows to each group member.

e) Each group member performs the analysis on their row. (The fastest in the group can help others or pick up one more row, as needed.)

f) If there is at least *some* evidence of difference, or better ($P \leq 0.15$), identify the process participant with best practice.

g) Share results, so each person has a completed table of results.

h) Discuss the results. Where would you focus your efforts to make improvements?

585

Exercise 29.3 --Small group exercise (cont.)

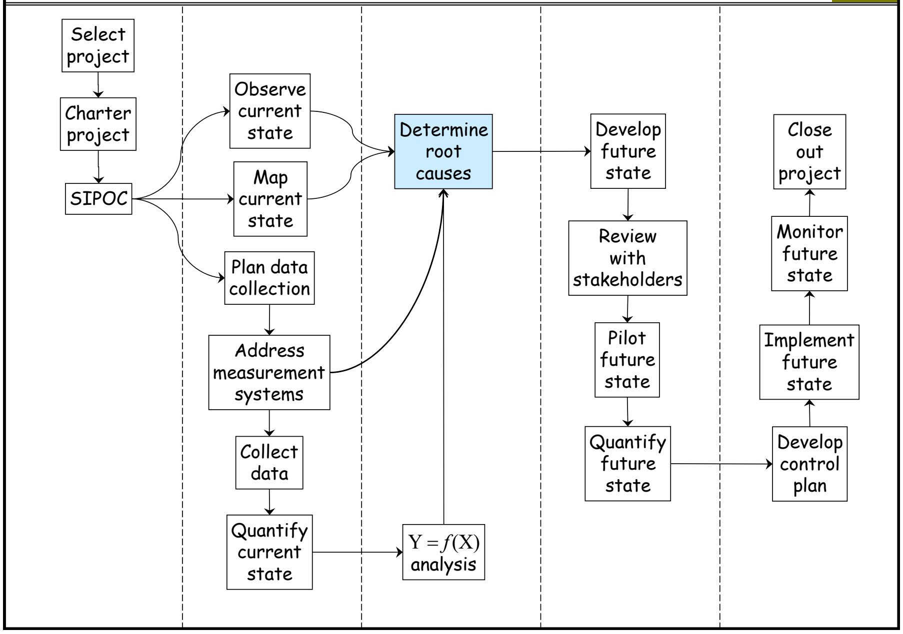
586

		Avg. PO-PD (P value)	Best practice (Who)	% MFG (P value)	Best practice (Who)
X's	Sales				
	PE				
	ME				
	QE				
	Drafter				
	Proto oper.				
	Baseline values:	29.5 days		49.4%	

586

30 Root Cause Analysis

587



Topics

588

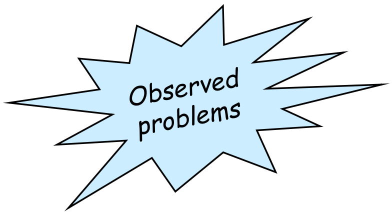
We'll discuss tools and techniques to use in conjunction with data analysis for identifying root causes:

- Failure Modes and Effects Analysis (FMEA)
- Multi-level Pareto Analysis
- Five Whys
- Five Whys/Cause and Effect Diagram based on $Y = f(X)$

Tools used in Root Cause Analysis

589

Usually we identify problems while mapping and observing the current state during the *Measure* phase

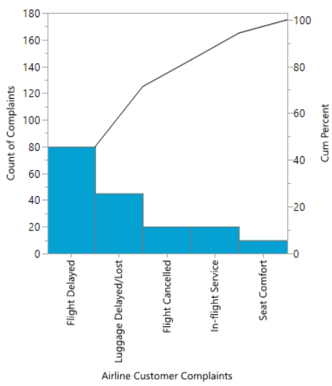


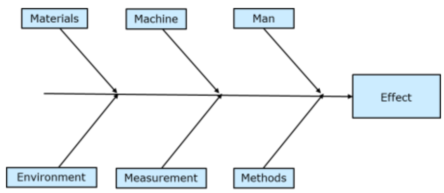
(aka opportunities for improvement)

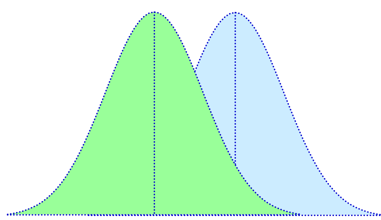
Tools used in Root Cause Analysis (cont.)

590

Analyses such as Cause & Effect diagrams, Pareto Charts and Testing for Statistical Significance point us in the direction of the root causes or critical x's







$p \leq 0.05$?

But, we usually need to dig deeper . . .

Failure Modes and Effects Analysis (FMEA)

591

FMEA can be used in the Analyze Phase to prioritize X's

- It is helpful at the *beginning* of the Analyze Phase:
  - to identify the X variables that are likely to have a significant impact on the primary metric Y, and to remove from consideration those that are deemed trivial
  - data collection and analysis are required for verification of prioritized failure modes, to validate their significant impact on Y, as FMEA is an opinion-based tool
- Actions for remedying failure modes with high RPNs (Risk Priority Numbers) are *not* discussed or taken in Analyze
- We will learn more about FMEA in the Improve Phase, where it is used to evaluate risk and prevent problems before they occur in the proposed process, per its original application.

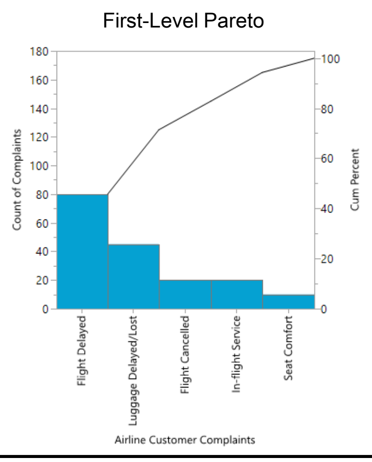
Process Functions	Requirements	Failure Modes	Effects	SEV	Causes	OCC	CN	Current Controls	DET	RPN
Reagent lot creation	New lot information distributed to OPS team	Printer malfunction	Delay in distribution to the OPS team	1	Electrical	1	**1**	One printer	1	**1**
Reagent creation	New reagent created based on processing demand	Operator error during manufacture of reagent	Processing delay, wasted sub-reagents, time lost, labor money	5	Did not use trained witness	1	**5**	SOP requires trained witness for procedure	1	**5**
Reagent storage	Storage of new reagent at point of use (laboratory)	Insufficent storage space in freezer or fridge	Reagent stock-out	4	Freezer space not reconciled	5	**20**	No control.	5	**100**

Example 1: Multi-Level Pareto Analysis

592

We can drill down to root causes using a series of Pareto Charts

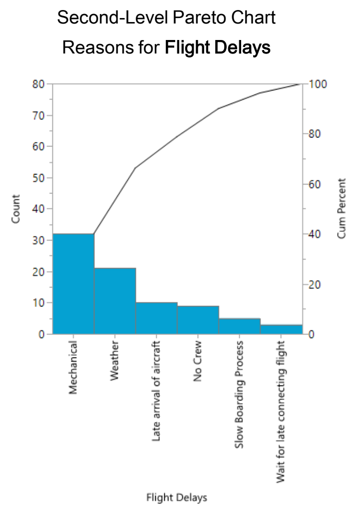
- From a first-level Pareto Chart, we can see which categories are contributing the most to our problem
- It's helpful to analyze the same categories based on Frequency, Cost &/or Time; using at least two is recommended



Example 1 (cont'd): Second-Level Pareto Chart

593

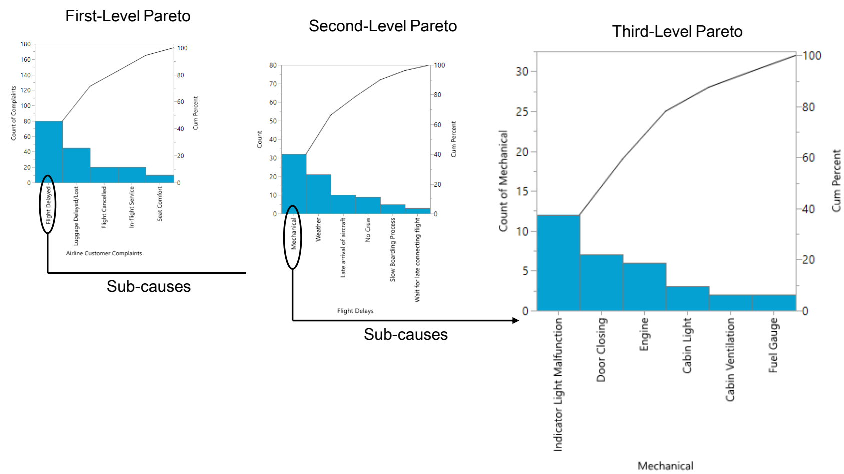
The highest bar(s) from the first-level Pareto can be broken down further into a second-level Pareto Chart:



Example 1 (cont'd): Multi-Level Pareto Analysis

594

By continuing to drill down, we can determine root causes of most frequently occurring defects.

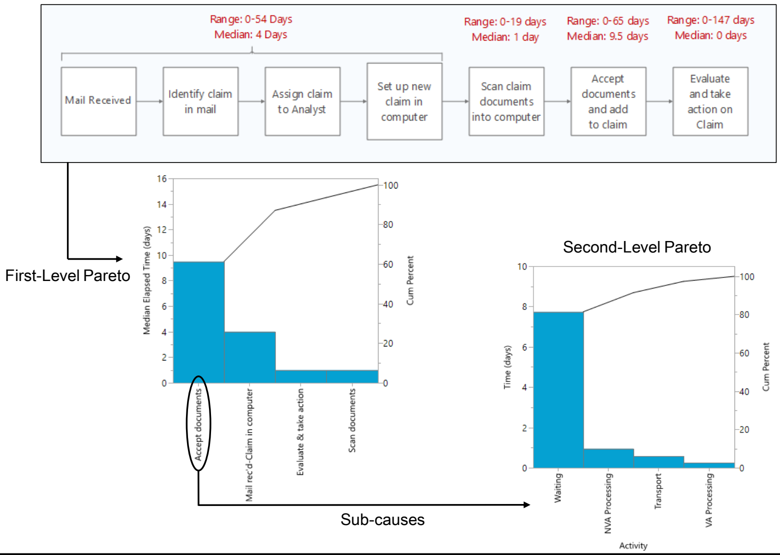


When data is not available for multi-level Pareto analysis, use the first-level Pareto Chart with 5 Whys to determine root causes.

Example 2: Multi-Level Pareto Analysis

595

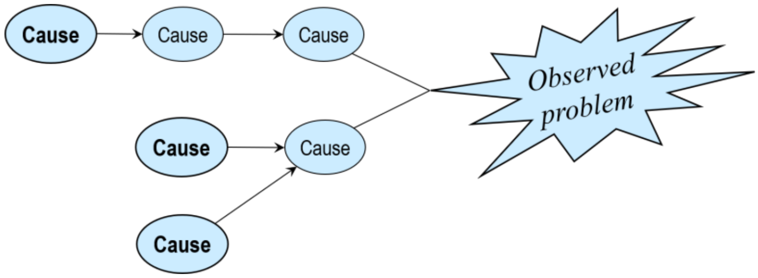
Lead time by high-level process step is measured:



5 Whys

596

- We work our way back to root causes by asking “why” questions



- This process is called “5 whys” because it usually takes no more than 5 questions
- The goal of 5 Whys is to get to a deep, actionable cause.

Getting to root cause with Five Whys

597

"The number of accidents in the plant was way up last month"

Do you know what caused the increase?	Workers are slipping and falling in Aisle 7 next to the molding machine.
Why are workers slipping and falling?	There's a puddle of water on the floor.
Where did the water on the floor come from?	It's dripping from the ceiling.
What caused it to start dripping from the ceiling?	A pane of glass is broken in the skylight.
How did the glass get broken?	A tree branch broke the glass during a storm.
How did the tree branch manage to hit the skylight?	The tree it came from was close to the building.

597

Exercise 30.1: Five Whys

598

- Your instructor will now lead you through a verbal exercise to practice the Five Whys technique.
- The instructor will make the opening statements and answer the questions.
- Class members will ask the questions.
- The instructor will indicate which class member is to ask the next question.

Please close your workbook now!

598

Exercise 30.1: Five Whys (cont'd) "There's too much scrap in the Coiling Department"	599
What kinds of defects are causing the scrap?	The vast majority are due to bad welds.
Why do we have so many bad welds?	The welders aren't very good.
Why aren't they very good?	Well, they're hired off the street, and they don't get much training.
You don't hire certified welders?	Are you kidding? We would have to pay them too much.
In that case, why aren't your welders given more training?	I don't know. I guess there isn't enough time. This is the way we've always done it.
Don't they get better as they become more experienced?	Well yeah, but they don't stay in this department long enough for that to help.

599

Exercise 30.1: Five Whys (cont'd) "There's too much scrap in the Coiling Department"	600
Why do they leave this department so soon?	There's another department where welders are used. As soon as there's an opening over there, everybody here applies for it.
Why are they so eager to work in the other department?	For one thing, the working conditions over there are much better. We have the highest accident rate in the company.
Is there another reason?	Over there they pay a dollar an hour more than here.

600

"I was late for work today."

601

Why were you late for work today?	I overslept.
Why did you oversleep?	My alarm didn't go off.
Why didn't your alarm go off?	The power went out last night.
Why did the power go out last night?	There was a thunderstorm.

What is wrong with this 5 Whys path?

If you get to a non-actionable root cause, back up and try to find a different path to an answer.

601

3 x 5 Whys

602

The best way to get to a deep, actionable root cause is to ask the 5 Whys at three different levels:

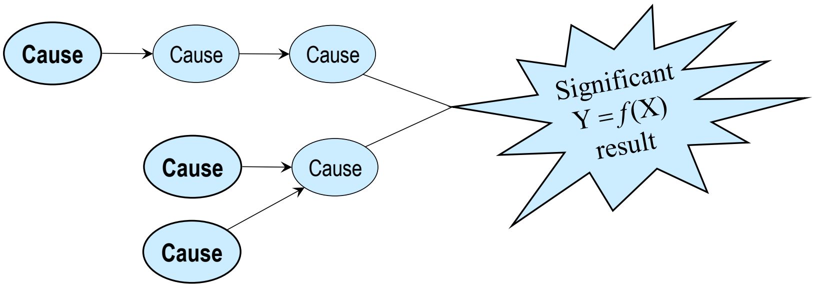
- Technical
  - ✓ Reason the problem occurs in terms of the physical chain of events that cause a process step to malfunction
- Escape
  - ✓ Reason the problem is not caught at the immediate process or work area (it "escapes" the intended controls)
- System
  - ✓ Underlying systemic reason(s) the problem occurs or is not caught (think in terms of organization-level structures and methodologies)

602

Five Whys based on $Y = f(X)$ analysis

603

- Data analysis provides the basis for penetrating questions
- After we have completed our $Y = f(X)$ analyses, we should interview process participants again to determine the causes of significant comparisons or correlations.
- 5 Whys and Cause and Effect (Fishbone) Diagrams are helpful "interviewing" tools.



603

Want to reduce external failures

604

Q "There is a significant correlation between dwell time and DPPM. What causes the variation in dwell time?"

A "The dwell time stretches out when operators are called away to do other things while they're getting ready to mold parts."

Q "Isn't there an upper spec on the dwell time?"

A "Yes. The operators are supposed to purge the tank if the dwell time gets too long, but they don't always do that."

Q . . .

Whenever we can collect data to verify the root cause found through 5 Whys, that should be done.

604

Want to reduce turnaround time

605

Q “The turnaround time is significantly longer for some account managers than for others. What do you think causes that?”

A “They don’t all use the same quotation preparation process.”

Q “Why not?”

A “There is no standard process. They have all developed their own way of doing it.”

Q . . .

Whenever observation can verify the root cause found through 5 Whys, that should be done

605

Want to reduce turnaround time (cont’d)

606

Q “The turnaround time is significantly longer for some business units than for others. What do you think causes that?”

A “Some of the business units aren’t using the automated configuration tool.”

Q “Why not?”

A . . .

Whenever observation or data collection can verify the root cause found through 5 Whys, that should be done.

606

Want to improve internal customer satisfaction

607

Q “The tool development process often results in slow line speeds and overweight material. What causes that?”

A “The testers slow the line down and increase the weight to get the dimensions on target.”

Q “Why do they use weight and line speed instead of other variables?”

A “They’re usually in a hurry. They’ve discovered that manipulating weight and line speed is the fastest way.”

Q . . .

Whenever observation or data collection can verify the root cause found through 5 Whys, that should be done.

Notes

608

Cause & Effect diagram revisited

609

It is important to note that Cause and Effect diagramming is a team process. Getting ideas from a variety of people involved in the process will be more effective than if one person tried to think of all the possibilities.

- This tool uses brainstorming, so remember to frame an open question and use clear ground rules.
- A good technique is to have people write ideas on sticky notes first (one idea per note), then place the notes under the appropriate heading.
- A facilitator should have some good prompts handy to help catalyze ideas.

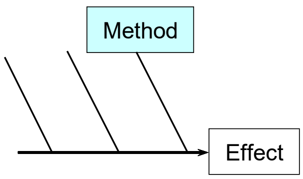
609

Cause & Effect Diagram — Questions

610

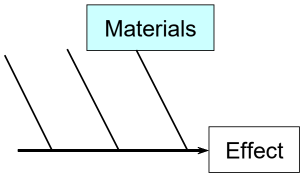
The **Method** category groups root causes related to how the work is done, the way the process is actually conducted:

Examples of questions to ask:
- Is the process adequately planned/designed?
- Are procedures correct, adequate, followed?
- Are checks in place?
- What might be an unusual situation?



The **Materials** category groups root causes related to parts, supplies, forms or information needed to execute a process:

Examples of questions to ask:
- Are bills of material current?
- Are parts or supplies obsolete?
- Are there defects in the materials?



610

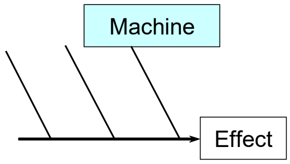
Cause & Effect Diagram — Questions

611

The **Machine** category groups root causes related to tools used in the process:

Examples of questions to ask:

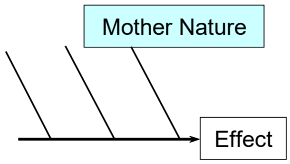
- Have machines been serviced/changed recently?
- Have equipment/tools been properly maintained?
- Are proper equipment/tools available?
- Is there machine to machine variation?



The **Environment** (a.k.a. Mother Nature) category groups root causes related to our work environment, market conditions, and regulatory issues.

Examples of questions to ask:

- Are there impacts from physical factors (temperature, humidity, lighting, particles, etc.)?
- Is the workplace safe and comfortable?
- Are outside regulations a factor?
- Does the company culture aid the process?



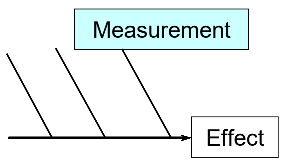
Cause & Effect Diagram — Questions

612

The **Measurement** category groups causes related to the measurement and measuring of a process activity or output:

Examples of questions to ask:

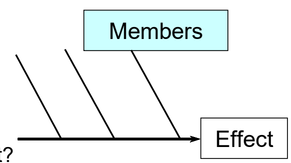
- Is there an appropriate measurement?
- Is there a valid measurement system?
- Is the data accurate &/or precise enough?
- Is data readily available?



The **Members** category groups root causes related to people, staffing, and organizations:

Examples of questions to ask:

- Are people trained properly, do they have the right skills and mental/physical capabilities?
- Is there person to person variation?
- Are people over–worked, stressed, etc.?
- Are short-cuts/noncompliance tolerated by management?



What if People are the Cause?

613

When considering variation from "Members," we have to dig deeper than a simple root cause of "operator error."

- A symptomatic "fix" of retraining a single operator won't necessarily prevent another person from making the same error.
- Training may not be an effective solution if the process itself is poorly designed, not documented, ineffective, etc.

613

Considering Human Factors

614

Studying human factors will be helpful in situations where the initial cause appears to be a person's behavior.

The FAA describes a simple method for categorizing human factor errors into two types:

- A **Mistake** happens when a person takes an action on purpose that is misguided or wrong, possibly due to an incorrect assumption, lack of understanding, misinterpretation, etc.
- A **Slip** is when a person plans to do one thing, but inadvertently does something else due to forgetfulness, confusion, time pressure, fatigue, etc.

Based on the Federal Aviation Administration's "Dirty Dozen"
https://www.faasafety.gov/files/gslac/library/documents/2012/Nov/71574/DirtyDozenWeb3.pdf

614

12 Common Causes of Human Factors Errors

615

Mistakes are often due to a lack of something:

1. Lack of Communication	Failure to transmit, receive, or provide sufficient feedback in order to complete a task.
2. Lack of knowledge	Failure to have training, information, &/or ability to conduct a task.
3. Lack of teamwork	Failure to work together to complete a shared goal.
4. Lack of Resources	Not having enough people, equipment, information, documentation, time, parts, materials, supplies, etc., to complete a task.
5. Lack of Assertiveness	Failure to speak up or otherwise document concerns about instructions/orders or actions of others.
6. Lack of awareness	Failure to recognize a situation, understand what it is, and predict the possible results.

615

12 Common Causes of Human Factors Errors

616

Slips are often due to the presence of something; often too much of it:

7. Complacency	Overconfidence from repeated experience on a specific activity.
8. Distractions	Anything that draws attention away from the task at hand; can be events or surrounding conditions.
9. Fatigue	Physical or mental exhaustion that threatens work performance.
10. Pressure	External or internal forces demanding high-level job performance; can be real or perceived.
11. Stress	Physical, emotional or chemical factor that causes physical or mental tension.
12. Norms	Expected, yet unwritten, rules of behavior.

616

Identifying root causes

617

At the conclusion of the Analyze Phase, the team must list those specific root causes or critical x's to be acted upon during the Improve Phase

- Review the analyses completed to:
  - ✓ determine those critical x's and root causes that have been validated as significant contributors to unsatisfactory performance in the primary metric
  - ✓ list those that are no longer under consideration

- The team should show the analyses that support their decision on which opportunities to address in the Improve Phase

617

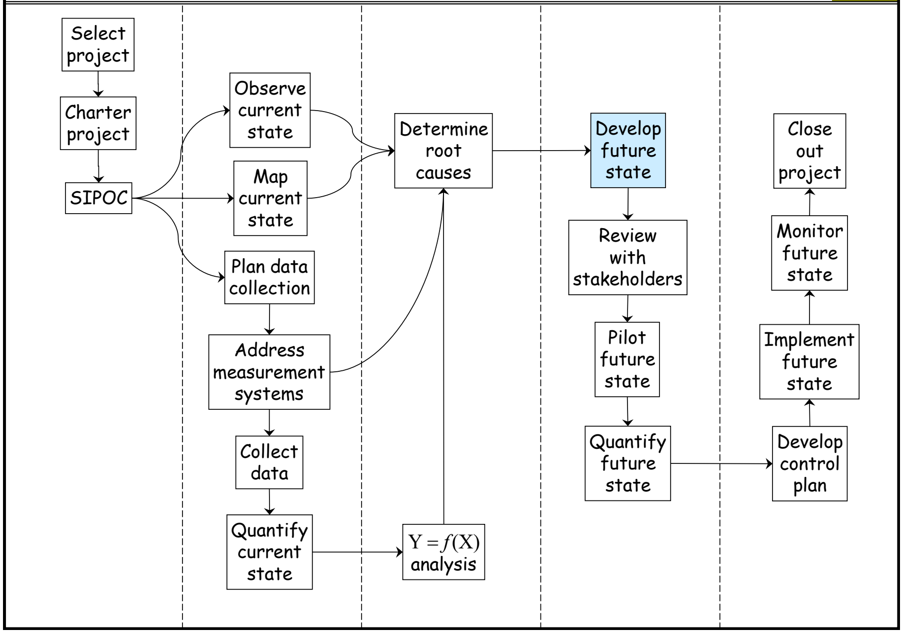
Notes

618

618

31 Developing and Prioritizing Solutions

619



Topics

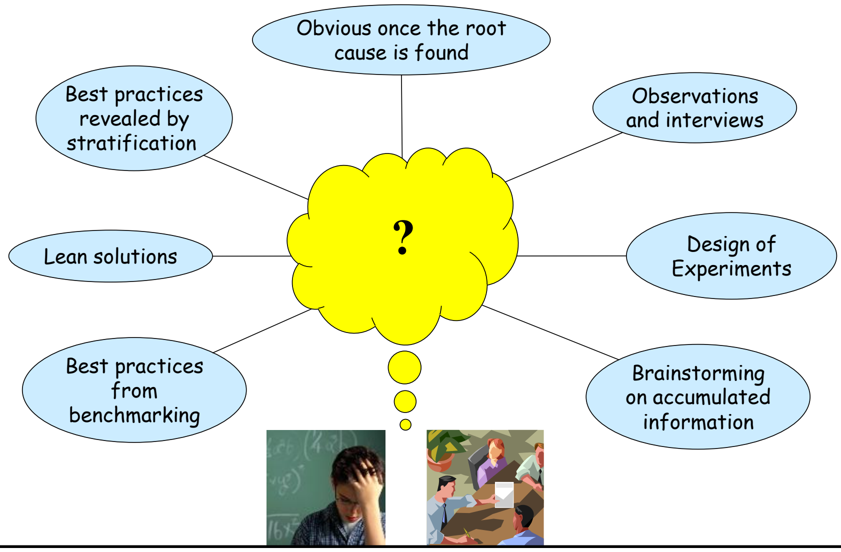
620

- Developing solutions
- Solution categories
- Mitigation for Human Factors Errors
- Prioritizing solutions

Developing solutions

621

Solutions come from many sources



Developing solutions (cont'd)

622

Improvement ideas can come from many sources. Some ideas will contribute more to the success of the future state than others. The greater the number of ideas, the greater the probability of discovering successful solutions. The team should generate as many improvement ideas as possible.

The nature of this process is that the initial list gets shorter. Some ideas are discarded along the way, others are retained intact, still others are modified or combined. This process leads to a future state that is likely to be best available within the constraints of the project.

Common solution categories

623

- Technology upgrades
- Lean solutions (we'll learn more about these in the next section of the course)
- Standardization
- Modification of procedures
- Optimization of processes or products (DOE)
- "Just do it" solutions that haven't yet been implemented

623

Solution categories (cont'd)

624

LSS projects address problems for which solutions are not known. Nevertheless, there are commonly occurring categories.

A common example of technology upgrade would be switching to a better measurement system.

We don't need a LSS project to tell us that Lean is good. But what if the organization lacks consensus on the benefits of these methods? A high priority LSS project that makes significant improvements by applying Lean solutions could help the organization recognize the value of Lean across the board.

The same applies for "just do it" solutions. Everyone knows what needs to be done, but it isn't getting done. A LSS project identifying and quantifying the need for the "just do it" solution might get some high level attention, cut through the lethargy, and stimulate action on the issue.

624

Mitigation for Human Factors Errors — Mistakes

625

1. Lack of Communication	• Never assume anything. • Improve communication: only 30% of verbal communication is remembered — usually the first and last part. Say the most important things at the beginning and repeat at the end. • Document instructions.
2. Lack of knowledge	• Don't guess or assume, ask when you don't know. • Use current documentation. • Access training/sources for knowledge.
3. Lack of teamwork	• Build a solid team; develop trust in the team. • Discuss how a task should be done. • Make sure everyone understands and agrees on tasks/commitments.
4. Lack of Resources	• Plan for resource needs, including sharing or pooling resources. • Identify and mitigate resource constraints.
5. Lack of Assertiveness	• Put safety first. • Express feelings, opinions, beliefs and needs in a positive, productive manner (offer positive solutions, resolve one issue at a time).
6. Lack of awareness	• See the whole picture: see dependencies and relationships between processes and systems. • Fully understand the procedure(s) to be used.

625

Mitigation for Human Factors Errors — Slips

626

7. Complacency	• Expect to make/find errors. • Learn from the mistakes of others. • Use checklists/documentation. • Don't sign/check-off if you didn't/haven't yet done it.
8. Distractions	• Get back in the groove after a distraction/interruption. • Use checklists/documentation. • Go back 3 steps when restarting a task.
9. Fatigue	• Watch for symptoms of fatigue in yourself and others. • Use buddy checks.
10. Pressure	• Put safety first. • Communicate concerns. • Ask for extra help.
11. Stress	• Use rational problem-solving approaches. • Take a short break when needed. • Discuss the problem with someone who can help.
12. Norms	• Put safety first. • "We've always done it that way" doesn't make it right. • Identify and eliminate negative norms.

626

Prioritizing solutions

627

- Uses the impact/feasibility method — same as prioritizing projects
- Defines "impact" as addressing the root causes identified by the project team
- Gives the organization a basis for making sound decisions in light of project findings
  - ✓ Opportunity to expedite implementation of solutions with high impact or high feasibility
  - ✓ Opportunity to postpone implementation of solutions with low impact and low feasibility

627

Instructions for prioritizing solutions

628

1. Open *Student Files* → *blank C&E matrix - impact & feasibility*.
2. In the *Metrics* sheet, change *Impact metrics* to *Root causes*.
3. List your prioritized root causes and relative weights (overall rankings).
4. List your feasibility metrics and relative weights.
5. Go to the *Impact ratings* sheet, change *Items to be ranked* to *Solutions*.
6. List the solutions you wish to rank.
7. Rate each solution for impact on each root cause (H, M, L).
8. Go to the *Feasibility ratings* sheet, rate each solution for each feasibility metric (H, M, L).
9. Go to the sheet *Impact - feasibility plot* to evaluate the results.

628

Student Files → prioritizing solutions - exercise

629

Root causes of Long Lead Time

Root Causes	Relative weights	Feasibility metrics	Relative weights
Variation in assembly process	2	Inexpensive	2
Design flaw within ATE system	2	Fast	2
PCBA design issue	2	Easy	1
Supplier's inconsistent use of fixture	1		
Material handling damage	1		

ATE = Automated Test Equipment

Metrics sheet

These are common feasibility metrics, but you can define the metrics and weights to suit your own situation.

Root causes determined in **Analyze** Phase. Weights indicate relative impact of cause on project metric

Metrics | Impact ratings | Feasibility ratings | Impact-feasibility plot | Impact calculations | Feasibility c

629

Prioritizing solutions (cont'd)

630

Impact ratings sheet

Root Causes	Variation in assembly process	Design flaw within ATE system	PCBA design issue	Supplier's inconsistent use of fixture	Material handling damage	0	0	0	0	0	0	0	0	0	0	Overall rankings
Relative weights	2	2	2	1	1	0	0	0	0	0	0	0	0	0	0	
Solution Ideas																
Job Instruction Training																0
ATE Design Change																0
PCBA Re-Design																0
Supplier Process Change																0
Improve material transport methods																0
																0
																0
																0
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																0

Metrics | Impact ratings | Feasibility ratings | Impact-feasibility plot | Impact calculations | Feasibility calculations | +

630

Prioritizing solutions (cont'd)

631

Feasibility ratings sheet

Feasibility metrics	Inexpensive	Fast	Easy	0	0	0	0	0	0	0	0	0	0	0	0	Overall rankings
Relative weights	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	
ATE Design Change																0
PCBA Re-Design																0
Supplier Process Change																0
Improve material transport methods																0
0																0
0																0
0																0
0																0
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0																0
0																0
0																0
0																0
0																0
0																0
0																0

Solution Id

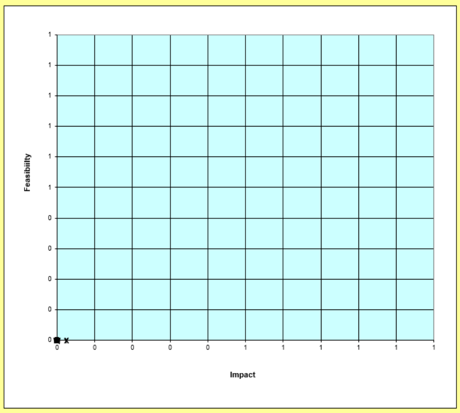
Metrics | Impact ratings | **Feasibility ratings** | Impact-feasibility plot | Impact calculations | Feasibility calculations

631

Prioritizing solutions (cont'd)

632

Solution Ideas	Tag	Impact	Feasibility
Job Instruction Training	A	0	0
ATE Design Change	B	0	0
PCBA Re-Design	C	0	0
Supplier Process Change	D	0	0
Improve material transport methods	E	0	0
0	F	0	0
0	G	0	0
0	H	0	0
0	I	0	0
0	J	0	0
0	K	0	0
0	L	0	0
0	M	0	0
0	N	0	0
0	O	0	0
0	P	0	0
0	Q	0	0
0	R	0	0
0	S	0	0



Impact-feasibility plot

Metrics | Impact ratings | Feasibility ratings | **Impact-feasibility plot** | Impact calculations | Feasibility calculations

632

Exercise 31.1

Open *Student Files* → *prioritizing solutions - exercise*.

Use the root causes and solution ideas as provided. Note that the first row of each sheet is frozen for ease of use during ranking.

Use your knowledge and experience to complete the following tasks:

a) Change the relative weights for the feasibility metrics as you see fit.

b) Fill out the *Impact ratings* sheet using H, M, L or blank.

c) Fill out the *Feasibility ratings* sheet using H, M, or L.

d) Use your impact-feasibility plot to decide which solution ideas should be implemented sooner, which should be implemented later, and perhaps, which should not be implemented.

633

Notes

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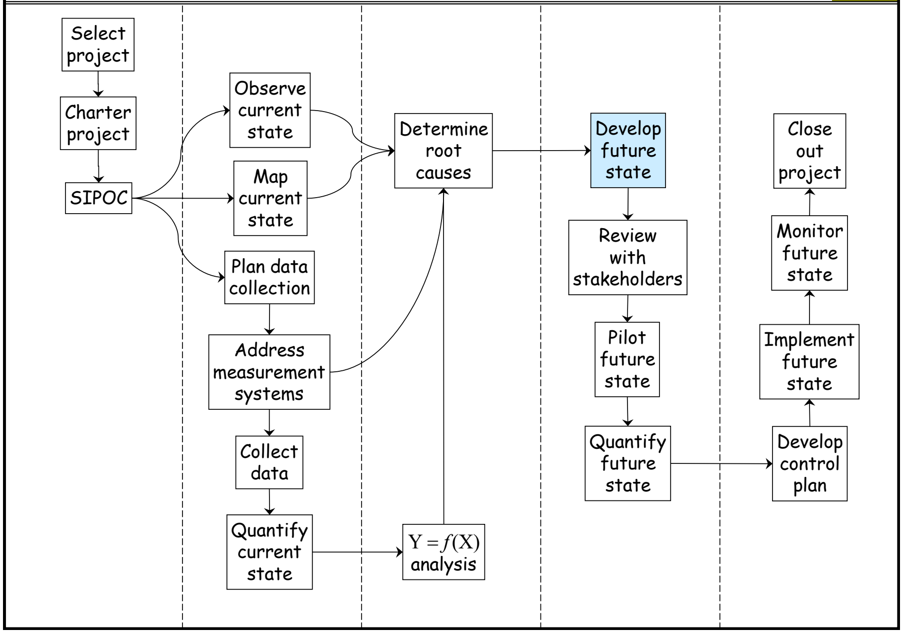
32 Lean Solutions

635



Commonly used Lean solutions

636

5S

Stop & fix

Pull systems

Visual management

Standardization

Value stream teams

Reduce batch sizes

Changeover reduction (SMED)

Work balancing (leveling)

Mistake proofing

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Categories of NVA

637

D	*Defects*: Failure to meet expected standards of quality or delivery
O	*Over production*: Making or doing more than is needed at the time
W	*Waiting*: People waiting to work, or things waiting to be worked on
N	*Not utilizing creativity*: Failure to integrate improvement cycles into the daily work of all employees
T	*Transportation*: People or things being moved from one place to another
I	*Inventory*: Storing supplies, WIP, or finished goods beyond what is needed
M	*Motion*: Excessive motion in the completion of work activities
E	*Extra processing*: Producing or delivering to a higher standard than is required

637

Notes

638

638

The 5S Vision

639

A Workplace that is:

- Clean, organized, orderly
- Efficient and pleasant
- Safe*
- The foundation for all other improvement activities

*Safety is a '6th S' that integrates safe practices into each of the 5S's to reduce hazards and risks.

Resulting In:

- Fewer accidents
- Improved efficiency
- Improved quality
- Workplace control

And therefore:

- Reduced waste
- Reduced cost

639

5S

640

Sort – Sort through and Sort out
- Keep what is needed – Eliminate what is not
- Reduce quantity of items to what is needed

Set in Order – A place for everything and everything in its place
- Identify best location and relocate out-of-place items
- Make locations visually identified – easy to see missing items
- Set height, quantity, and size limits
- Organize for safety

Shine – Shine and Inspect through cleaning
- Filthy work environments lead to poor morale
- Spills and debris are safety hazards
- It's easier to identify a maintenance need on clean equipment

Standardize
- Build the framework for maintaining Sort, Set in Order, and Shine
- Create clarity about what is and is not normal with simple action plans

Sustain
- Incorporate 5S into the daily work cycle

640

Pull systems for supply replenishment

641

- Material usage should be first-in-first-out (FIFO)
- Supply orders are triggered by *kanbans* (cards, empty bins, or other signals)
- The objective is to minimize stock-outs without keeping excessive supply quantities on hand

641

Kanban card for supply items

642

- An order is triggered when the minimum quantity is reached*
- A kanban card goes with the order, returns with the delivery
- The minimum quantity should represent what is needed to span the delivery cycle time

Item Name ______________________

Max. Quantity _________

Min. Quantity _________

Re-order Qty. _________ **(Max – Min)**

Vendor _________________________

Catalog Pg. No. _______

- The maximum quantity should represent a desired upper bound for supply quantity on hand

*What can cause this system to fail?

642

Example: two-bin kanban system

643

- Two bins for each item (see next slide)
- Amount in each bin = min. quantity = order quantity
- Order when top bin is empty, move bottom bin to top
- Visual system, easy to use
- The max and min quantities can be determined by trial and error
- If usage data is available, there is a better way

643

Two-bin system (cont'd)

644

644

Using data to set max/min values

645

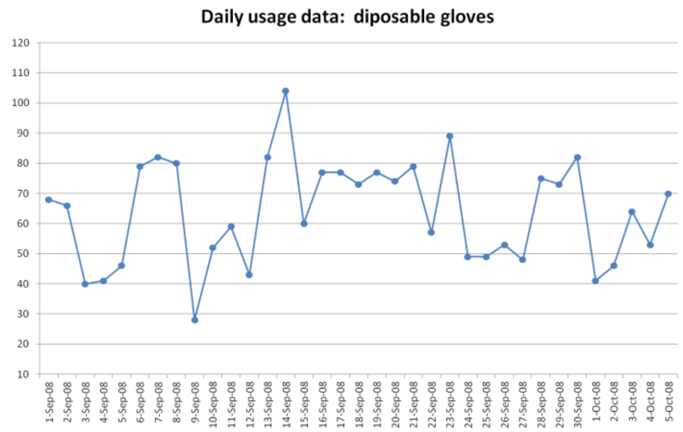
- Required inputs
  - ✓ Time period for usage data (hourly, each shift, daily, weekly, . . .)
  - ✓ Average usage per time period
  - ✓ Standard deviation of usage per time period
  - ✓ Minimum order quantity
  - ✓ Min. value (number of orders)
  - ✓ Max. value (number of orders)

- Values calculated in the simulation
  - ✓ Starting quantity for each period
  - ✓ Quantity received during each period
  - ✓ Quantity used during each period
  - ✓ Ending quantity for each period
  - ✓ Quantity ordered during each period

Setting max/min values (cont'd)

646

Data Sets → usage of disposable gloves



Average = 63.9
Std. dev. = 17.2

Setting max/min values (cont'd)

647

Student Files → kanban setup

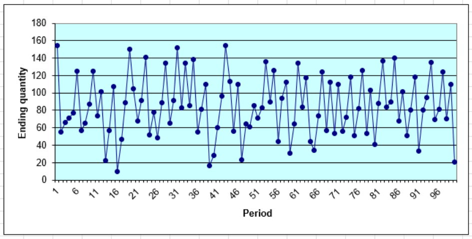
Avg. usage each period	63.9 (If usage data cannot be obtained, get independent best guesses from people close to the process and average them.)
Std. dev. of usage each period	17.2 (If usage data cannot be obtained, get best-guess high and low values and use (high-low)/6.)
Minimum order quantity	100
Min. value (# orders)	1
Max. value (# orders)	2

Min and Max cannot be equal

Period (hours, shifts, days, weeks...)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Starting quantity	200	154	55	66	71	77	125	57	65	87	125	74	101	22	57	107	10	119
Quantity received	0	0	100	100	100	100	0	100	100	100	0	100	0	100	100	0	100	0
Quantity used	46	99	89	95	94	52	68	92	78	62	51	73	79	65	50	97	63	72
Ending quantity	154	55	66	71	77	125	57	65	87	125	74	101	22	57	107	10	47	47
Quantity ordered	0	100	100	100	100	0	100	100	100	0	100	0	100	100	0	100	100	100

CW	CX	CY	CZ	DA
			mu	sigsq
			4.12	0.07
100			Avg.	
131			88.8	
0				
51				
80			87.6	
100				

1-period delivery means when an order placed, it's delivered the next day. 2-period is a 2-day delivery, and so on...



To run a new simulation, click on a blank cell at the end of a row in this area, hit the Space Bar, then the Enter key.

Average ending qty. 84.8 | # Orders 66 | # Stock-outs 0

These values are help convert the observed demand average & standard deviation into parameters used in a lognormal probability model for demand.

1-period delivery | 2-period delivery | 3-period delivery | 4-period delivery | 5-period delivery

647

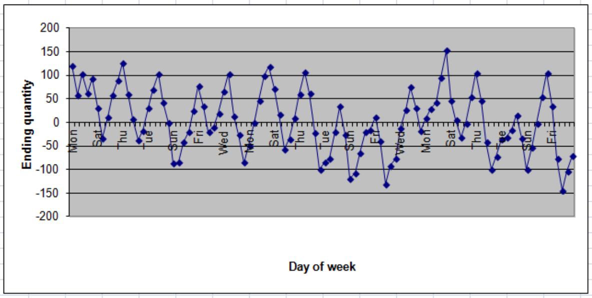
Setting max/min values (cont'd)

648

Student Files → kanban setup - weekdays only

Avg. usage each period	63.9 (If usage data cannot be obtained, get independent best guesses from people close to the process and average them.)
Std. dev. of usage each period	17.2 (If usage data cannot be obtained, get best-guess high and low values and use (high-low)/6.)
Minimum order quantity	100
Min. value (# orders)	1
Max. value (# orders)	2

Day of week	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri
Beginning quantity	200	120	59	103	63	93	32	-34	12	58	89	126	61	8	-38	-17	31	70	103
Quantity received	0	0	100	0	100	0	0	100	100	100	100	0	0	0	100	100	100	100	0
Quantity used	80	61	56	40	70	61	66	54	54	69	63	65	53	46	79	52	61	67	61
Ending quantity	120	59	103	63	93	32	-34	12	58	89	126	61	8	-38	-17	31	70	103	42
Quantity ordered	0	100	0	100	100	0	0	100	100	100	0	100	0	0	100	100	100	0	100



Average ending qty. 4.5 | # Orders 62 | # Stock-outs 49

648

Organizing by departments

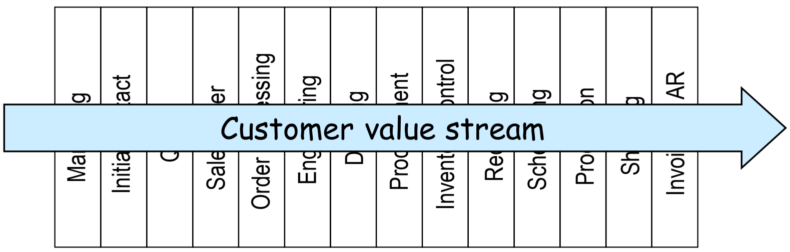
649

- Departmental boundaries create “silos”
- Often, no single entity has overall responsibility for customer satisfaction
- Vestige of industrial revolution — need for specialization
- Hand offs between silos are opportunities for poor communication and lack of coordination

649

Organizing by value stream

650



- Customer value stream spans all silos

"We want to not only show respect to our people, the same way we want to show respect to everyone we meet in life, we also want to respect their humanity, what it is that makes us human, which is our ability to think and feel – we have to respect that humanity in the way we design the work, so that the work enables their very human characteristics to flourish."

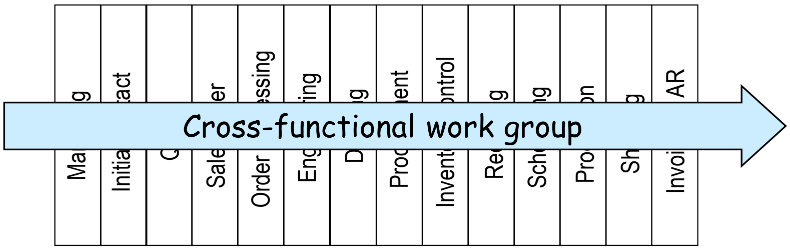
— Fuji Cho, as quoted in John Shook's “Managing to Learn”

Mr. Fuji Cho has held many leadership positions at Toyota, including President and is currently an Honorary Chairman of the company. He was explaining in this quote why they did not call their operating philosophy the “Toyota Production Method” but the "Respect for Humanity" system.

650

Organizing by value stream (cont'd)

651



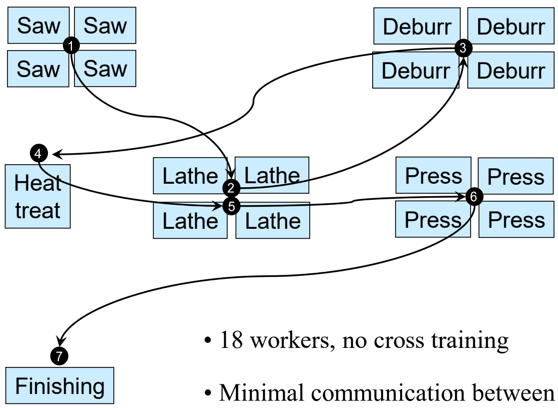
- Responsible for entire value stream for a product/service "family"
- Physical co–location is ideal (work cells)
  - Alternative: "value stream team"
- Stand-up meetings: every day, shift, or other frequent interval
  - Alternative: virtual meetings

Notes

652

Manufacturing operation in silos

653

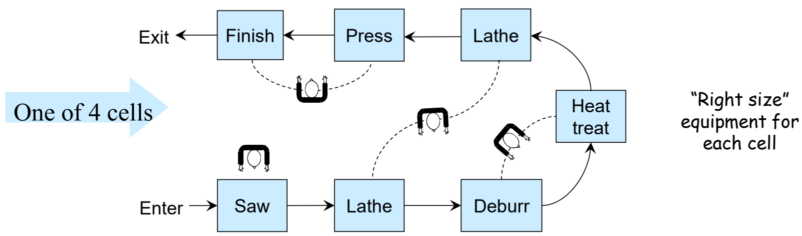


- 18 workers, no cross training
- Minimal communication between silos
- Each silo handles all products
- Silos produce as much as possible, all the time (push system)
- WIP moves between silos in large batches → long lead time

653

Manufacturing operation in U-shaped work cells*

654



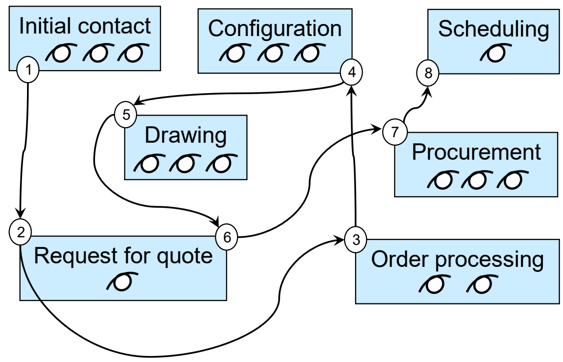
- Each cell handles all operations for one product family, and produces just what is needed to meet current demand (pull system)
- Continuous flow → minimal WIP → short lead time
- Rapid response to workflow or quality problems
- 16 workers instead of 18 — what happened to the other 2?

*Physical co-location is not always possible in process industries, where equipment determines capacity and is difficult or impossible to relocate. See **Lean for the Process Industries** by Peter King for ideas on how to apply Lean in this situation.

654

Transactional process in silos

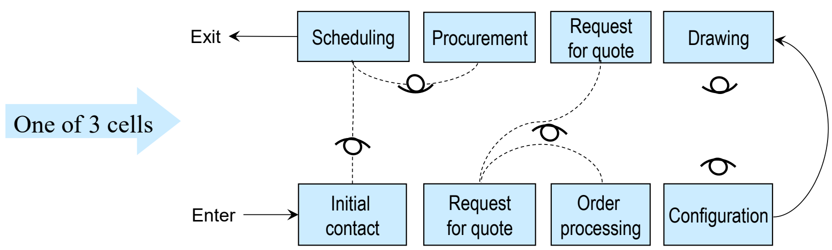
655



- 16 workers, no cross training
- Each silo handles all transactions
- Minimal communication between silos
- Lots of do overs (not shown in diagram)
- Lots of WIP → long turnaround time

Transactional process in U-shaped work cells

656



- Each cell handles all steps for one transaction family
- Continuous flow → minimal WIP→ short turnaround time
- Rapid response to errors or workflow problems
- 15 workers instead of 16 — what happened to the other one?

Reduce batch sizes (keep the work moving)

657

Don't do things in batches.
The ideal is to do one thing at a time.
Come as close to this as you can.

- Wait a minute — batching is supposed to be "efficient"
- Maybe, but here are some problems with batching:
  - ✓ A customer who wants just one item has to wait for a whole batch to be completed
  - ✓ Reduces flexibility in building different products.
  - ✓ Items accumulate until the batch quantity is reached — wastes space, creates opportunities for defects

657

Reduce batch sizes (cont'd)

658

Of course, there can be a legitimate problem with reducing batch sizes: it increases the number of changeovers.

Fortunately, this is a problem for which Lean has excellent solutions. Lean projects have reduced changeover times by 80% or more.

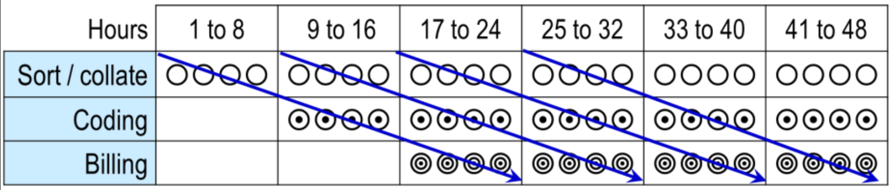
- ✓ Shigeo Shingo pioneered the Single Minute Exchange of Die (SMED) methodology

658

Current state: daily batching

659

3 operations
2 hours per transaction per operation

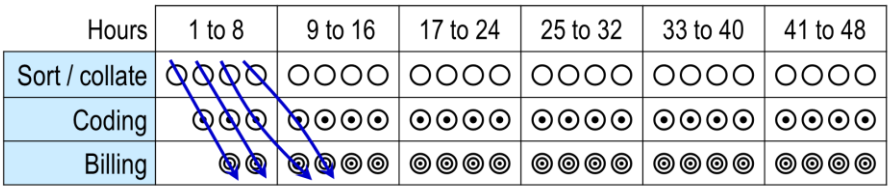


Lead time = 24 hours (3 days)

Future state: continuous flow

660

3 operations
2 hours per transaction per operation



Lead time = 6 hours (less than one day)

VSM Definitions Redux

661

Available Working Time (AWT)	• The time a process is available to conduct work • AWT excludes time when work isn't occurring such as time for breaks, meetings, lunch, preventative maintenance, estimates of unplanned downtime, change overs, etc.
Throughput (Tput)	• The average number of good parts or transactions completed over a period of time • Typically measured as average over at least several days • Throughput, lead time, and inventory are related through Little's Law

661

VSM Definitions Redux (cont'd)

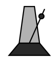
662

Lead time (LT)	• The total elapsed time to produce one defect free product or transaction • The time difference between when a part or transaction enters and leaves a process
Customer Demand Rate (CDR)	• The number of parts or transactions that the customer desires over a period of time (usually a day, week, or month)

662

VSM Definitions Redux (cont'd)

663

Takt time (TT)	• The pace at which an operation should complete products or transactions in order to meet customer demand during the Available Working Time.  • Available working time during a period divided by the number of products or transactions *required* during that same period
Cycle time (CT)	• The fastest repeatable time between part or transaction completions using the current processes and resources • Shows how a process is capable of performing  • Combines with AWT to determine capacity

663

VSM Definitions Redux (cont'd)

664

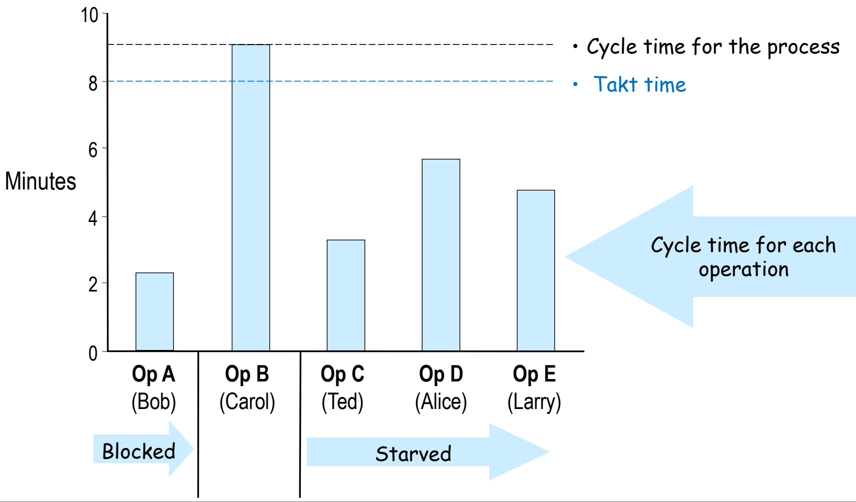
Process Cycle Efficiency (PCE)	• The percentage of time that WIP is being transformed by VA activities. In other words, the percentage of lead time that is value added.
Work In Progress (WIP)	• Includes items waiting to be worked on and items actively being worked on. WIP includes all of the inventory in the production system.
Little's law	• Lead Time = (WIP) / (Throughput)

664

Work balancing

665

- Cycle time for a process = cycle time for the *slowest* operation
- This process is unable to meet the customer's needs



665

Work balancing (cont'd)

666

- Operation A can complete 1 part every 2.2 minutes, operation B can complete 1 part every 9 minutes
- If A runs at full capacity, its output will pile up in front of B
- Common example of waste: overproduction
- Operations C, D, and E can produce faster than B, but their capacity cannot be utilized
- They can complete parts only as fast as B supplies them
  - Cycle time for C, D, and E is 9 minutes
  - Cycle time for the process is 9 minutes

666

Improving work balance by adding resources

667

- Add a second resource (Moe) to operation B
- Together, Carol and Moe can complete 2 parts or transactions every 9 minutes
- New cycle time for operation B is $9 \div 2 = 4.5$ mins (see next slide)
- New cycle time for the process is 5.8 mins (cycle time for operation D)

667

Effect of multiple resources on cycle time

668

- Remember: the lead time is the time interval between units leaving a process.
- If a resource processes only one unit at a time, then the cycle time for that resource equals the lead time.
- Suppose the cycle time for one resource (machine or person) is 6 minutes and 4 workers (or machines) perform this task.
- Collectively, they can complete 4 parts or transactions every 6 minutes
- Their cycle time is:

$$(6 \text{ mins}) / (4 \text{ parts or transactions}) = 1.5 \text{ mins}$$

- Similarly, if a machine processes a batch of 4 parts every 6 minutes, the cycle time is 1.5 minutes.

668

Effect of multiple resources on cycle time (cont'd)

669

- For a conveyorized process, the cycle time is the time interval between units exiting the conveyor.
- Imagine a conveyorized wash process that runs at a speed such that parts are washed for 6 minutes. Given its length and conveyor speed, a part exits the machine every 1.5 minutes. Its cycle time is 1.5 minutes.
- If there were two identical wash processes in a production line, their combined cycle time would be 1.5/2 = 0.75 minutes = 45 sec.

669

Multiple resources (cont'd)

670

- In general:

$$\text{Cycle time of multiple resources} = \frac{\text{(Cycle time of one resource)}}{\text{(\# Resources)}}$$

- To determine the number of resources required to meet customer demand, we can substitute 'Takt time' for 'Cycle time of multiple resources' in the equation above and solve the equation for 'Resources':

$$\text{\# Resources needed} = \frac{\text{(Cycle time of one resource)}}{\text{(Takt time)}}$$

670

Improving work balance by cross training

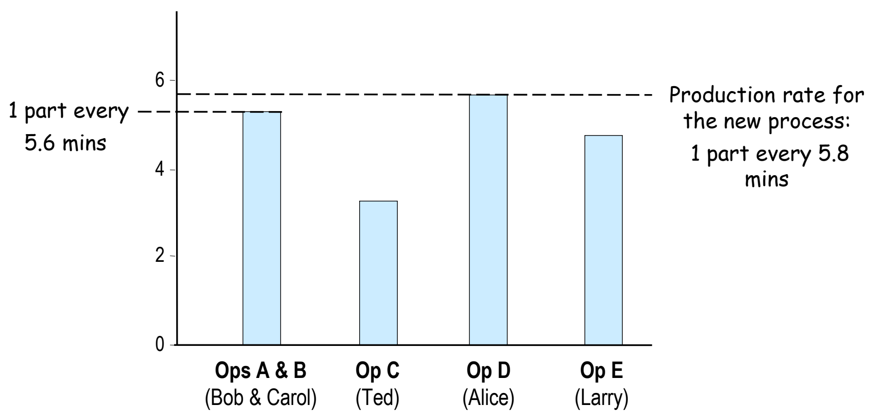
671

- Teach Bob how to do B, teach Carol how to do A, have them both do A & B
- Process time for A & B = 2.2 + 9.0 = 11.2
- New cycle time for A + B = 11.2 / 2 = 5.6 mins
- Process cycle time is once again 5.8 mins, and we didn't have to add a resource
- Cross training is a more cost-effective way to meet customer demand.
- Where is the next best opportunity for cross training?

671

Cross training (cont'd)

672



672

Examples of mistake-proofing (Poke Yoke)

673

- Designing connecting cables and ports so that a cable cannot be plugged into the wrong port
- Programming software so that the user cannot proceed unless necessary information is filled in
- Auto fill of previously entered information on electronic forms
- Pull down menus in computer programs — especially for data entry
- Using feedback control systems and alarms on equipment
- Fixturing to prevent incorrect placement and hold things in place

673

Exercise 32.1 Lean workshop

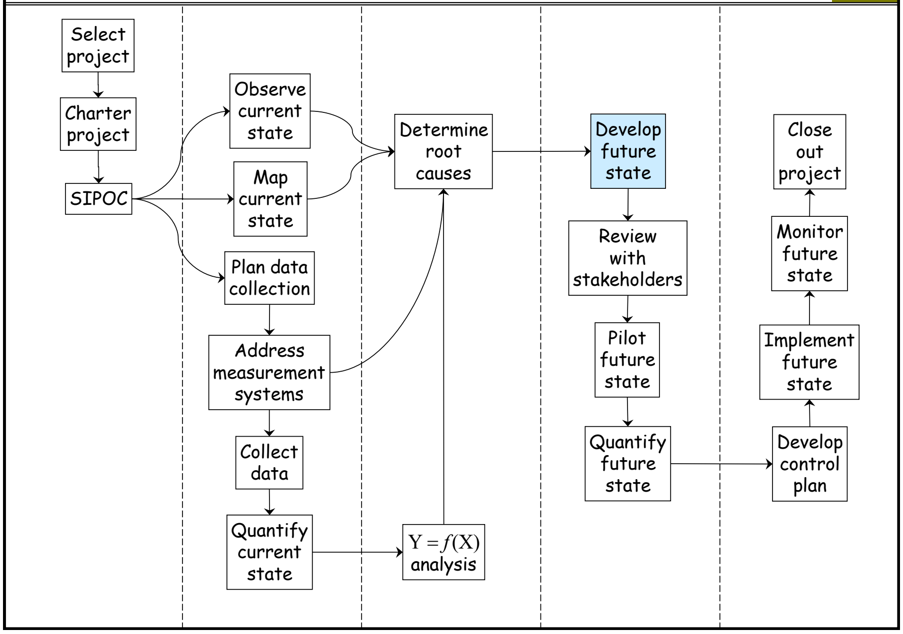
674

The Instructor will provide directions for this workshop.

674

33 Theory of Constraints (TOC)

675



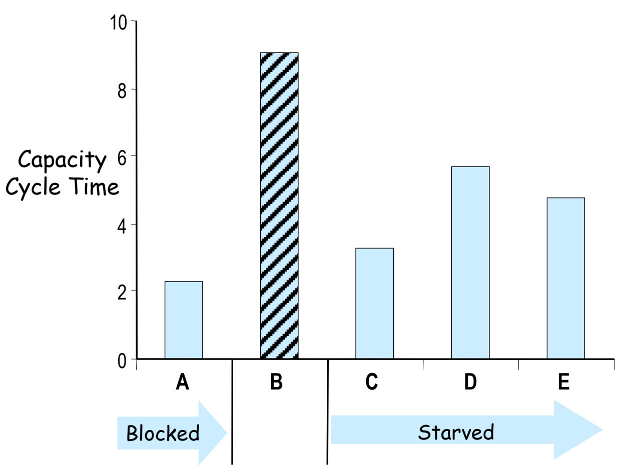
675

TOC (cont'd)

676

What if cross training is not feasible?

What if the bottleneck is machine capacity?



676

TOC (cont'd)

677

TOC improvement cycle	Lean terminology
1. *Identify* the system constraint (the "drum")	Find the bottleneck ("pacemaker")
2. *Exploit* the identified constraint (includes establishing the "buffer")	• Move resources to the bottleneck • Minimize NVA at the bottleneck • Maintain needed level of "safety" WIP
3. *Subordinate* everything else to the constraint (establish the "rope")	Pull system synchronized with the takt time of the bottleneck
4. *Elevate* the constraint	Add enough resources to eliminate the bottleneck
5. Return to step #1	Find the new bottleneck, repeat same steps

677

Ways to identify the constraint

678

- Greatest WIP
- Longest cycle time
- Longest process time
- Highest % utilization

678

Example: current state

679

Q

Front end
4 machines
4 operators

Q

Heat treat
1 machine
1 operator
Max qty = 60

Q

Back end
4 machines
4 operators

Lead time				120 mins		
"process" time	0	4 min	0	90 mins (load change = 30 mins)	0	4 min
Cycle time		4 mins/4 pcs = 1 min		120 mins/60 pcs = 2 mins		4 mins/4 pcs = 1 min
Constrained cycle time		1 min		2 mins		2 mins

Blocked

Starved

679

Future state #1: reallocate resources

680

Front end
4 machines
(1 idle)
3 operators

Q

Q

Heat treat
1 machine
3 operators
Max qty = 60

Q

Back end
4 machines
(1 idle)
3 operators

Lead time				100 mins		
"process" time	0	4 min	0	90 mins (load change = 10 mins)	0	4 min
Cycle time		4 mins/3 pcs = 1.33 mins		100 mins/60 pcs = 1.67 mins		4 mins/3 pcs = 1.33 mins
Constrained cycle time		1.33 mins		1.67 mins		1.67 mins

Less over-production

Less WIP

Faster load change

680

Future state #2: improve load change process

681

	Q	Front end	Q	Heat treat	Q	Back end
		4 machines (1 idle) 3 operators		1 machine 3 operators Max qty = 60		4 machines (1 idle) 3 operators
Lead time				95 mins		
"process" time	0	4 min	0	90 mins (load change = 5 mins)	0	4 min
Cycle time		4 mins/3 pcs = 1.33 mins		95 mins/60 pcs = 1.58 mins		4 mins/3 pcs = 1.33 mins
Constrained cycle time		1.33 mins		1.58 mins		1.58 mins

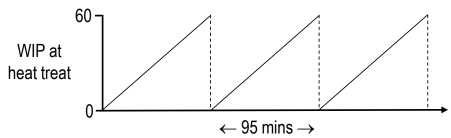
Even faster load change

681

Future state #3: pull system in front end

682

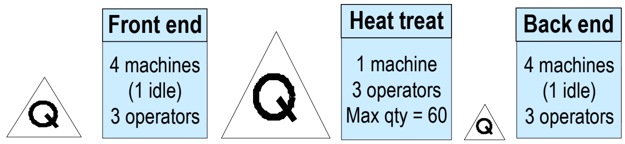
	Q	Front end	Q	Heat treat	Q	Back end
		4 machines (1 idle) 3 operators		1 machine 3 operators Max qty = 60		4 machines (1 idle) 3 operators
Lead time				95 mins		
"process" time	0	4 min	0	90 mins (load change = 5 mins)	0	4 min
Cycle time		4 mins/3 pcs = 1.33 mins		95 mins/60 pcs = 1.58 mins		4 mins/3 pcs = 1.33 mins
Constrained cycle time		1.58 mins		1.58 mins		1.58 mins



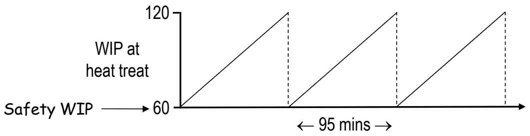
682

Future state #4: establish and maintain safety WIP

683



Lead time				95 mins		
"process" time	0	4 min	0	90 mins (load change = 5 mins)	0	4 min
Cycle time		4 mins/3 pcs = 1.33 mins		95 mins/60 pcs = 1.58 mins		4 mins/3 pcs = 1.33 mins
Constrained cycle time		1.58 mins		1.58 mins		1.58 mins



683

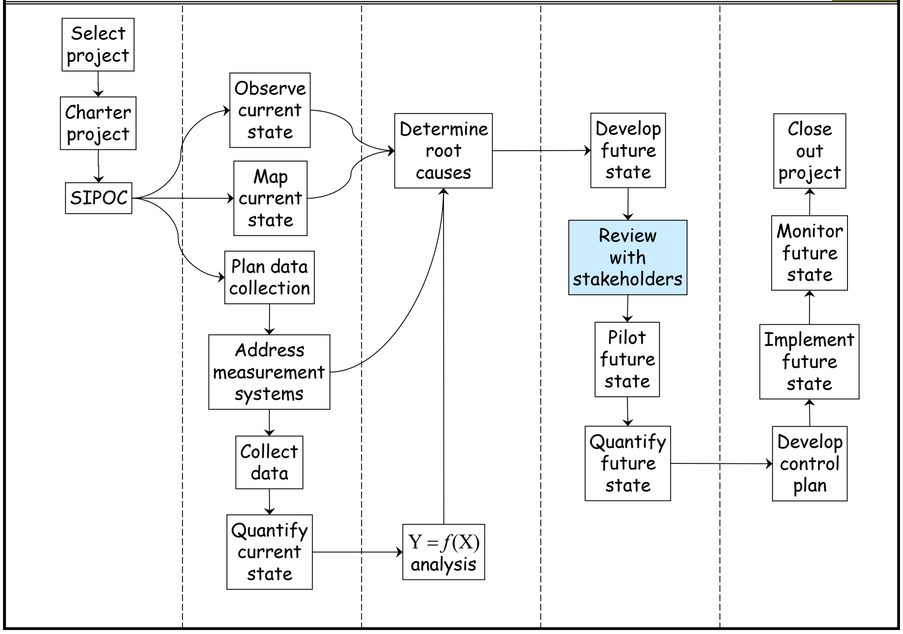
Notes

684

684

34 Reviewing the Proposed Future State

685



685

Reviewing the future state

686

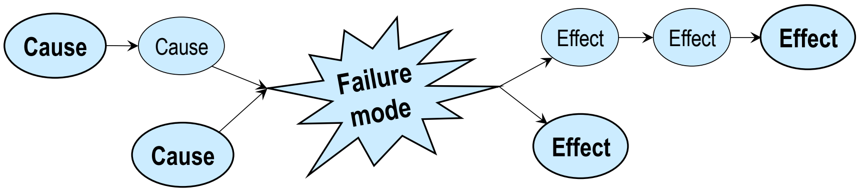
- Use *Failure Modes and Effects Analysis* to identify problems (failure modes) that could occur in your new process and their impact (effects)
- Put things in place in the new process, to prevent or mitigate these failure modes, before they happen
- After you develop your proposed future state, the next step is to review it with stakeholders
  - Give them an opportunity to voice concerns or suggest enhancements prior to piloting
  - This can be an informal process of presentation and discussion

686

Failure Modes & Effects Analysis (FMEA)

687

1. Identify potential failure modes before deploying a new product, service, or process



3. Identify and prioritize root causes of potential failure modes

2. Identify and evaluate ultimate effects of potential failure modes

4. Identify and take corrective actions to eliminate or reduce the occurrence of root causes

687

The role of FMEA in a LSS project

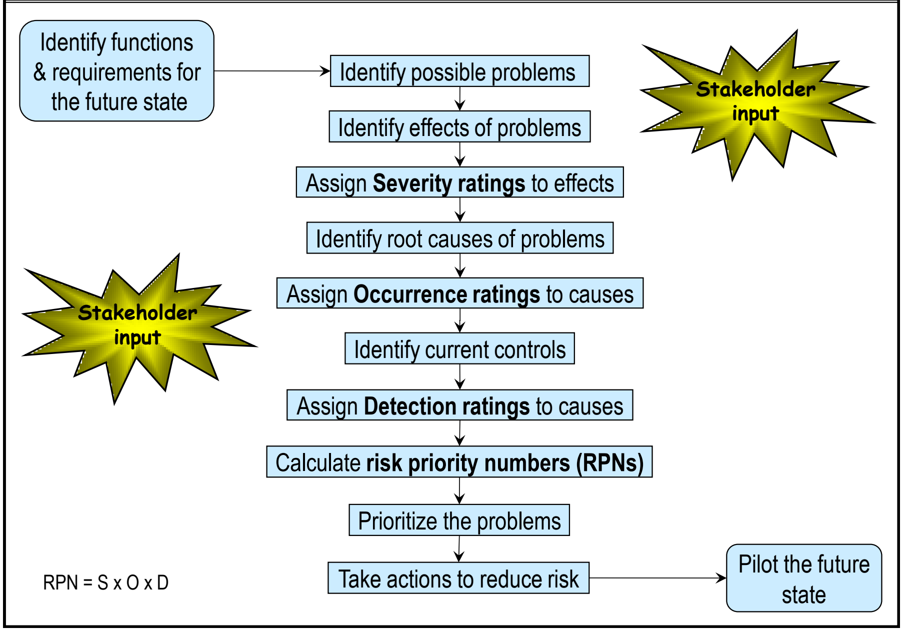
688

- Identify and prioritize stakeholder concerns with the proposed future state
- Take appropriate corrective action prior to piloting the future state
- Use results to strengthen the control plan for the future state

688

Detailed FMEA process

689



689

Example of a Severity rating

690

Level		*Description*
10	Hazardous, no warning	May endanger machine or assembly operator. Failure causes unsafe product operation or noncompliance with government regulation. Failure will occur without warning.
9	Hazardous, warning	May endanger machine or assembly operator. Failure causes unsafe product operation or noncompliance with government regulation. Failure will occur with warning.
8	Very high	Major disruption to production line. 100% of product may have to be scrapped. Product is inoperable with loss of Primary Function.
7	High	Minor disruption to production line. Product may have to be sorted and a portion scrapped. Product is operable but at a reduced level of performance.
6	Moderate	Minor disruption to production line. A portion of the product may have to be scrapped (no sorting). Product is operable but comfort or convenience item(s) are inoperable.
5	Low	Minor disruption to production line. 100% of the product may have to be reworked. Product is operable but comfort or convenience item(s) operate at a reduced level of performance.
4	Very low	Minor disruption to production line. Product may have to be sorted and a portion reworked. Fit/finish or squeak/rattle item does not conform. Most customers notice defect.
3	Minor	Minor disruption to production line. Some product may require rework on-line but out-of-station. Fit/finish or squeak/rattle item does not conform. Average customers notice defect.
2	Very minor	Minor disruption to production line. Some product may require rework on-line but in-station. Fit/finish or squeak/rattle item does not conform. Discriminating customers notice defect.
1	None	No effect.

690

Example of an Occurrence rating

691

Level		Description	Failure Rate
10	Very high	Failure is almost inevitable.	≥□ 1 in 2
9			1 in 3
8	High	Generally associated with processes similar to previous processes that have often failed.	1 in 8
7			1 in 20
6	Moderate	Generally associated with processes similar to previous processes which have experienced occasional failures, but not in major proportions.	1 in 80
5			1 in 400
4			1 in 2000
3	Low	Isolated failures associated with similar processes.	1 in 15,000
2	Very low	Only isolated failures associated with almost identical processes.	1 in 150,000
1	Remote	Failure is unlikely. No failures ever associated with almost identical processes.	≤ 1 in 1,500,000

691

Example of a Detection rating

692

Level		Description
10	Almost impossible	No known controls available to detect failure mode or cause.
9	Very remote	Very remote likelihood current controls will detect failure mode or cause.
8	Remote	Remote likelihood current controls will detect failure mode or cause.
7	Very low	Very low likelihood current controls will detect failure mode or cause.
6	Low	Low likelihood current controls will detect failure mode or cause.
5	Moderate	Moderate likelihood current controls will detect failure mode or cause.
4	Moderately high	Moderately high likelihood current controls will detect failure mode or cause.
3	High	High likelihood current controls will detect failure mode or cause.
2	Very high	Very high likelihood current controls will detect failure mode or cause.
1	Almost certain	Current controls almost certain to detect failure mode or cause. Reliable detection controls are known with similar processes.

692

FMEA ratings

693

- The previous three slides give examples of traditional 1–10 ratings for severity, occurrence, and non–detection
- Note the detailed quantitative operational definitions
- Customers or regulatory agencies may require this level of detail
- For the application to LSS projects, qualitative 1–5 ratings are often sufficient:
    1. Very low
    2. Low
    3. Moderate
    4. High
    5. Very high

Project example

694

Problem statement

Operations staff within the Gene Expression Lab (GEL) are experiencing frequent material stock outs while performing procedures. They have to stop processing samples until the missing material is delivered. This increases process cycle time and reduces the quality of the data deliverables. Other labs directly affected by this problem are:

- ✓ Tissue Homogenization
- ✓ Experiment Processing
- ✓ Sample Processing

Goal statement

- Reduce frequency of stock outs by 50%.
- Reduce time lost due to stock outs by 50%.

Constraint

No increase in labor cost.

Current state data

695

Average daily number of stock outs	2.1
Average time to fill material requests	4 hrs
Annualized direct labor cost	$91,000

695

FMEA step 1 for Proposed Future State Process

696

Process Functions	Requirements	Failure Modes	Effects	Sev
Reagent lot creation	New lot information distributed to OPS team			
Reagent creation	New reagent created based on processing demand			
Reagent storage	Storage of new reagent at point of use (laboratory)			
Material storage	Stocking of materials and reagents in designated location within the functional laboratory			
Material Distribution	Replenishment of materials based on MIN/MAX values			

696

FMEA step 2

697

Process Functions	Requirements	Failure Modes	Effects	Sev
Reagent lot creation	New lot information distributed to OPS team	Printer malfunction		
Reagent creation	New reagent created based on processing demand	Operator error during manufacturing of reagent		
Reagent storage	Storage of new reagent at point of use (laboratory)	Insufficent storage space in freezer or fridge		
Material storage	Stocking of materials and reagents in designated location within the functional laboratory	Insufficient shelf space for materials.		
		Staff is unclear where material items should be stored		
Material Distribution	Distribution of materials based on MIN/MAX forecasting	MIN/MAX values not accurate		

697

FMEA step 3

698

Process Functions	Requirements	Failure Modes	Effects	Sev
Reagent lot creation	New lot information distributed to OPS team	Printer malfunction	Delay in distribution to the OPS team	5
Reagent creation	New reagent created based on processing demand	Operator error during manufacturing of reagent	(1) Processing delay (2) Wasted sub-reagents (3) Time lost (4) Labor money	10
Reagent storage	Storage of new reagent at point of use (laboratory)	Insufficent storage space in freezer or fridge	Reagent stock-out	8
Material storage	Stocking of materials and reagents in designated location within the functional laboratory	Insufficient shelf space for materials.	Material stock-out	5
		Staff is unclear where material items should be stored	Materials not stocked in designated location within the functional area	5
Material Distribution	Distribution of materials based on MIN/MAX forecasting	MIN/MAX values not accurate	Material shortage	5

698

FMEA step 4

699

Effects	Sev	Causes	Occ	Current Controls	Det	RPN	Recommended Actions
Delay in distribution to the OPS team	5	Electrical	1				
(1) Processing delay (2) Wasted sub-reagents (3) Time lost (4) Labor money	10	Did not use trained witness	1				
Reagent stock-out	8	Freezer space not reconciled	10				
Material stock-out	5	Too many items on shelving	5				
Materials not stocked in designated location within the functional area	5	Insufficent labeling system to designate material and reagent locations	5				
Material shortage	5	Forecasting not accurate	5				

699

FMEA step 5

700

Failure Modes	Effects	Sev	Causes	Occ	Current Controls	Det	RPN
Printer malfunction	Delay in distribution to the OPS team	5	Electrical	1	One printer	1	
Operator error during manufacturing of reagent	(1) Processing delay (2) Wasted sub-reagents (3) Time lost (4) Labor money	10	Did not use trained witness	1	SOP requires trained witness for procedure	5	
Insufficent storage space in freezer or fridge	Reagent stock-out	8	Freezer space not reconciled	10	No control.	10	
Insufficient shelf space for materials.	Material stock-out	5	Too many items on shelving	5	Shelving units with four shelves	10	
Fisher staff is unclear where material items should be stored	Materials not stocked in designated location within the functional area	5	Insufficent labeling system to designate material and reagent locations	5	Labels on shelving only	5	
MIN/MAX values not accurate	Material shortage	5	Forecasting not accurate	5	Master Science Forecasting	10	

700

FMEA step 6

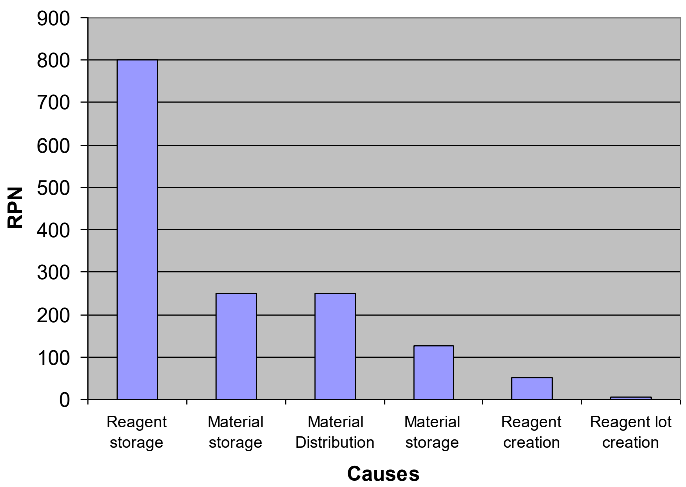
701

Effects	Sev	Causes	Occ	Current Controls	Det	RPN	Recommended Actions
Delay in distribution to the OPS team	5	Electrical	1	One printer	1	5	
(1) Processing delay (2) Wasted sub-reagents (3) Time lost (4) Labor money	10	Did not use trained witness	1	SOP requires trained witness for procedure	5	50	
Reagent stock-out	8	Freezer space not reconciled	10	No control.	10	800	
Material stock-out	5	Too many items on shelving	5	Shelving units with four shelves	10	250	
Materials not stocked in designated location within the functional area	5	Insufficent labeling system to designate material and reagent locations	5	Labels on shelving only	5	125	
Material shortage	5	Forecasting not accurate	5	Master Science Forecasting	10	250	

701

Pareto of causes by RPN

702



702

FMEA step 7

703

Effects	Sev	Causes	Occ	Current Controls	Det	RPN	Recommended Actions
Delay in distribution to the OPS team	5	Electrical	1	One printer	1	5	Install back-up printer
(1) Processing delay (2) Wasted sub-reagents (3) Time lost (4) Labor money	10	Did not use trained witness	1	SOP requires trained witness for procedure	5	50	No further action required
Reagent stock-out	8	Freezer space not reconciled	10	No control.	10	800	Frequent consolidation of freezer inventory
Material stock-out	5	Too many items on shelving	5	Shelving units with four shelves	10	250	Add more shelves to accommodate additional materials
Materials not stocked in designated location within the functional area	5	Insufficent labeling system to designate material and reagent locations	5	Labels on shelving only	5	125	Place labels on freezer canes and fridge shelves to designate locations
Material shortage	5	Forecasting not accurate	5	Master Science Forecasting	10	250	Review MIN/MAX values quarterly for frequently used materials

703

Results from pilot data

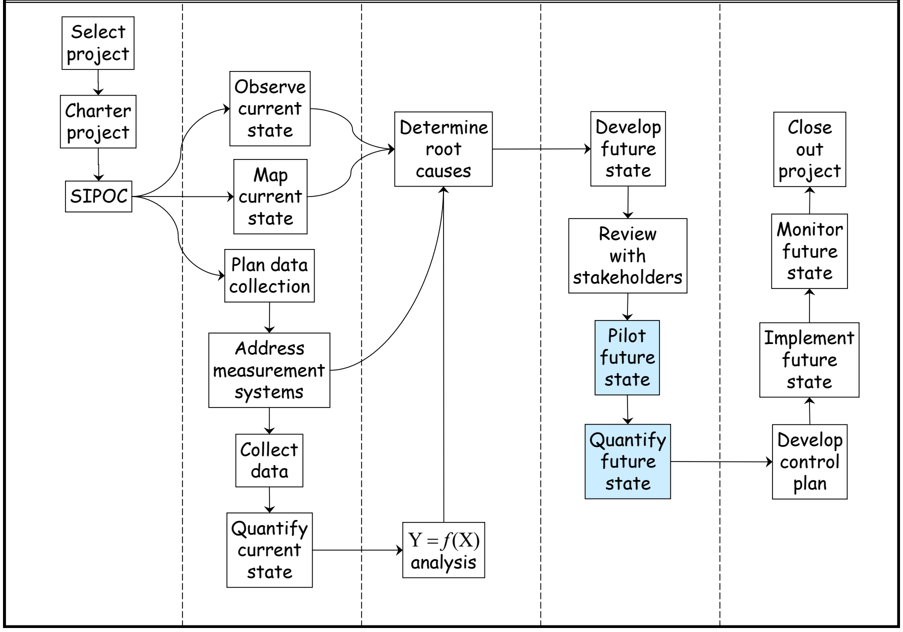
704

	Current state	Future state	Reduction
Average daily number of stock outs	2.1	0.02	99%
Average time to fill mat’l requests	4 hrs	2.3 hrs	42%
Annualized direct labor cost	$91,000	$1,000	99%

704

35 Piloting the Future State

705



705

Piloting the future state

706

- Small scale implementation under close observation
- Scope should be limited*
- Time period should be relatively short

*We try to scope LSS projects into manageable chunks. Because of this, the pilot scope may sometimes be the same as the project scope.

706

Benefits of piloting

707

- Identify unanticipated failure modes
- Identify unintended consequences
- Indicates whether or not improvement objectives will be met
- Reduces problems in full scale implementation

Piloting checklist

708

- ❑ What is the scope? (Location, work area, product, customer, duration, . . .)
- ❑ Who are the participants? (Process owner, process participants, stakeholders, team members, . . .)
- ❑ What data is to be collected? (Y variables and project metrics should be same as in Define and Measure phases.)
- ❑ What measurement systems will be used? (These may have been improved during the project.)
- ❑ What is the sampling plan and sample size necessary to represent typical variation sources?
- ❑ Have we communicated plans to all concerned parties?

Sample size calculation for a pilot study

709

Student Files → calculator - sample size → Comparisons

Y is a quantitative measurement		
Sample size per population	9	Sample size for the pilot
Standard deviation of Y	1	Current state standard deviation
Desired DTD	1	Baseline average minus goal
Actual DTD	0.9993	Set C7 to the value in C6 by changing C4 (Use *Data → What-If Analysis → Goal Seek*)
% Confidence level	95	

Y is pass/fail, yes/no, etc.		
% Defective - population A	10	Baseline value from charter
% Defective - population B	5	Goal from charter
DTD	5	
Sample size per population	213	Sample size for the pilot

DTD = Difference to Detect

Example: quotation process pilot study

710

Scope of the pilot: Business Unit 8

Std Dev = 2.7 days

Metric	Baseline (BU 8)	Goal
Average TAT	3.4 days	1.5 days
TAT > 3	37.5%	10%

DTD = 1.9 days

If you have more than one statistical metric, you must use the largest of the calculated sample sizes

Quantitative Y variable	
Sample size per population	17
Standard deviation of Y	2.7
Desired DTD	1.9
Actual DTD	1.8999
% Confidence level	95

Pass/fail Y variable	
% Defective - population A	37.5
% Defective - population B	10
DTD	27.5
Sample size per population	18

Sample size for the pilot should be at least 18

TAT = Turnaround Time

Exercise 35.1

711

Open *Student Files* → *calculator–sample size* → *Comparisons* and use the info given below to calculate the sample size for each metric for the MBDP pilot.

Metric	Baseline	Goal	DTD	Sample Size (n)
Average PO-PD*	29.5 days	50% reduction		
% PO-PD > 30	38.7%	50% reduction		
% MFG not happy	49.4%	50% reduction		

* PO-PD = time from Purchase Order receipt to Product Delivery

Std Dev of PO-PD = 19.5 days

What should be your minimum sample size for the pilot study?

Analyzing pilot results

712

- Collect observations — what worked, what didn't
- Statistical comparison of "before" and "after"
- Evaluate improved project metrics relative to goals
- Establish new statistical baselines
  - They will form the basis for statistical monitoring after implementation

Redux: Significance testing — Pass/Fail Y

713

Based on the data given below, did our project achieve the goal of a 50% reduction in % defective?

	Sample size	No. defective	% Defective
Current state	500	147	29.4%
Future state pilot	10	1	10.0%

Student Files → calculator - chi square test

Group labels	Defective? Yes	No	Sample size	% Defective	P-value
Current	147	353	500	29.40	**0.1808**
Future	1	9	10	10.00	
Totals	148	362	510		

Did we use an adequate sample size for the Future State pilot study?

713

Redux: Significance testing — Quantitative Y

714

Open *Data Sets → lead time.*

Did our project achieve the goal of a 50% reduction in average lead time?

Process	Lead time
Current	71
Current	81
Current	75
Current	87
Current	93
Current	67
Current	89
Future	61
Future	58
Future	42
Future	55
Future	54
Future	61
Future	49

Current	Future
71	61
81	58
75	42
87	55
93	54
67	61
89	49

Data
↓
Data Analysis
↓
Anova: Single Factor
↓
OK

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance	Std Dev
Current	7	563	80.42857	95.61905	**9.8**
Future	7	380	54.28571	47.2381	**6.9**

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2392.1	1	2392.071	33.489	**8.65E-05**	4.747225
Within Groups	857.14	12	71.42857		p = 0	
Total	3249.2	13				

Did we use an adequate sample size for the Future State pilot study?

714

Redux: Interpreting P values - “Statistical Standard of Evidence”

715

Probability of NO difference or correlation (P value)	Level of evidence that samples ARE different or variables ARE correlated	Confidence level (CL) for difference/correlation
1.00		
0.15	None	None
0.05	Some	85% ≤ CL < 95%
0.01	Strong	95% ≤ CL < 99%
& lower toward zero	Very Strong	CL ≥ 99%

715

Notes

716

716

Exercise 35.2

Open *Student Files* → *Case Studies* → *MBDP* → *MBDP current* & *future pilot*.

a) Test for a significant improvement in average PO–PD. Give the P value and its interpretation in terms of standards of evidence.

b) Did we achieve our goal of 50% reduction for average PO–PD?

c) (Optional) Create a Box and Whisker Plot showing the change in PO–PD from the current state to the future state pilot.

d) Test for a significant improvement in % PO–PD > 30. Give the P value and its interpretation in terms of standards of evidence.

Exercise 35.2 (cont'd)

e) Did we achieve our goal of 50% reduction for % PO–PD > 30?

f) Test for a significant improvement in % MFG not happy. Give the P value and its interpretation in terms of standards of evidence.

g) Did we achieve our goal of 50% reduction for % MFG not happy?

h) Save your work and keep the file open.

Exercise 35.3

719

Open *Student Files* → *Case Studies* → *quotation process* → *quotation process current & future pilot*.

a) Test for a significant improvement in average TAT (turnaround time). Give the P value and its interpretation in terms of standards of evidence.

b) Did we achieve our goal of 1.5 days for average TAT?

c) Optional: Create a Box and Whisker Plot showing the change in TAT from the current state to the future state pilot.

719

Exercise 35.3 (cont'd)

720

d) Test for a significant improvement in % TAT > 3. Give the P value and its interpretation in terms of standards of evidence.

e) Did we achieve our goal of reducing % TAT > 3 to 10%?

f) Test for a significant improvement in the PO hit rate. Give the P value and its interpretation in terms of standards of evidence.

g) Save your work and keep the file open.

720

Margin of Error (MOE) calculation for a pilot study

721

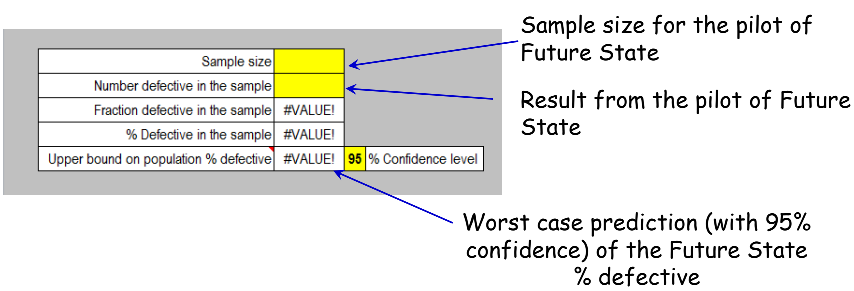
- In Module 22 Data Collection, we explored the concept of the Margin of Error (MOE) and how to use it to calculate a sample size to estimate Current State population baselines for project metrics.
- We learned that the more precisely we wanted to estimate an overall percent defective or average, the more we had to “spend” in sample size.
- When we are analyzing results from a Future State pilot study, the resulting P value will be affected by the sample size.
  - If we get a P value of 0.05 or less, we have strong evidence of a difference. In this case, it may be helpful to get a prediction of how high an overall defect rate could go, or an upper and lower bound on the average for the Future State process.
  - If we get a P value of greater than 0.05, i.e., some or no evidence of a difference, and we suspect we didn’t “spend” enough on our sample size, it could be helpful to get a prediction of whether a larger sample size would have made a difference.
- The *Student Files→ calculator – margin of error* will give us these boundaries.

721

MOE calculation for a pilot study — Pass/Fail Y

722

Student Files→ calculator – margin of error → % Defective



722

Example: pilot study MOE calculation — Pass/Fail

723

We'll use our Redux on Significance testing for Pass/Fail Y

	Sample size	No. defective	% Defective
Current state	500	147	29.4%
Future state pilot	10	1	10.0%

Open *Student Files→ calculator – margin of error → % Defective*

Sample size	10		
Number defective in the sample	1		
Fraction defective in the sample	0.1000		
% Defective in the sample	10.00		
Upper bound on population % defective	39.4	95	% Confidence level

In our Redux, we found p = 0.18 — no evidence of difference. A higher upper bound on the future state % defective than the current state baseline is another way of saying there is no evidence of difference. However, we noted the fact of the small sample size for the pilot.

723

Example: pilot MOE calculation — Pass/Fail (cont'd)

724

We can use the *calculator – margin of error* to make some predictions of what would happen if a larger sample size with the same defect rate were used.

Sample size	170		
Number defective in the sample	17		
Fraction defective in the sample	0.1000		
% Defective in the sample	10.00		
Upper bound on population % defective	14.62195	95	% Confidence level

- An upper bound of 14.6% overall defective sounds a lot better than the Current State average of 29.4%.
- It may be worth collecting more samples for the Future State process before giving up on the proposed improvements.

724

MOE calculation for a pilot study — Quantitative Y

725

Open *Student Files→ calculator – margin of error → Pop. mean of quant. Y*

Sample size (N)	
Sample mean	
Sample standard deviation	
% Confidence level	95
t-value	#NUM!
MOE for population mean	#NUM!

Confidence interval
(#NUM! , #NUM!)

Sample size, mean and std. dev. for the pilot of Future State

Predicted 95% confidence interval on the population mean (range within which the *center* of the population distribution would fall).

Using the MOE calculator is a way to be a careful consumer of data. In addition to the P value, it helps us evaluate whether the significant difference is worth the cost to implement it by giving us a "confidence interval" on the benefit.

Example: pilot study MOE calculation — Quantitative Y

726

We'll use our Redux on Significance testing for Quantitative Y

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*	***Std Dev***
Current	7	563	80.42857	95.61905	**9.8**
Future	7	380	54.28571	47.2381	**6.9**

Open *Student Files→ calculator – margin of error → Pop. mean of quant. Y*

Sample size (N)	7
Sample mean	54.29
Sample standard deviation	6.87
% Confidence level	95
t-value	2.9687
MOE for population mean	7.7119

Confidence interval
(46.57 , 62.00)

We can also enter a larger N with the same mean and std dev for the Future State to see the effect on the confidence interval.

In our Redux, we found p = 0 — very strong evidence of a difference. The MOE on the average lead time gives us an upper bound of 62 days, much lower than the Current State average of 80.4!

Exercise 35.4

727

Open *Student Files → Case Studies → MBDP → MBDP current & future pilot*.

Go back to your results from Exercise 35.2 for the Future State pilot data and use the appropriate MOE calculator to determine the following information:

a) 95% Confidence Interval on the average PO–PD:

b) Upper bound on the % PO–PD > 30, with a 95% Confidence level:

c) Upper bound on the % MFG not happy:

Exercise 35.5

728

Open *Student Files → Case Studies → quotation process → quotation process current & future pilot*.

Go back to your results from Exercise 35.3 for the Future State pilot data and use the appropriate MOE calculator to determine the following information:

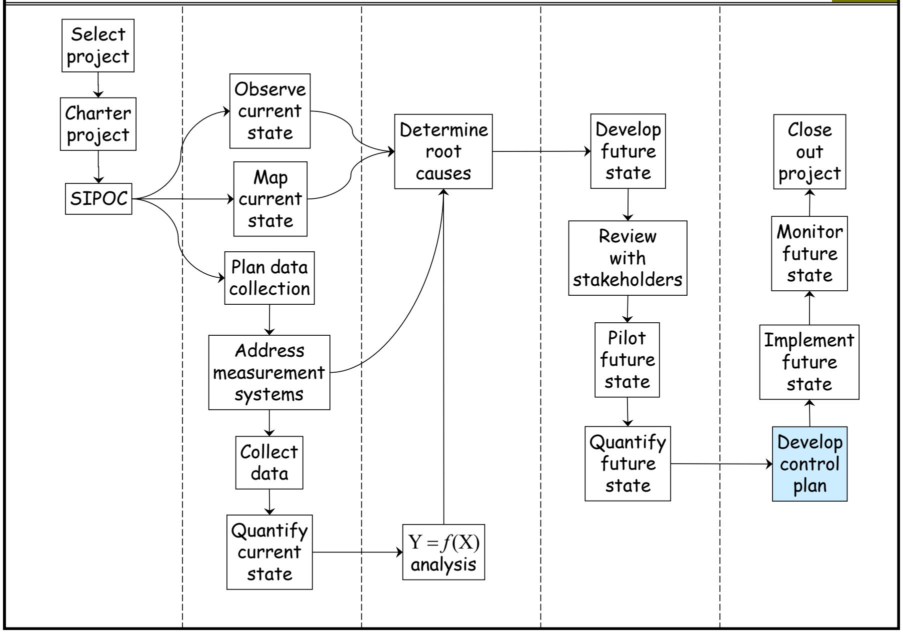
a) 95% Confidence Interval on the average TAT:

b) Upper bound on the % TAT > 3, with a 95% Confidence level:

c) Upper bound on the PO "No" rate:

36 Control Plan

729



729

What is a control plan?

730

- A summary of the plan to sustain the gains from a LSS project
- The project team helps the in–scope process owner and participants develop the plan
- Project team advises the in–scope process owner and participants on statistical monitoring issues
- Most common control methods: standardized practice/procedure, training, auditing, control chart
- Most common control chart quantities: *individual measurements*, *averages*, and *percentages*

730

Student Files → blank control plan

731

Process name:	
Process owner:	
Revision date:	

Process step	Control method	Frequency	Data variable	Meas. system	Metric to monitor	Control limits		Response plan owner	Response plan location
						Lower	Upper		

731

Student Files \ Case Studies \ tool development \ tool development control plan

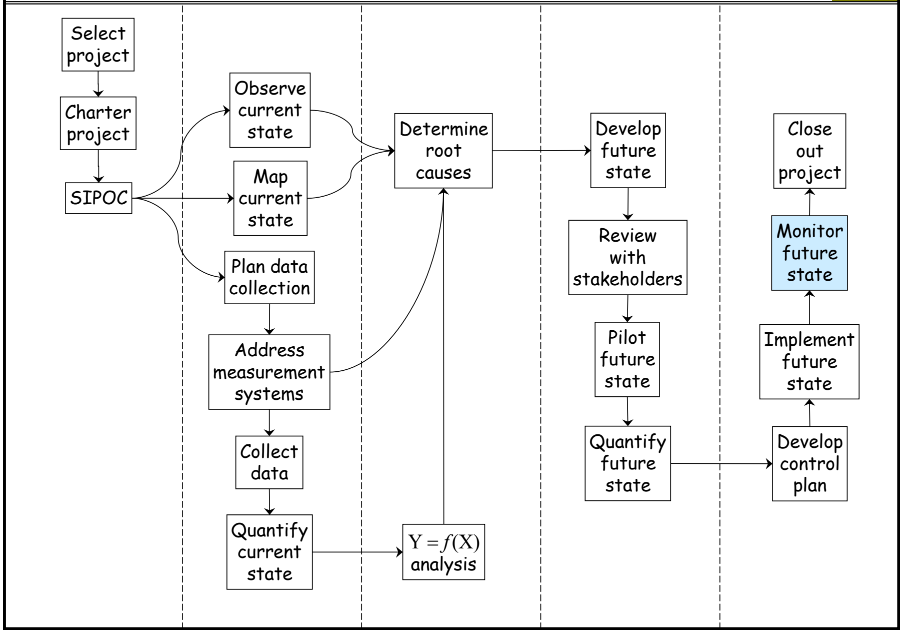
732

Process name:	Tool Testing Process
Process owner:	Testing Area Manager
Revision date:	

Process step	Control method	Frequency	Data variable	Meas. system	Metric to monitor	Control limits		Response plan owner	Response plan location
						Lower	Upper		
Determine run conditions	Audit compliance with new procedure requiring special approval to change weight or line speed	Monthly, then Quarterly	Run conditions						
Determine run conditions	Disable weight and line speed controls on test line								
Release to manufacturing	Control chart	Weekly	Number of days in testing	Database	Average		TBD	Testing area manager	TBD
Release to manufacturing	Control chart	Weekly	Number of rework cycles	Database	Average		TBD	Testing area manager	TBD
Dimensional inspection	Install DVT gage and train testers to use it								
Dimensional inspection	Periodic gage R&R	TBD	Spec dimensions	DVT	% of Tolerance		TBD	Testing Engineer	TBD

732

37 Statistical Monitoring



733

Statistical monitoring*

- Two kinds of variation
- Quantifying common cause variation
- Establishing control limits
- Commonly used control charts
- Interpreting control charts
- Response plans
- Relationship to Process Capability

*The more commonly used term is Statistical Process Control (SPC), even though it has nothing to do with "control" in the usual sense.

734

Exercise 37.1

735

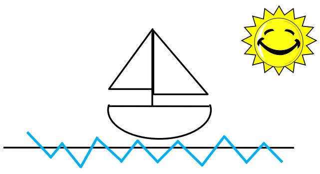
a) Sign your name five times in the space provided below.

b) Put your pencil or pen into the other hand. Sign your name once in the space provided below.

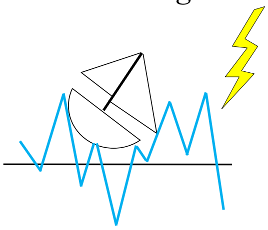
Two kinds of variation

736

Variation due to *common causes*



Variation due to *assignable causes*



Two kinds of variation (cont'd)

737

Common causes	*Assignable causes*
Random variation	Systematic variation
Inherent in the process as currently defined	External factors, mistakes, malfunctions, miscommunications, etc.
Myriad small fluctuations, causes *cannot* be assigned	Relatively few large fluctuations, causes *can* be assigned and removed
Outcomes are predictable within statistical limits	Outcomes are not predictable at all

737

Quantifying common cause variation

738

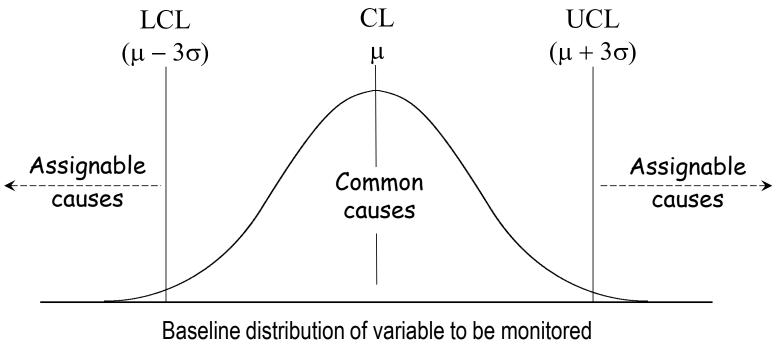
- Common cause variation is usually represented by upper and lower *control limits*
- Upper control limit (UCL) = $\mu + 3\sigma$
- Lower control limit (LCL) = $\mu - 3\sigma$
- These are also called *three-sigma limits*
- Center Line (CL) = μ

738

Common cause variation (cont'd)

739

Control limits provide an *operational definition* of common cause variation

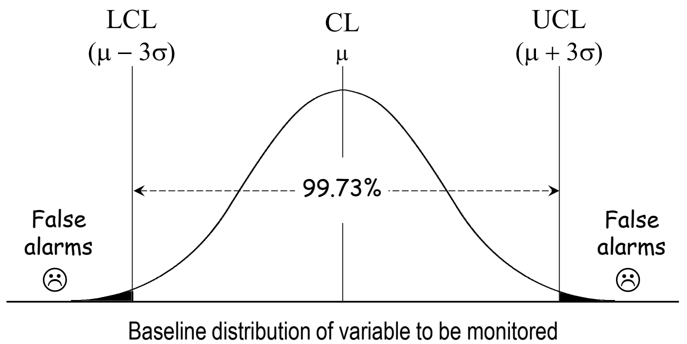


μ = average
σ = standard deviation

Common cause variation (cont'd)

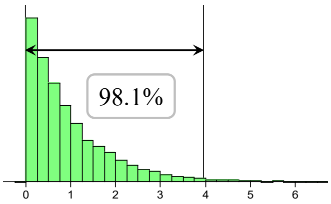
740

If the quantity to be monitored follows a Normal distribution, the chance of a *false alarm* is 0.27%

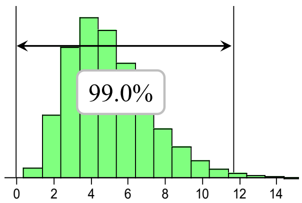


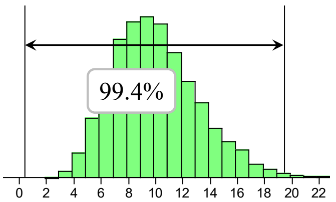
Common cause variation (cont'd)

741



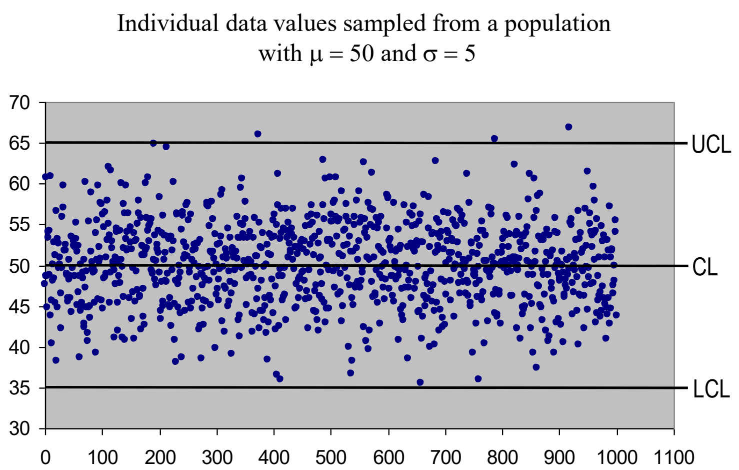
- 3σ limits are shown for three non–Normal distributions
- Data doesn't need to be Normally distributed for most charts
- The *Central Limit Theorem* also greatly reduces the effect of non-Normality when samples are used
- 3σ limits are an economic compromise between *false alarms* and *missed signals*





Behavior of Averages: the "Central Limit" effect

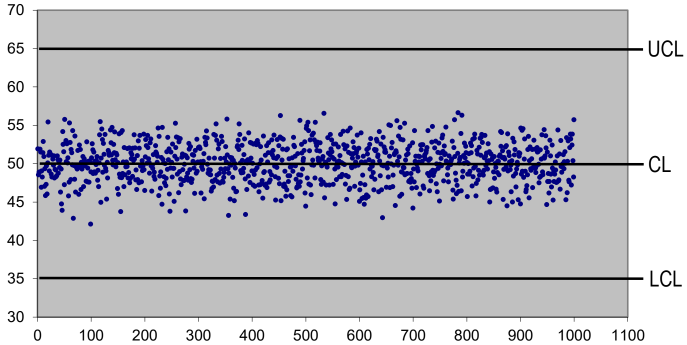
742



Behavior of Averages: the "Central Limit" effect (cont'd)

743

Averages of 4 data values sampled from the same population
with $\mu = 50$ and $\sigma = 5$



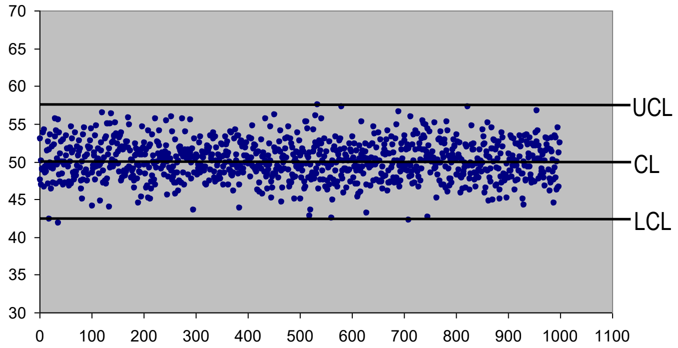
- Why would the limits shown above be ineffective for statistical monitoring of the averages?
- Control limits for a distribution of averages must be calculated a different way.

743

Behavior of Averages: the "Central Limit" effect (cont'd)

744

Averages of 4 data values sampled from the same population
with $\mu = 50$ and $\sigma = 5$



- These are the true control limits for the averages.
- In addition to the obvious narrowing of the distribution, the Central Limit Theorem (stated simply), concludes that subgroup averages converge to a Normal distribution, even if the underlying distribution is non-Normal.

744

The Standard Deviation of Averages

745

If we repeatedly sample sets of N individual data values from a population with mean μ and standard deviation σ, and calculate the average in each case, the *standard deviation of the averages* is:

$$\frac{\sigma}{\sqrt{N}}$$

Control Limits for Averages

746

If we repeatedly sample sets of N individual data values from a population with mean μ and standard deviation σ, and calculate the average in each case, the *three-sigma limits for the averages* are:

$$\text{UCL} = \mu + 3\frac{\sigma}{\sqrt{N}}$$

$$\text{LCL} = \mu - 3\frac{\sigma}{\sqrt{N}}$$

Establishing Control Limits

747

- Control Limits are calculated using data *representative* of day-to-day process operation
- The exact calculation for three sigma limits depends on the type of control chart being used
- The type of control chart used depends on the type of data and the sampling method
- At least 20 – 25 sample subgroups should be used to set control limits
- Data from a pilot run can be used to set control limits for the "future state" process, if the pilot is representative of the process that will be implemented.
  - If not, run the "future state" process long enough to gather a sufficient sample.

Control limits are *not* the same as specification limits!

747

Sampling for control charts

748

To detect process shifts, we need to take a *reasonable* sample of the process.

- Samples should estimate, or try to represent, the population.
- Samples need to be taken in the order of production and as soon as possible in an operation to get an early warning of defects.
- The chance of variation from assignable causes should be *minimized within* an individual sample set (pull parts for a sample close together in time).
- The chance of variation from assignable causes should be *maximized between* samples (time separation between samples).
- Pulling subgroups of parts at a predetermined interval works best.
  - Do not pre-identify which parts will form the SPC sample before they are manufactured (avoid bias).
  - Do not adjust the process during sampling.

748

Common Shewhart control charts

749

Quantitative measurement:

- $\overline{X}$ & s (sample average and standard deviation)
- $\overline{X}$ & R (sample average and range)
- IX and MR (individual values and moving range)

Categorical classification:

- p (fraction defective)

749

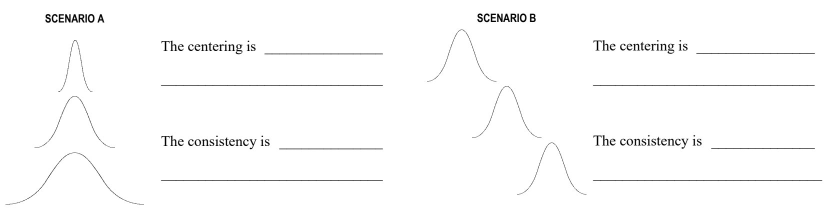
Quantitative control charts

750

With quantitative control charts, we pull samples from the process and use them to estimate how the process as a whole is performing.

We can then answer two important questions using two graphs:

1. Is the process staying centered?
2. Is the process staying consistent?



750

Quantitative control charts (cont'd)

751

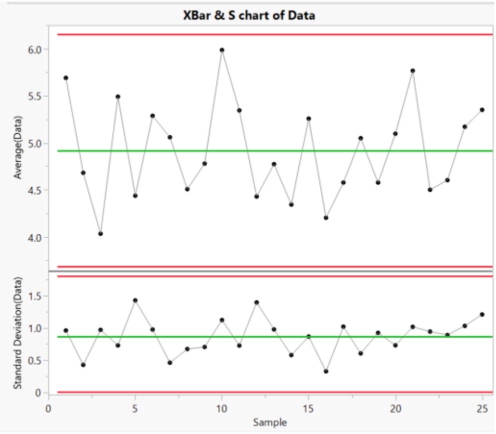
Control Chart	Statistics Plotted	Sample Size	Description
X-bar & R	Average & Range	2–5	The X-bar and R chart was the first and most common quantitative control chart used in SPC, only because in the days before calculators and statistical software, Range was easier to calculate than Standard Deviation. The X-bar and R chart can be useful for monitoring product, process or environmental characteristics when the sample size is fairly small (say 5 or less). But given the prevalence of software tools available, it should really be replaced by the X-bar and s chart unless there is a particular need for spotting "outlier" range values.
X-bar & s	Average & Standard Deviation	5–15	The X-bar and s chart is useful for monitoring product, process or environmental characteristics, especially when the sample size is larger (say, more than 5). Again, the standard deviation chart will be more robust than range because all data are used, not just the highest and lowest numbers.
IX & MR	Individual & Moving Range	1	The IX and MR chart is used when the sample size is one. A single sample may need to be taken because: • It is expensive to take samples. • The measurement method is destructive. • It is the only sample size that makes sense for that process. Because an average cannot be calculated for a sample size of one, the individual data points are used. When there is only one number, standard deviation and range cannot be calculated. Instead, we use what is called the *Moving Range*.

751

Example: $\overline{X}$ and s chart

752

For each sample, the average is plotted on the $\overline{X}$ chart (centering) and the standard deviation (consistency) is plotted below on the s chart.



JMP Output of $\overline{X}$s Chart of *control chart diameter*

752

Control limit calculations for X–bar and s charts

Monitoring frequency	*Metric to monitor*	*Statistic(s) Needed*	*Control limits*
Hourly Daily Weekly Monthly Quarterly etc.	*$\bar{X}$ chart:* Average	Average (μ) Standard deviation (σ)	$UCL = \mu + 3\frac{\sigma}{\sqrt{N}}$ $CL = \mu$ $LCL = \mu - 3\frac{\sigma}{\sqrt{N}}$
	s chart: Standard Deviation	Standard deviation (σ)	$UCL = \bar{\sigma} + 3\frac{\sigma}{\sqrt{2(N-1)}}$ $CL = \bar{\sigma}$ $LCL = \bar{\sigma} - 3\frac{\sigma}{\sqrt{2(N-1)}}$

Control limit calculations for X–bar and s charts (cont'd)

Notes for the $\bar{X}$ and s chart formulas:

σ	is the overall standard deviation, calculated from all the individual data points (the X's from all the samples)
$\frac{\sigma}{\sqrt{N}}$	is the standard deviation of all the sample averages (aka standard error of the mean)
$\bar{\sigma}$	is the average of all the sample standard deviations
$\frac{\sigma}{\sqrt{2(N-1)}}$	is the standard deviation of the sample standard deviations

Exercise 37.2

755

We want to use $\overline{X}$ and s control charts to monitor a critical dimension, diameter, of the parts we are producing. Open *Data Sets → control chart diameter*. Does the baseline data appear to be adequate to represent process variation?
Use Excel formulas for the following:

a) Calculate the average ($\bar{x}$) and standard deviation (s) for each subgroup of five parts.

b) Calculate the overall average, which will be the center line (CL) of the $\overline{X}$ chart. There are two ways to do so: take the average of all the data points or take the average of the subgroup averages. The name given to the statistic from the second method is $\overline{\overline{X}}$ (X-double bar) aka the Grand Average.

c) Calculate the average of the subgroup standard deviations, ($\overline{\sigma}$), which will be the Center Line (CL) for the standard deviation chart.

755

Exercise 37.2 (cont'd)

756

d) Calculate the various components needed for the control limit calculations, as laid out in the file *Data Sets → control chart diameter*:

$\sigma =$ ______ $\sqrt{N} =$ ______ $\frac{\sigma}{\sqrt{N}} =$ ______

$\sqrt{2(N-1)} =$ ______ $\frac{\sigma}{\sqrt{2(N-1)}} =$ ______

e) Use the numbers found above to calculate the upper and lower control limits for each chart.

$UCL_{\bar{x}} =$

$CL_{\bar{x}} =$

$LCL_{\bar{x}} =$

$UCL_s =$

$CL_s =$

$LCL_s =$

756

Control limits for X–bar and R charts

$\overline{X}$ Chart Control Limits:

$UCL = \overline{\overline{x}} + A_2\overline{R}$

$CL = \overline{\overline{x}}$

$LCL = \overline{\overline{x}} - A_2\overline{R}$

R Chart Control Limits:

$UCL = \overline{R}D_4$

$CL = \overline{R}$

$LCL = \overline{R}D_3$

Constants for sample size n

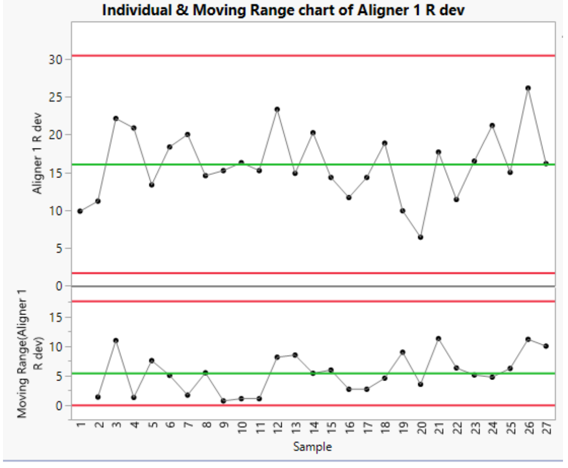
n	A_2	D_3	D_4	d_2
2	1.880	0.000	3.267	1.128
3	1.023	0.000	2.574	1.693
4	0.729	0.000	2.282	2.059
5	0.577	0.000	2.114	2.326
6	0.483	0.000	2.004	2.534
7	0.419	0.076	1.924	2.704
8	0.373	0.136	1.864	2.847
9	0.377	0.184	1.816	2.97
10	0.308	0.223	1.777	3.078

From Introduction to Statistical Quality Control by Douglas C. Montgomery

757

Example: Individual and Moving Range chart

For each unit, the measurement is plotted on the Individual chart and the Moving Range is plotted below.

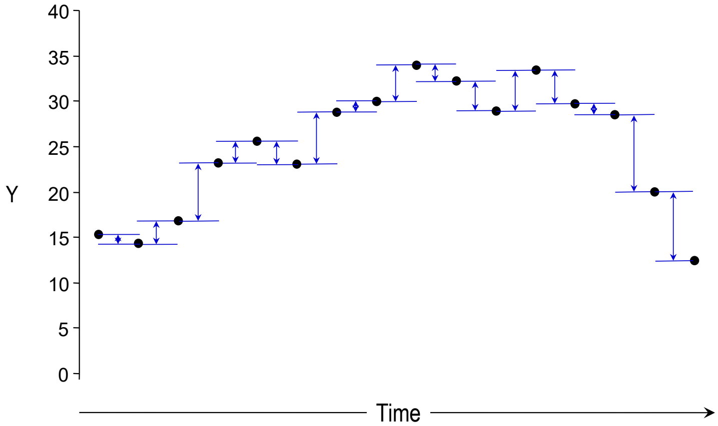


Why is the first point missing on the MR chart?

Estimating standard deviation using the moving range method

759

Each moving range is the absolute value of the difference between consecutive data points.



759

Control limit calculations for Individual and Moving Range chart

760

Individual Chart Control Limits:

$$\mathrm{UCL} = \bar{x} + 3\frac{\overline{MR}}{d_2}$$

$$\mathrm{CL} = \bar{x} \qquad\qquad \mathrm{MR} = |x_i - x_{i-1}|$$

$$\mathrm{LCL} = \bar{x} - 3\frac{\overline{MR}}{d_2}$$

The value of d_2 is 1.128 since the range is between two consecutive points.

Moving Range Chart Control Limits:

$$\mathrm{UCL} = D_4\overline{MR} = 3.267\overline{MR}$$

$$\mathrm{CL} = \overline{MR}$$

$$\mathrm{LCL} = D_3\overline{MR} = 0$$

The same constants shown previously are also used here.

760

Individual and Moving Range chart calculator

761

To make it easier to calculate the moving range, open
Student Files → calculator – individual moving range chart

B4 | =ABS(A4-A3)

	A	B	C	D	E	F	G	H	I
1		Formulas for n=2		Individual Measurements Chart			Moving Range Chart		
2	Data	Moving Ranges	Average Moving Range	LCL	CL	UCL	LCL	CL	UCL
3			0.0000	#DIV/0!	#DIV/0!	#DIV/0!	0.0000	0.0000	0.0000
4		0.0000							
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									

- Paste your data into cell A3
- Copy cell B4 down to the end of your data

761

Example: Individual and Moving Range chart calculator

762

Excerpted data from *Data Sets→ solution properties*

	A	B	C	D	E	F	G	H	I
1		Formulas for n=2		Individual Measurements Chart			Moving Range Chart		
2	Spec grav	Moving Ranges	Average Moving Range	LCL	CL	UCL	LCL	CL	UCL
3	0.9239		0.0007	0.9212	0.9231	0.9250	0.0000	0.0007	0.0023
4	0.9233	0.0006							
5	0.9236	0.0003							
6	0.9224	0.0012							
7	0.9231	0.0007							
8	0.9224	0.0007							
9	0.9231	0.0007							
10	0.9236	0.0005							
11	0.9230	0.0006							
12	0.9233	0.0003							
13	0.9229	0.0004							
14	0.9232	0.0003							
15	0.9225	0.0007							
16	0.9218	0.0007							

- If data (Y variable) ≥ 0 and LCL < 0, ignore LCL
- With MR calculations, the number of decimal places shown may need to be increased

762

Exercise 37.3

763

We want to use $\bar{X}$ and MR control charts to monitor radial deviation. This measurement requires special equipment and is very time-consuming, hence the sample size of one.

Open *Data Sets* → *control chart aligner*

Open *Student Files* → *calculator - individual moving range chart*

a) Copy the R dev data into the calculator (Paste Values).

b) Copy the calculation in cell B4 down Column B, in order to calculate the moving range for R dev. What is the average moving range?

$\overline{MR}$ =

Exercise 37.3 (cont'd)

764

c) What are the control limits for the Individual Chart?

UCL =

CL =

LCL =

d) What are the control limits for the Moving Range Chart?

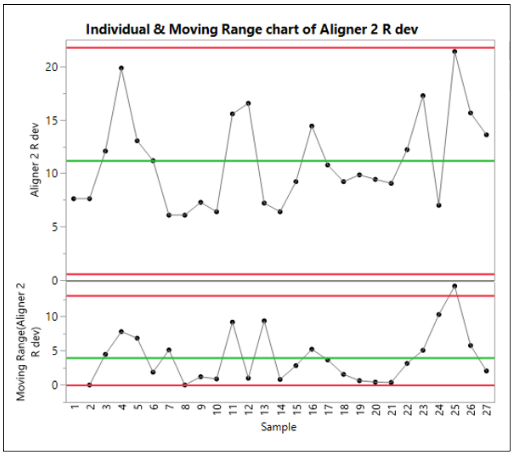
UCL =

CL =

LCL =

Individual & Moving Range chart plotted

765



JMP Output of Individuals & MR Chart of Aligner 2 R dev
Data Sets → control chart aligner

p Chart

766

The p Chart is used when:

- Samples are periodically taken and it's determined whether each unit in the sample is good or bad
- The data plotted is fraction or percent defective

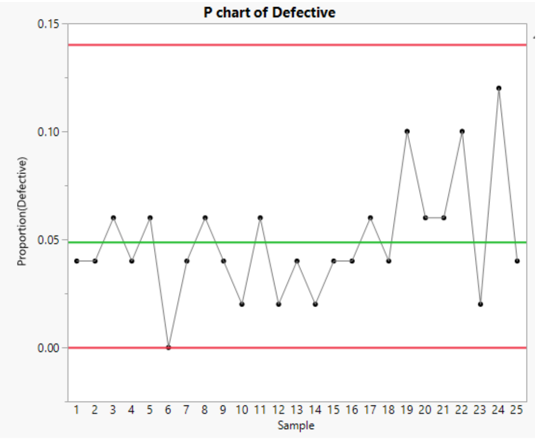
p Chart control limits are based on the Binomial distribution, since pass/fail data is binomial.

- The standard deviation of the Binomial distribution is: $\sqrt{\frac{p(1-p)}{n}}$

p Chart (cont'd)

767

Example of a p Chart (created in JMP)



In this case, there were 50 units in each sample. Overall percent defective was about 5% for this timeframe.

767

p Chart (cont'd)

768

Control Limits for the p Chart

$$\mathrm{UCL} = \bar{\mathrm{p}} + 3\sqrt{\frac{\bar{\mathrm{p}}(1-\bar{\mathrm{p}})}{\mathrm{n}}}$$

$$\mathrm{CL} = \bar{\mathrm{p}}$$

$$\mathrm{LCL} = \bar{\mathrm{p}} - 3\sqrt{\frac{\bar{\mathrm{p}}(1-\bar{\mathrm{p}})}{\mathrm{n}}}$$

$$\bar{\mathrm{p}} = \frac{\text{Total number of defective units in the samples}}{\text{Total number of units in the samples}}$$

$$\mathrm{n} = \text{number of items in each sample}$$

These control limits are the mean +/- 3 sigma for this distribution.

768

Exercise 37.4

769

We want to use a percent defective (p) control chart to monitor the weekly defects per unit occurring during an in-process assembly inspection.

Open *Data Sets → control chart parts inspected & defective*

Use Excel formulas for the following and during calculations, keep the numbers in "fraction defective" form vs percentage:

a) The sample size varies each week, so we'll use an average sample size for calculating control limits. Calculate the average weekly sample size. What concerns might there be about using this number?

b) Calculate the overall fraction defective, $\bar{p}$. Hint: we determined this number in Exercise 23.2 a).

This number will be the center line (CL) for the p chart.

Exercise 37.4 (cont'd)

770

c) Use the average sample size and $\bar{p}$ found above to calculate the upper and lower control limits for the p chart.

UCL =

CL =

LCL =

d) Optional: Copy the formulas for the control limits down the column for all of the data and use line charts to plot the fraction defective with control chart limits.

Other Shewhart control charts

771

Categorical classification:

- np chart: number (count) of defective items per sample with a fixed quantity
- u chart: count of defects per unit
- c chart: count of defects) per sample with a fixed quantity

For np, c and u charts, the control limit calculations and chart appearance are similar to the p chart.

Details of these and other specialized control charts are beyond the scope of this course. More information can be found in any basic statistical process control textbook or reference.

771

Interpreting control charts

772

Once the control chart is created, the most valuable work can begin — discerning what the chart is telling us about process variation.

- Is the process “in control” or “out?”
- Are there warning signs that the process may go out of control soon?
- What actions should be take in response to the control chart signals?

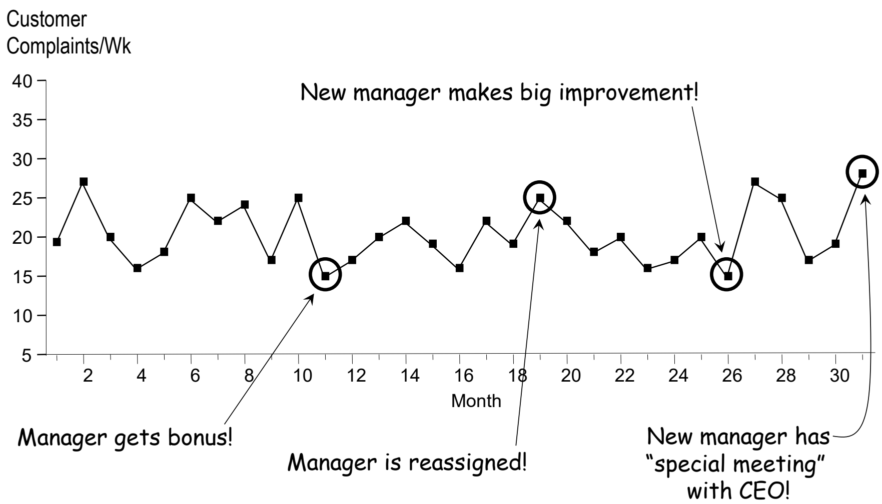
The rules we’ll discuss for deciding whether a process is in or out of control work only for *statistical* control limits — *not* for specification limits.

- Our concern with specification limits is whether an item conforms or not.
- Inspection and testing must be used to screen out bad parts, not control limits.

772

A hypothetical KPI scenario

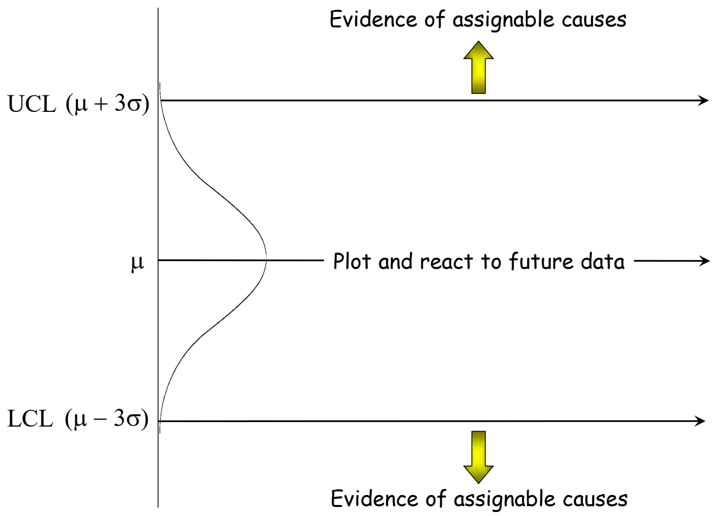
773



773

Using control limits

774



774

Back to our hypothetical scenario

775

Control Limits show there are no assignable causes!

Run charts can cause us to overreact.

775

Using control limits (cont'd)

776

- Control limits provide an operational definition of assignable cause variation
- Simplest rule: points inside the limits are common cause variation, points outside the limits have assignable causes
- 27 in 10,000 common cause data points are expected to fall outside the control limits* — this is the nominal *false alarm* rate
- Assignable causes may occur without producing points outside the limits — these are *missed signals*
- To reduce missed signals, additional rules are sometimes applied

*Assuming a Normal distribution.

776

Using control limits (cont'd)

777

When monitoring a straightforward KPI, such as number of customer complaints/week or monthly on-time delivery, Management may only want to see a chart of the KPI metric itself.

- In this case, it may be sufficient to use an X-bar or IX chart without the associated standard deviation or range chart.
- Adding control limits to the resulting X-bar or IX chart will provide a statistical basis for action.
- It may also be helpful to add a target or goal line to the chart (aligned with the KPI calculation method).
- An associated variation chart could be created for deeper root cause analysis if necessary. For example:
  - Are late deliveries "normal" for the organization?
  - Are there inconsistencies between divisions for global KPI charts?

777

Notes

778

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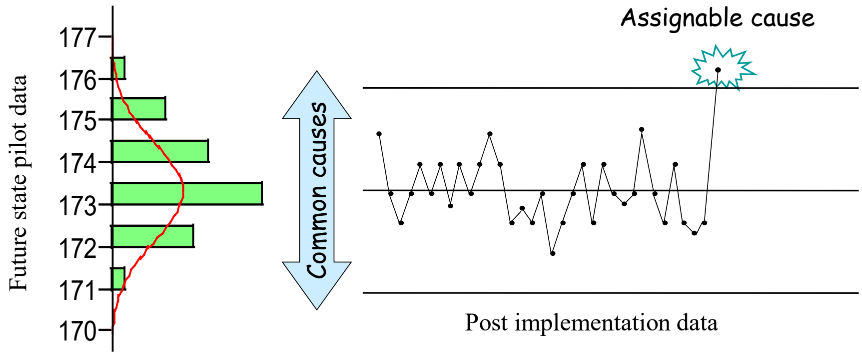
Using control limits (cont'd)

779

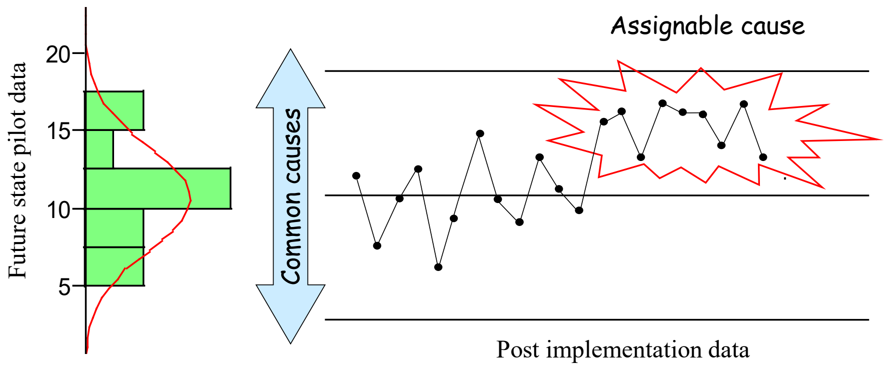


1. This event has probability 0.00135 (0.0027 ÷ 2)
2. Investigate to determine the cause
3. Take corrective action to eliminate the cause

779

Using control limits (cont'd)

780



1. This event has probability 0.00195 [$(0.5)^9$]
2. Investigate to determine the cause
3. Take corrective action to eliminate the cause

780

Additional tests for assignable causes

781

Control chart zones: A, B, and C

Additional tests for assignable causes (cont'd)

782

The zone system is based on 3σ limits

- C is the region within 1 standard deviation of the mean
- B is the region more than 1 but less than 2 standard deviations from the mean
- A is the region more than 2 but less than 3 standard deviations from the mean
- These tests for "statistical significance" are also referred to as the Western Electric Rules.

Additional tests for assignable causes (cont'd)

783

Test 1	One point beyond A (This is the basic test & always used.)
Test 2	9 points in a row on the same side of the average.
Test 3	6 points in a row steadily increasing or decreasing.
Test 4	14 points in a row alternating up and down.
Test 5	Any 2 out of 3 points in a row in A or beyond.
Test 6	Any 4 out of 5 points in B or beyond.
Test 7	15 points in a row in C, above and below the center line.
Test 8	8 points in a row on each side of the average with none in C.

783

OOC Tests most commonly used (and most useful)

784

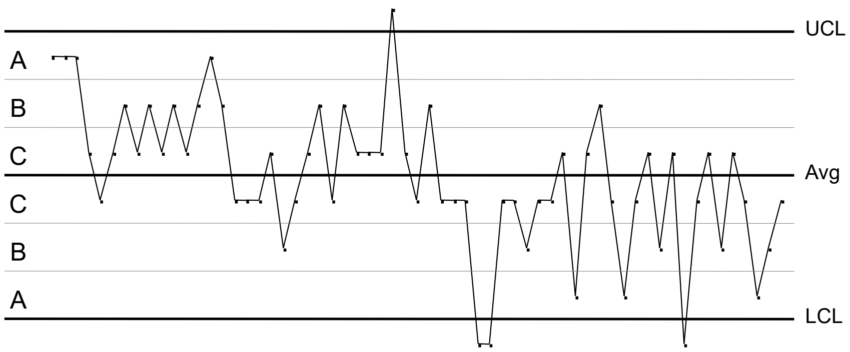
Test 1	One or more points outside the control limits
Test 2	Nine or more points in a row on one side of the average
Test 3	6 points in a row steadily increasing or decreasing

784

Exercise 37.5

785

Circle occurrences of Tests 1 and 2 on the control chart shown below. Indicate which is which.



Exercise 37.6

786

The data sets needed are in the *Student Files \ Case Studies \ quotation process.*

a) Open *quotation process current & future pilot* and *Student Files → calculator – individual moving range chart.*

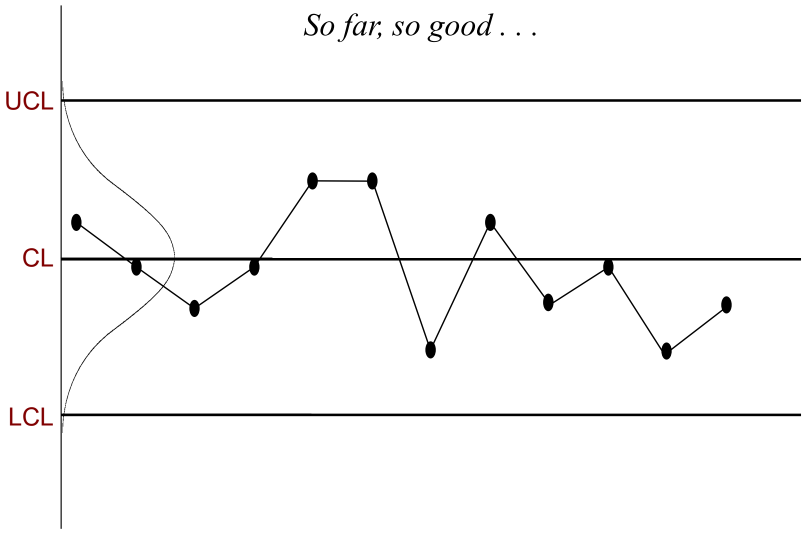
b) Use the future pilot data to calculate control limits for an Individual and Moving Range (IX & MR) chart of TAT.

c) Open *quotation process post implementation*. Create an IX chart by plotting the TAT data, then add lines for the CL and UCL as calculated in (b) for the IX chart.

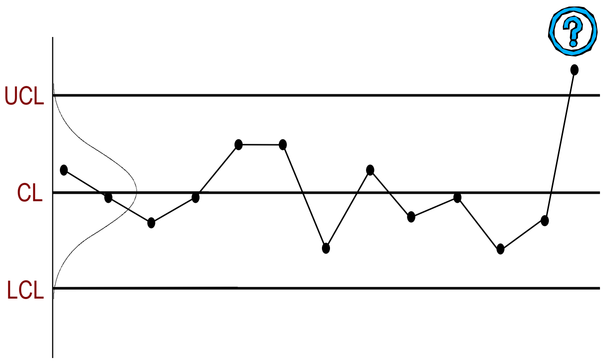
d) Identify the quote number and account manager for any TATs above the UCL.

Response plans

So far, so good . . .



Out-of-control event (OOC)

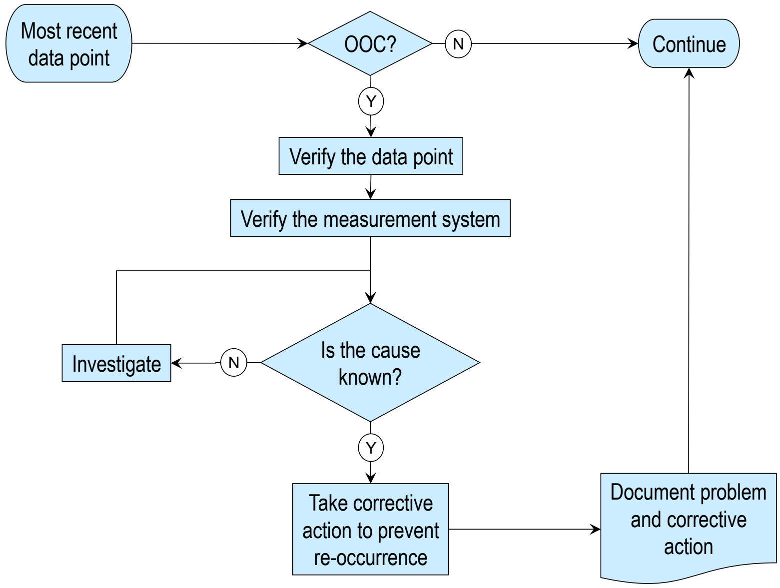


1. Investigate to determine the cause
2. Take corrective action to eliminate the cause

Step 1 requires a *response plan*

Response plan "skeleton"

789



789

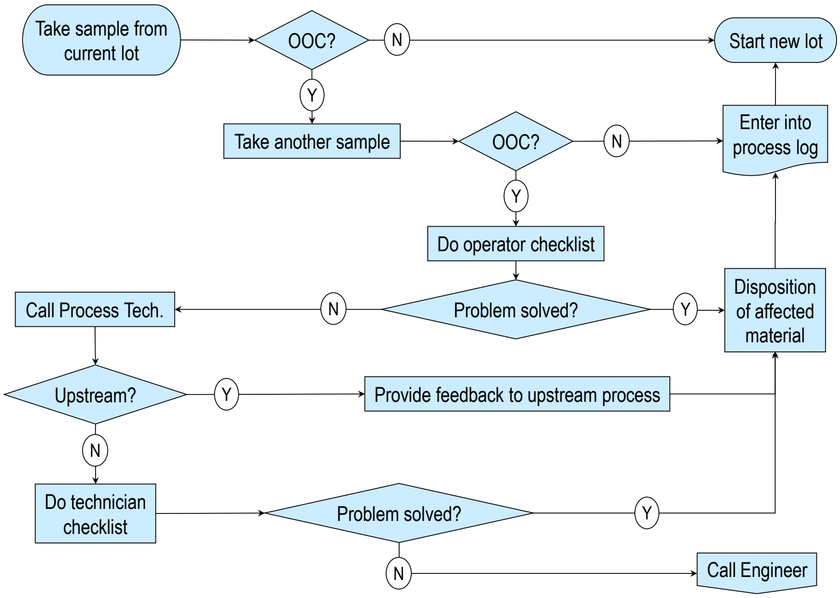
Response plan (cont'd)

790

- OOC stands for *out of control*
- OOC means the control chart indicates an assignable cause according to one or more selected tests
  - ✓ It means something statistically significant has occurred
  - ✓ Whether this condition is good or bad for the process &/or outputs requires knowledgeable interpretation of the control chart
- The success of statistical monitoring depends on having a documented plan for responding to OOCs
  - ✓ The most effective form of documentation is a process map like the ones shown herein
  - ✓ The response plan should be posted in a place clearly visible or easily accessible to process participants

790

Response plan example

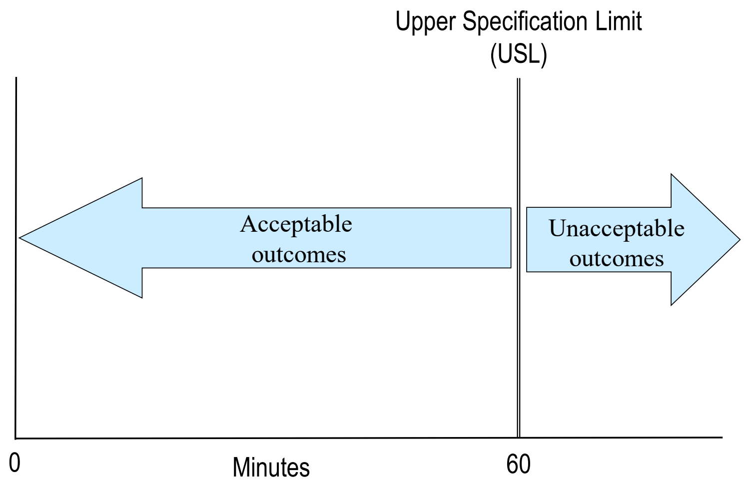


Response plan (cont'd)

- Example from a high-volume automated assembly process ("sanitized")
- Development team: operators, technicians, engineers, area manager
- Based on experience, they wanted to verify an OOC with a second sample from the same lot
- Note the escalation from Operator to Technician to Engineer.
- When an OOC was confirmed, production was halted
- Within a few months:
  - Chronic equipment and process problems were solved
  - Unplanned downtime and need for Engineering support plummeted
  - Engineers able to focus more on process improvement
  - Productivity increased dramatically

What about performance requirements?

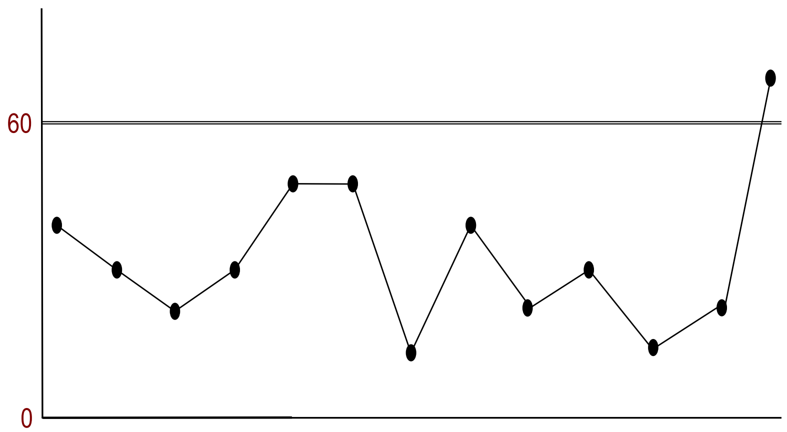
793



Out-of-specification event (OOS)

794

What do we do now?



Scenario 1: process capability is good

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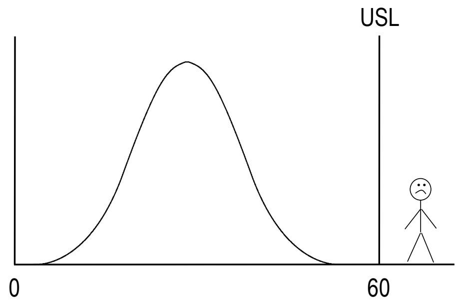
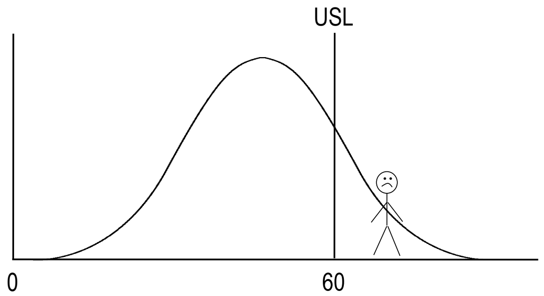


- If the process has good capability, it will virtually never produce a defective outcome, unless there is an assignable cause
- Any OOS point is also OOC
- Any OOS point should trigger the response plan

795

Scenario 2: process capability is poor

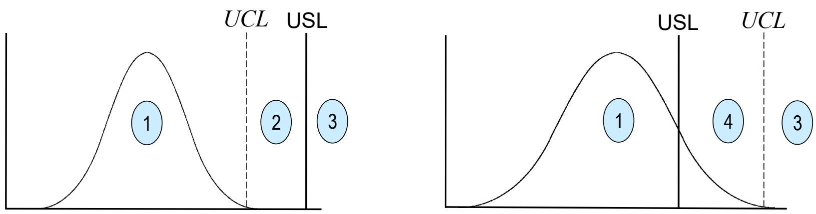
796



- If the process has poor capability, there will be OOS outcomes that are not OOC
- These outcomes do not indicate assignable causes
- They should *not* trigger the OOC response plan

796

Exercise 37.7



Check the appropriate actions for outcomes in each of the 4 zones shown above.

Zone	Initiate OOC response plan	Scrap, rework, do over, etc.	Do nothing
1			
2			
3			
4			

Notes

Project closure and monitoring of the Future State

799

- The project team's work is finished when:
  - ✓ Concerns raised about the Future State process by the process owner, participants, and stakeholders have been addressed
  - ✓ A Control Plan has been developed and implemented in collaboration with the in scope process owner and participants
  - ✓ Changes to equipment, facilities, materials, etc. required for the Future State process have been implemented
  - ✓ Procedural documents have been updated as needed
  - ✓ Necessary training for process participants and stakeholders has been provided
  - ✓ Any other identified action items have been closed
- Although the Six Sigma project is closed, the Future State process lives on under the guidance of the process owner
- Project team members can then be deployed to their next improvement effort!

799

Summary

800

Thank you for participating

in ETI Group's

Lean Six Sigma Green Belt Workshop!

Your Instructor will provide all necessary instructions for the final LSS GB Exam.

The exam is intended to be both an assessment of comprehension and a reinforcement of the DMAIC roadmap.

You will also receive a link to a Course Evaluation.

We appreciate you taking a few minutes of your time to provide us with constructive feedback.

800