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

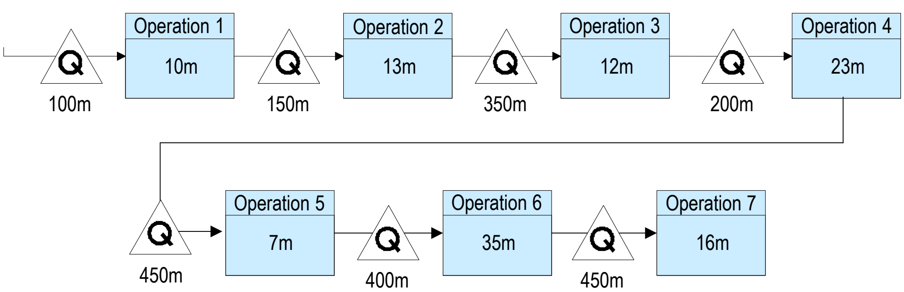
- Activities that are not CVA, but cannot feasibly be eliminated under current constraints
- Examples include audits, reporting, regulatory compliance, etc.
- Goal: Question and reduce

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

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What is the priority: reducing CVA or reducing NVA?

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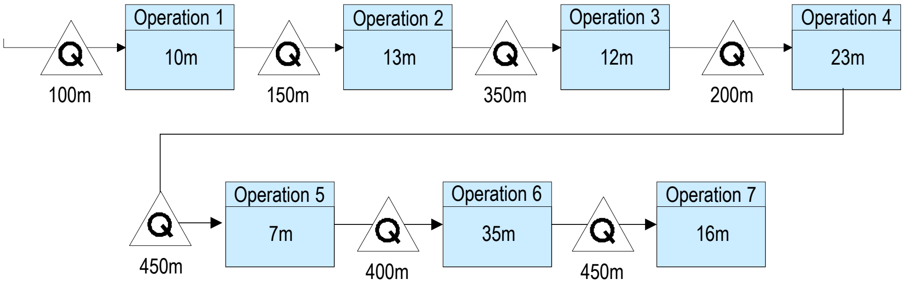

	Current state	50% reduction in process time	50% reduction in wait time
Process time	116 m	58 m	116 m
Wait time	2,100 m	2,100 m	1,050 m
Lead time	2,216 m	2,158 m	1,166 m
Reduction in lead time →		**2.6%**	**47.4%**

Reduce NVA, not CVA!

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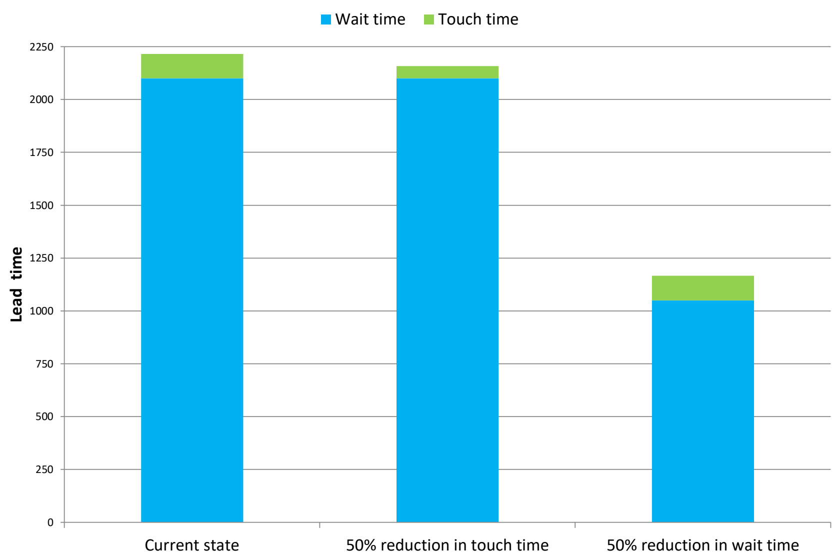

Categories of NVA

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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*: 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*:

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Example of organizing work by department

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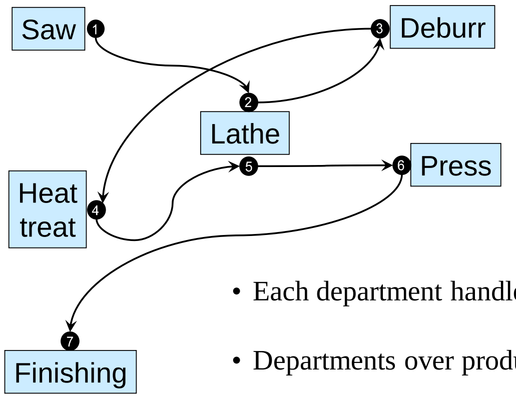

- Each department handles all products → inefficient
- Departments over produce → high levels of WIP
- WIP is valued as an asset — in reality it's a cash sink
- WIP moves between departments in large batches → long lead times, long lags before defects are discovered
- Poor layout → excessive transport

Example of organizing work by value stream

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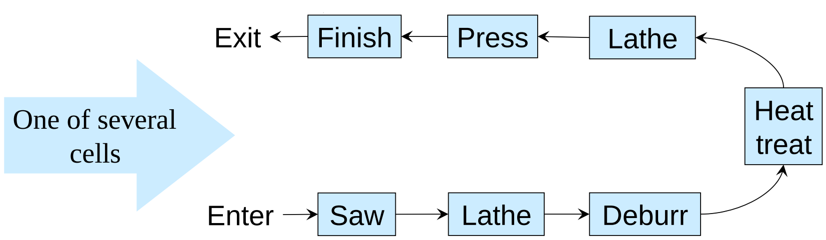

- Each cell handles particular, similar products → efficient
- Cells produce only to current customer demand → low levels of WIP, less cash tied up
- WIP moves through each cell in small batches → short lead times
- Proximity of operations → minimal transport, defects identified immediately

The kaizen culture

- *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"

The spirit of kaizen

- 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

Kaizen events

- *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

Characteristics of a typical kaizen event

- Emphasis on "tribal knowledge" (*a.k.a.* "wisdom of the organization")
- Causes of the problem are not difficult to identify
- Solutions are not difficult to develop
- Bias for action
  - ✓ Develop solutions during the event
  - ✓ Reconsider previous solution ideas that were discarded
  - ✓ Implement solutions during the event if possible

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
  - War room
  - 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*)

μ

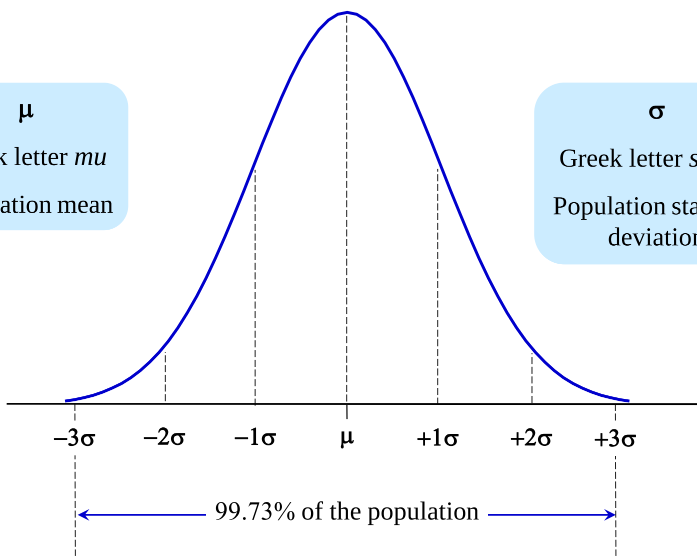
Greek letter *mu*

Population mean

σ

Greek letter *sigma*

Population standard deviation



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Process capability

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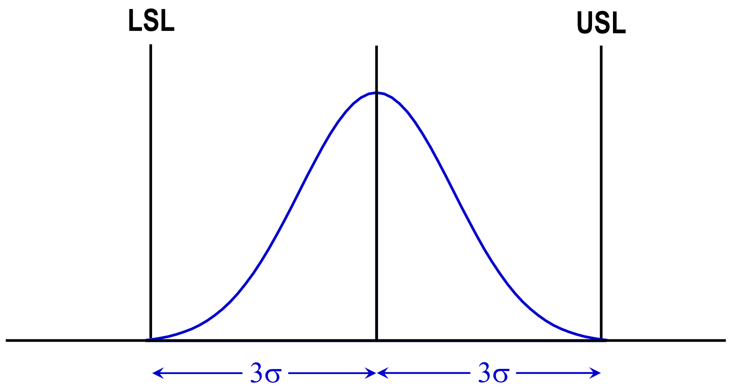

0.27% defective (first pass)

Process capability (cont'd)

24

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

For the Normal distribution shown above, 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 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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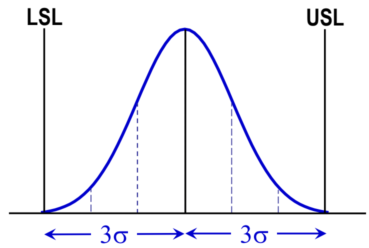
In the 1980s, Motorola questioned the adequacy of 0.27% defective as an improvement objective



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

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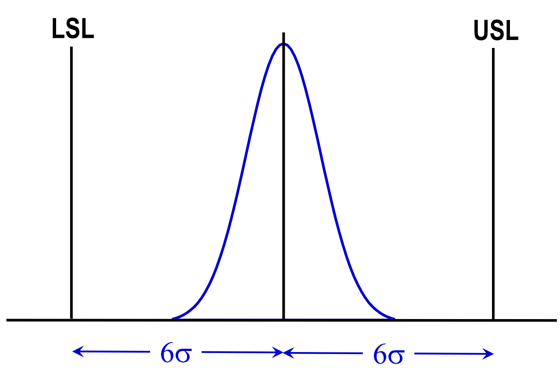
Pursuit of perfect quality (cont'd)

26

Motorola proposed a more aggressive objective



2 defective parts per *billion*

26

Allowing the mean to wander

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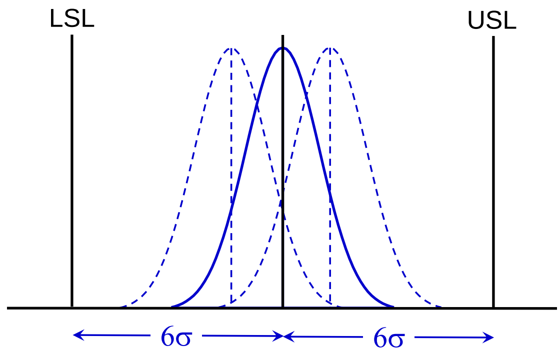

At most 3.4 defective parts per million (DPPM)

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 $\pm$ 1.5σ offset was somewhat arbitrary, but 3.4 DPPM became the definition of "Six Sigma quality"

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

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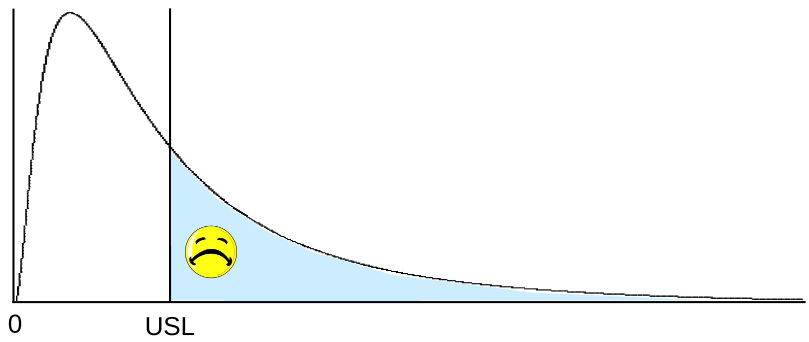
Before improvement project



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. . . in fact, often it isn't

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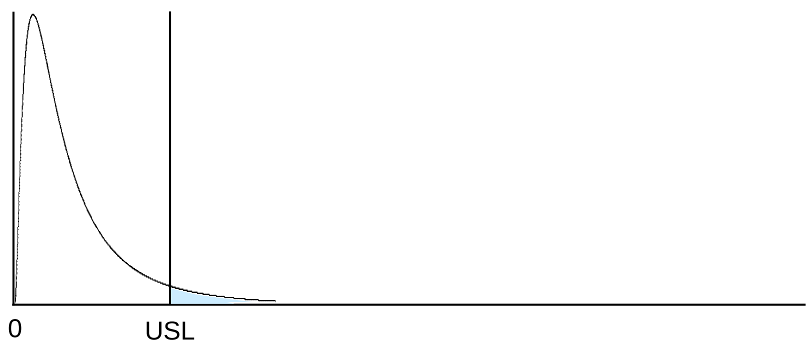
After improvement project



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Why set the quality bar so high?

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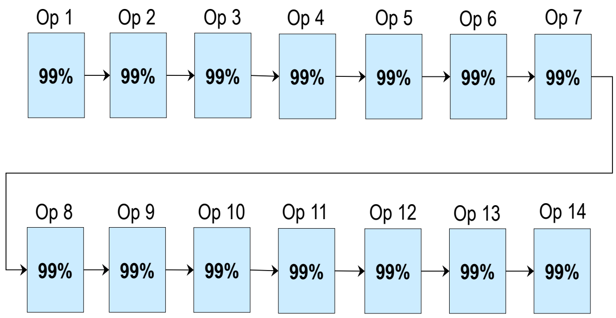
Suppose we have 10,000 DPPM (99% yield) for each operation



Area manager: "Our overall yield is 99%"

Is this true?

We can't repeal the laws of probability!

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$$\text{Overall yield}^{*} = \text{Probability of no defect in 14 operations}$$

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

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

$$= 0.868746 \rightarrow 86.9\%$$

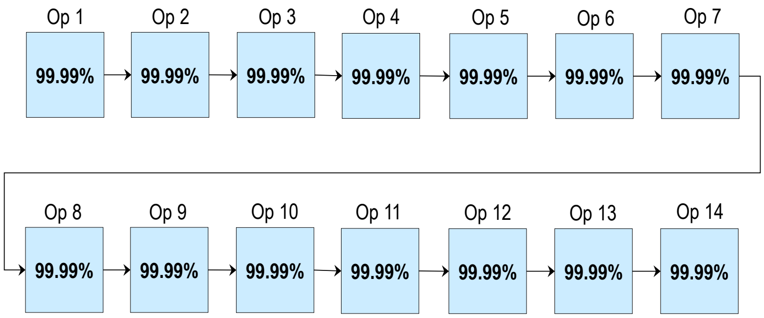
131,254 DPPM

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

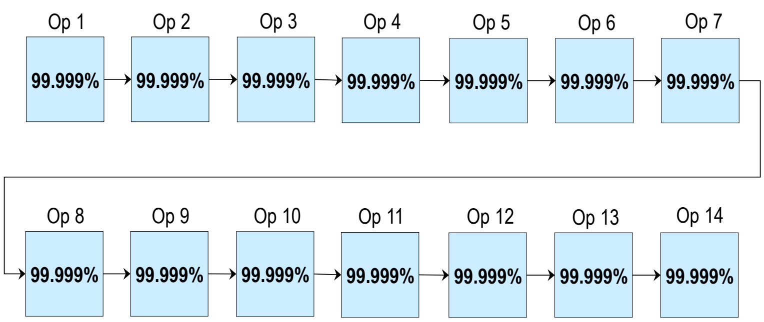
1399 DPPM

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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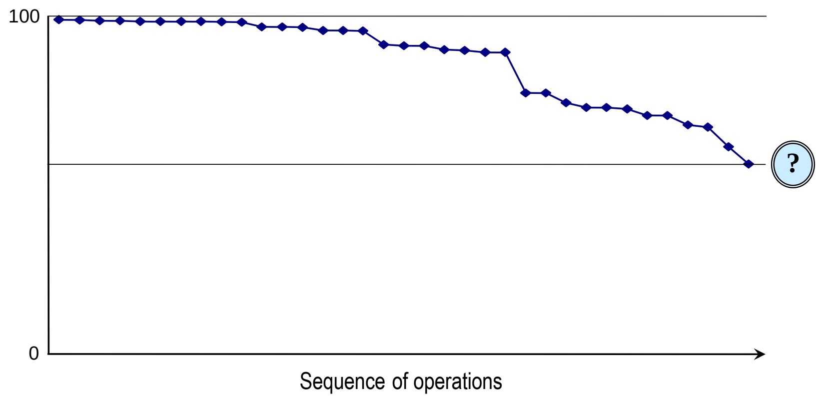
Exercise 2.1

35

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.)



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."*

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

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- 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

In many cases, failure rates are quantified as percentages

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Definition of "opportunity"	Fraction defective	Expressed as a percentage	Focus
Each part	Defective parts / All parts	% Defective	Customer
Each possible defect on a part	Defects / (All parts) × (possible defects per part)	Defects per 100 opportunities (DPHO)	Process
Each transaction	Defective transactions / All transactions	% Defective	Customer
Each possible error in a transaction	Errors / (All transactions) × (possible errors per transaction)	Defects per 100 opportunities (DPHO)	Process

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 RFQ turnaround time (not counting increased PO hit 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

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- 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 TPS solutions can be adapted to many circumstances	Project roadmap provides a method for finding solutions

A single improvement infrastructure

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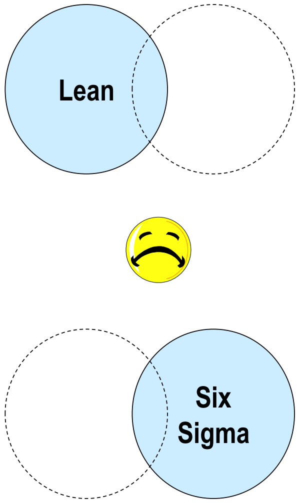

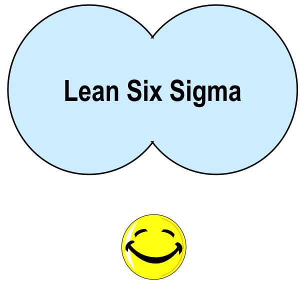

- Eliminates redundancy
- Eliminates wasteful competition for resources
- Provides a universal roadmap for improvement projects

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Lean Six Sigma

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Originally, 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.

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4 Relation of LSS to Other Initiatives

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

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Strategic planning

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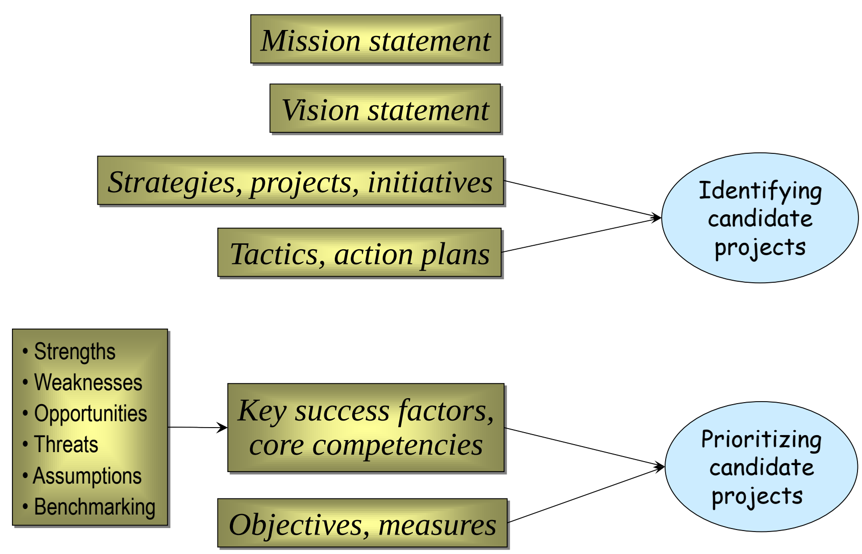

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ISO 9001

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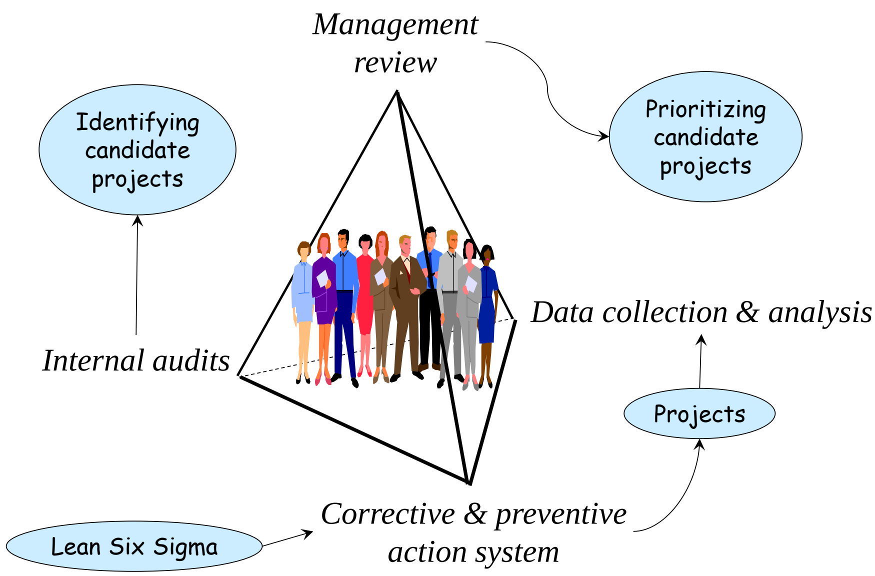

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Voice of the customer

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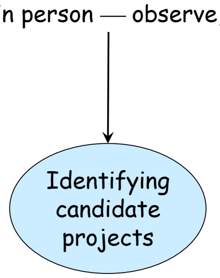
- Resolving complaints does not increase customer satisfaction
- Suppliers must *proactively* discover what customers really want
  - ✓ Collect and analyze data on customer feedback, complaints, returns, . . .
  - ✓ Visit customers in person — observe, listen, learn



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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

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	✓	✓		✓

Must limit projects in process

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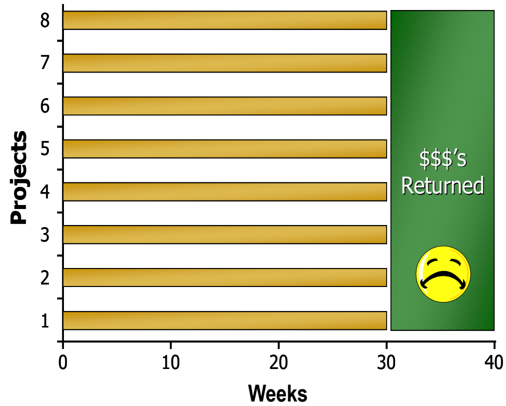

- Suppose we have two "belts", each leading four projects
- They are spread too thin
- It takes a long time to get the projects done
- It takes a long time to accrue the benefits

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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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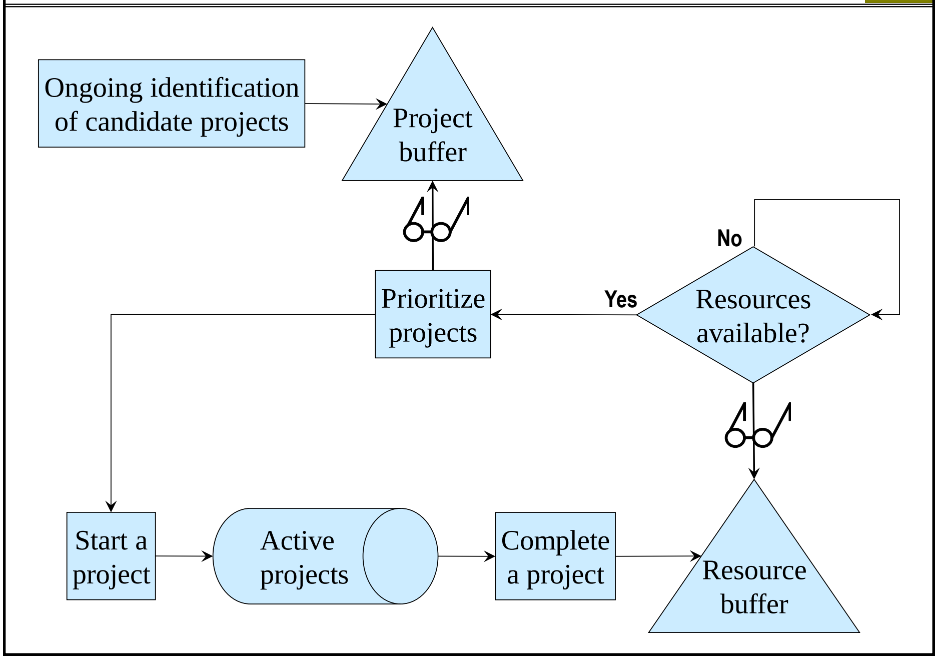
Continuous improvement cycles



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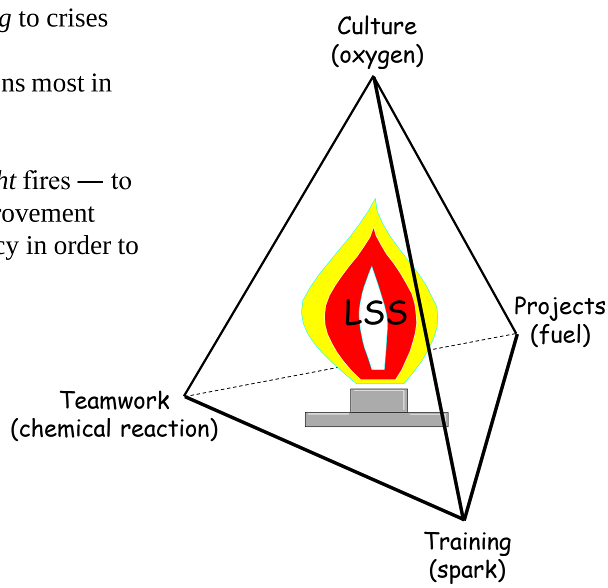
LSS and the Fire model

- 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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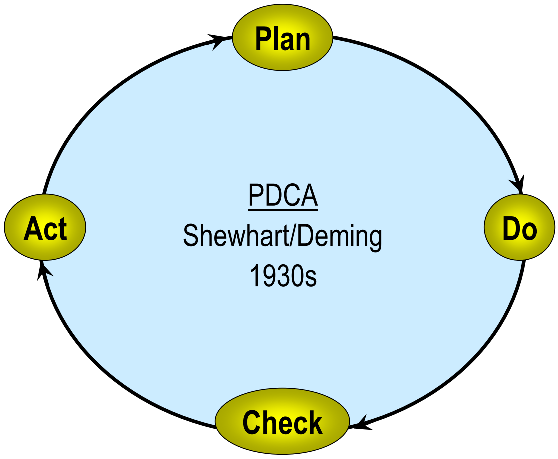

The scientific method applied to business problems

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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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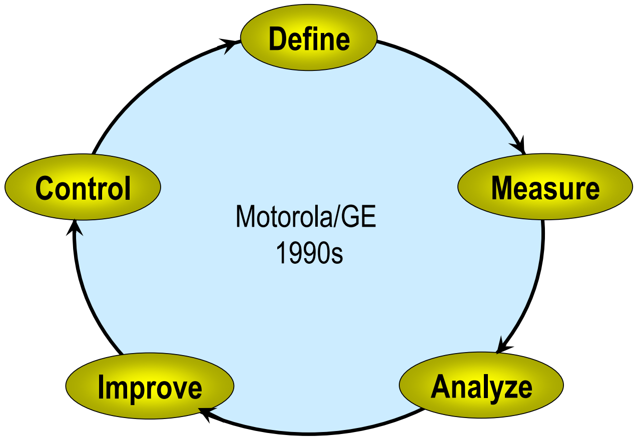
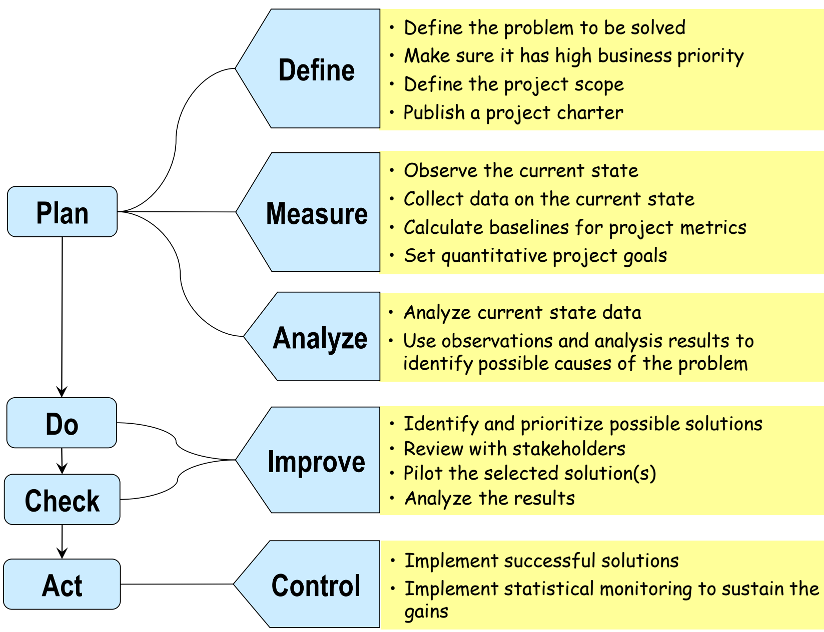


A high level description of today's most widely used improvement project roadmap

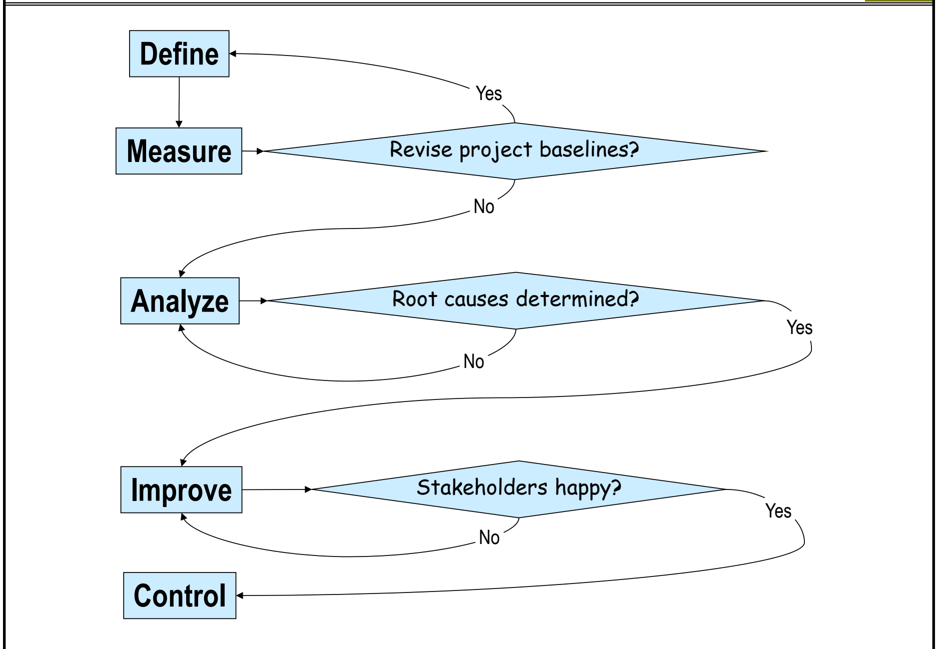
DMAIC has more "teeth" than PDCA

64



Common DMAIC complications

65



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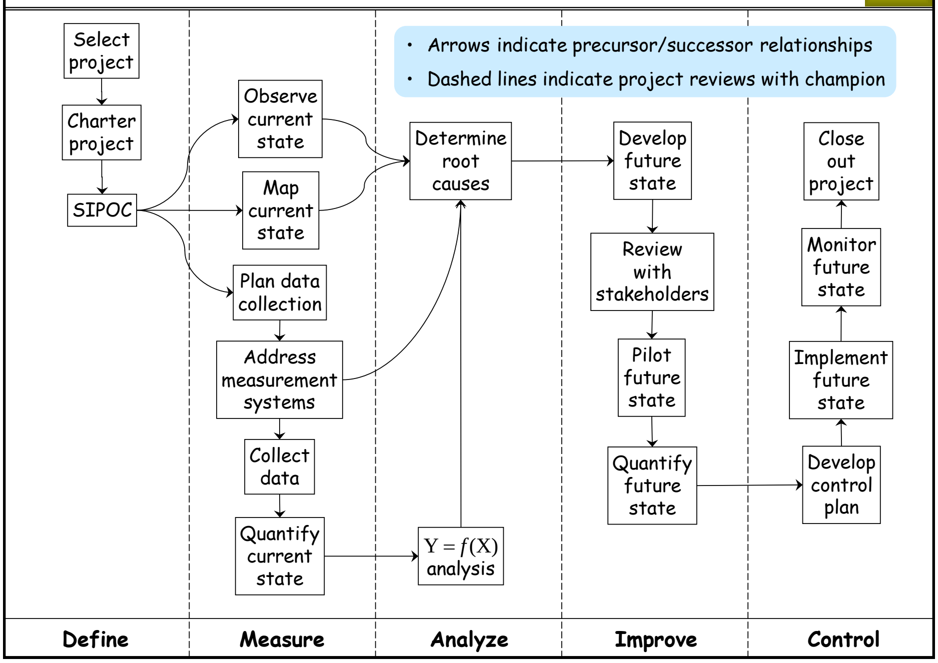
The LSS project roadmap (detailed version of DMAIC)

66



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Strengths of LSS projects

67

- 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

67

Characteristics of LSS projects

68

- 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

68

Examples of LSS projects

69

	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

69

Other types of projects (non-LSS)

70

- 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

70

Examples of non-LSS projects

71

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

71

Exercise 6.1

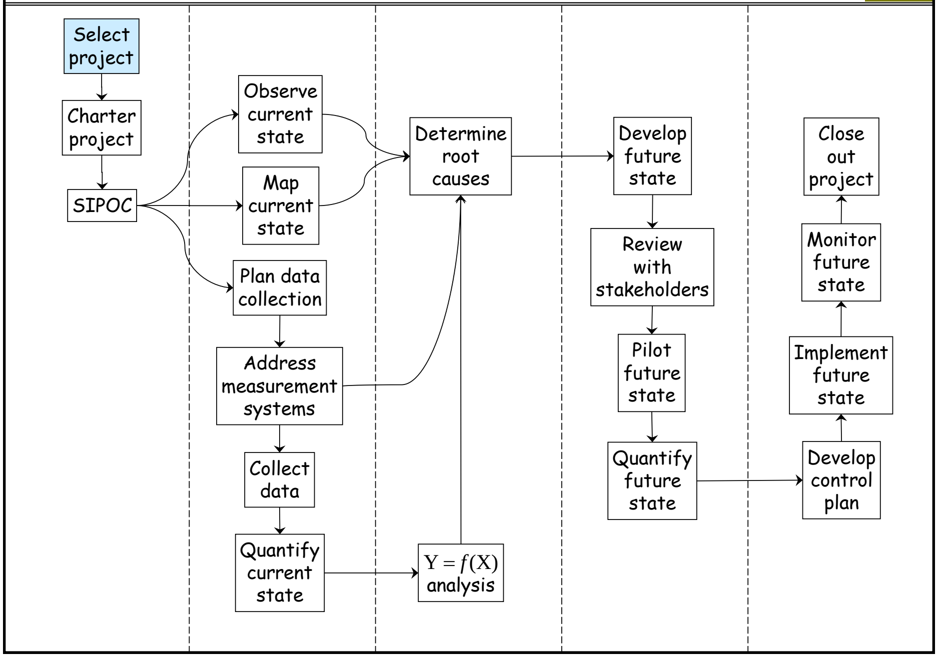
72

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		

72

7 Identifying Candidate Projects

73



Where do candidate projects come from?

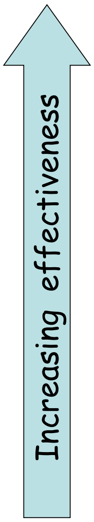
74

- 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

75



- 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 . . .

75

VOC survey method

76

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?

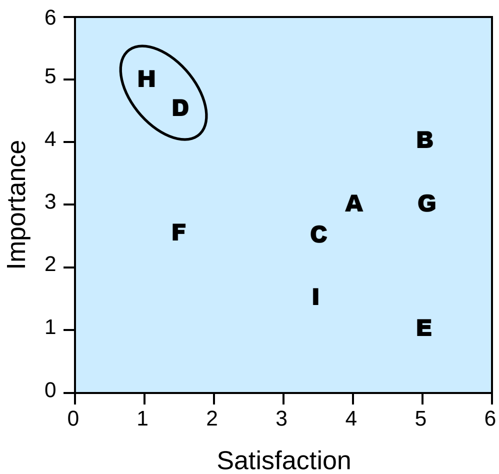
H. What is your level of satisfaction with our delivery performance relative to your requested delivery date?

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

76

"Perceptual map" based on VOC data

77



- 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)

77

Exercise 7.1

78

Think about and be prepared to discuss the following questions:

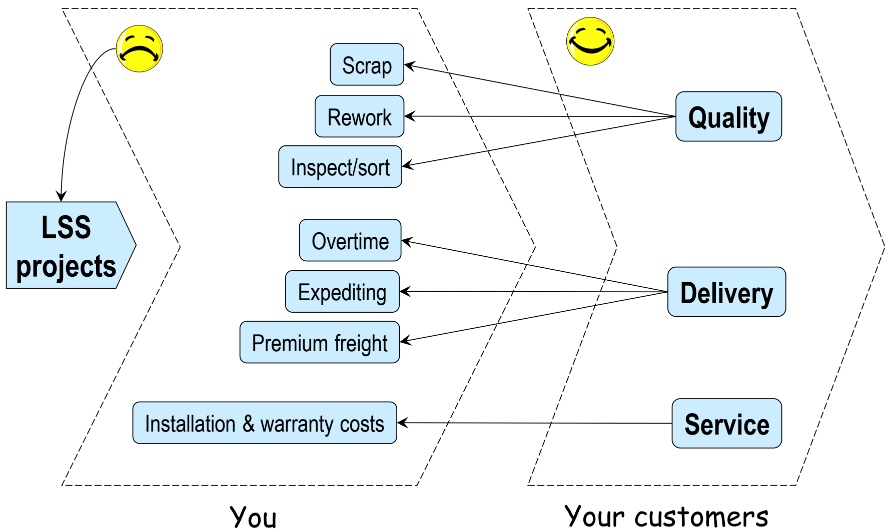
(a) What VOC information does your company receive, and how is it obtained?

(b) Give examples of decisions, actions, or improvement projects based on VOC information.

Often your customers are happy . . .

79

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



79

Cost-of-waste analysis

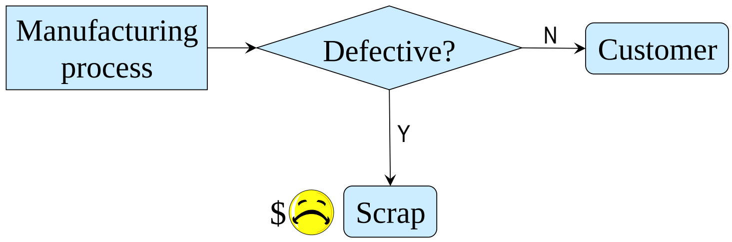
80

- 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

80

Apparent cost of poor quality

81



81

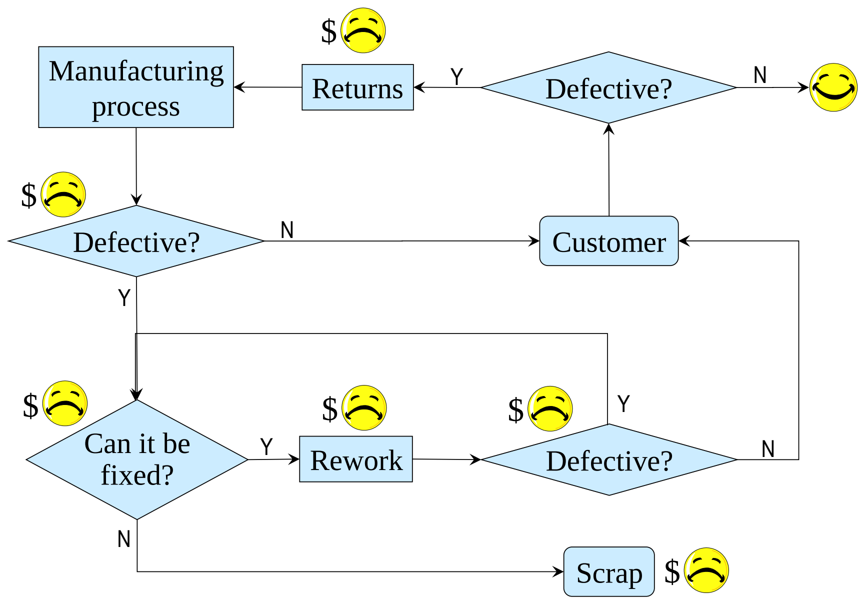
What is the real cost of poor quality?

82

82

The "hidden factory"

83



83

Hidden factory (cont'd)

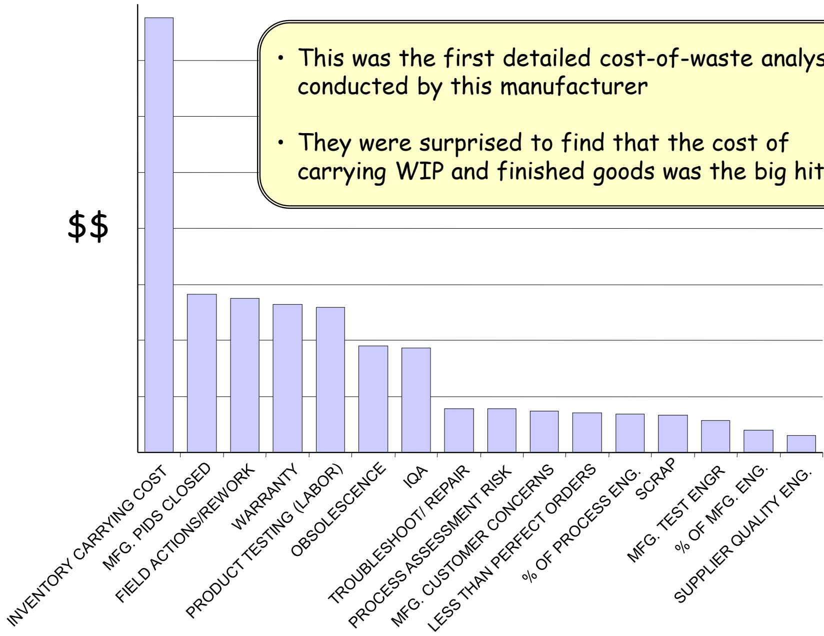
84

- 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

84

Example: cost-of-waste analysis

85



- 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

85

Costs of poor transactional quality

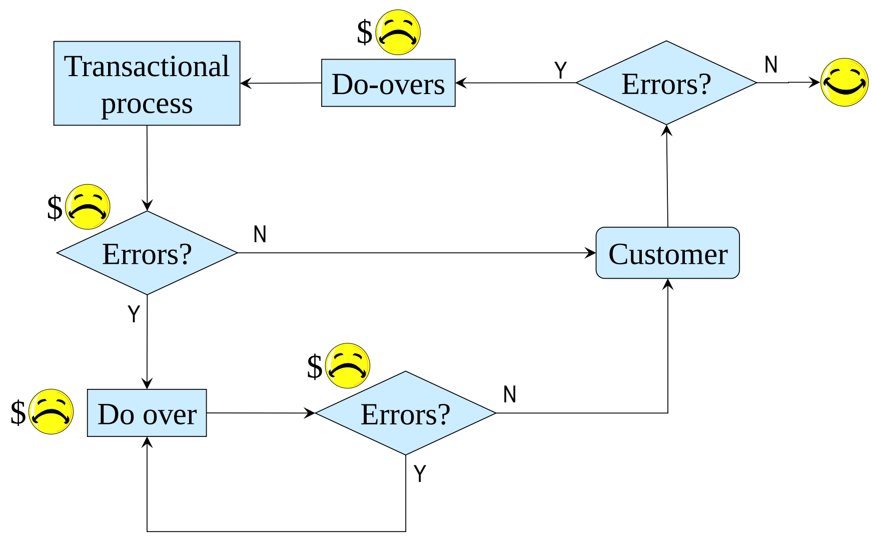
86

- 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

86

The “hidden office”

87



Hidden office (cont’d)

88

- 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

Other costs of waste (from the Lean playbook)

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

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 spread-sheet 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

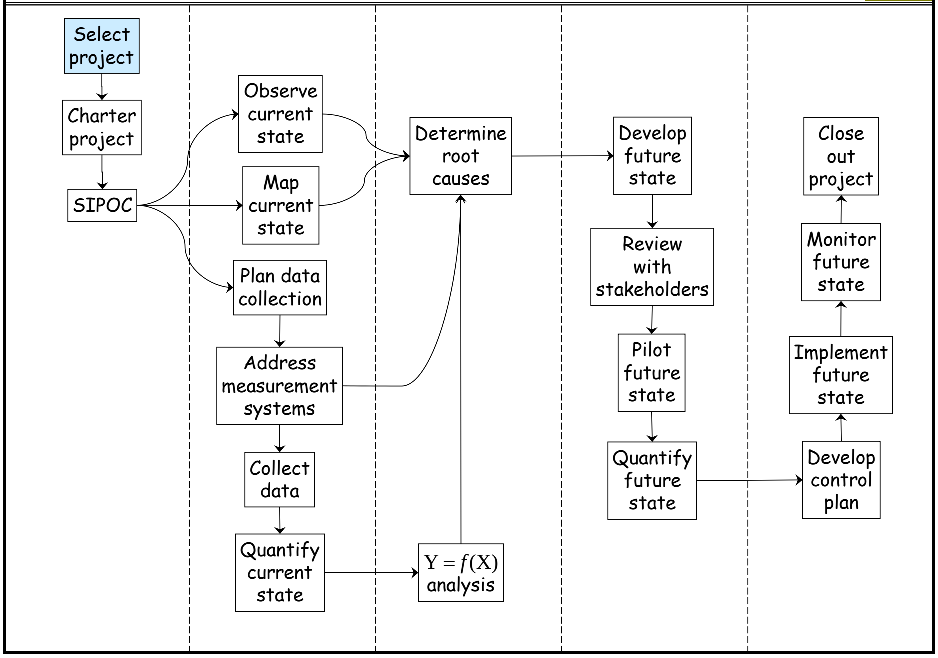
Average rates	
Product cost per dose	$14
Disposal fee per dose	$42
Labor cost per hour	$23

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

91



Qualitative description of a good improvement project

92

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?

Examples of project feasibility metrics

93

- ✓ 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
- ✓ . . .

93

Feasibility metrics (cont'd)

94

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 work flow, then it is valid.

94

Measures of project impact: KPIs

95

- ✓ 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
- ✓ . . .

95

KPIs (cont'd)

96

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.

96

Instructions for prioritizing projects

97

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).

97

Prioritizing projects (cont'd)

98

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.

98

Student Files \ prioritizing projects – example 1

99

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

99

Metrics (cont'd)

100

- 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.

100

Impact ratings

101

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			

101

Comments on impact and feasibility ratings

102

The slide above 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*, 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.

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.

102

Feasibility ratings

103

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

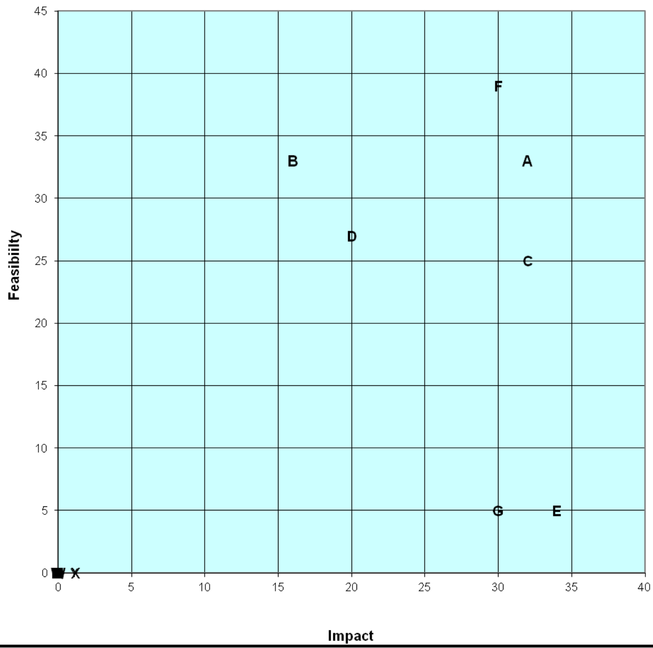
104

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)

105



Impact-feasibility plot (cont'd)

106

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).

Student Files \ prioritizing projects - example 2

107

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		

107

Impact and feasibility scores

108

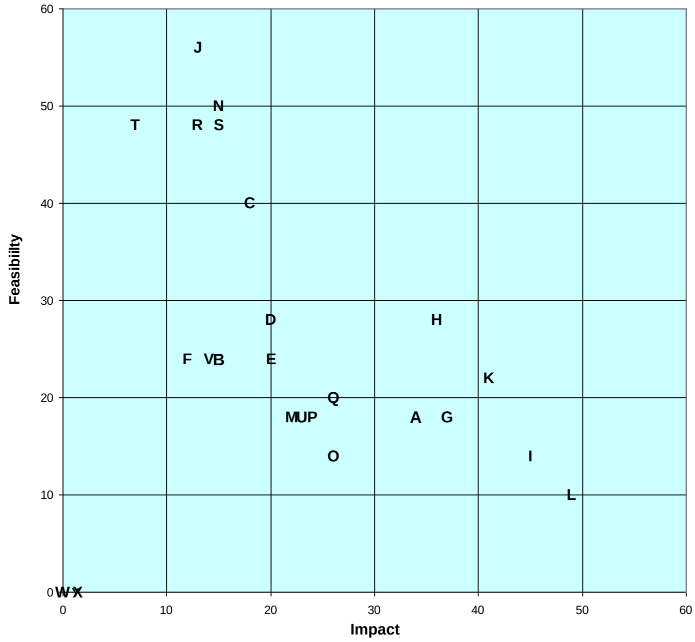
22 projects!

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

108

Impact-feasibility plot

109



109

Impact-feasibility plot (cont'd)

110

- 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

110

Exercise 8.1

111

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

a) If the weights for the given KPIs and feasibility metrics don't fit your company, feel free to change them.

b) Rate the projects with respect to impact

c) Rate the projects with respect to feasibility.

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

Exercise 8.2

112

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.

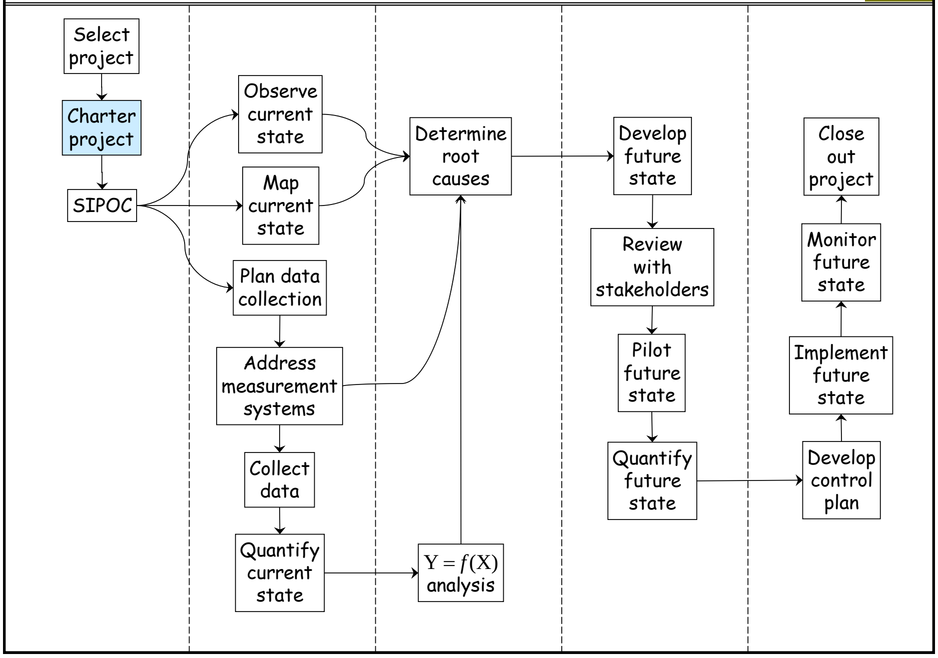
(b) Identify feasibility metrics likely to be used by your organization to prioritize improvement projects.

(c) Compile a list of candidate improvement projects.

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

9 Chartering LSS Projects

113



113

Elements of a project charter

114

- Project title
- Problem and goal statements
- Value stream scope
- Workflow scope
- Constraints, concerns, assumptions
- Primary project metrics, baseline values & goals, KPIs affected
- Secondary ("do no harm") metrics, baseline values
- Team members and roles
- Resources and roles
- Stakeholders and their connection to the project
- Start and project review dates

114

Purpose of the charter

115

- 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

115

The charter must evolve with the project

116

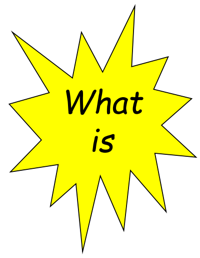
- Baselines for benefit metrics may not be known initially — update the charter when these are determined
- Project scope may be modified as new information comes to light
- Stakeholders may change if the project scope is modified
- Additional resources may be needed to overcome unanticipated barriers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

116

Problem statement

117

- Describes the current situation in objective terms
- Does not suggest or imply 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



117

Problem statement guidelines

118

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.

118

Critiquing a problem statement

119

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.

Checklist for critiquing a problem statement

120

- ❑ What is happening?
  Industrial accidents
- ❑ Who is affected by the problem?
  Employees directly, the company indirectly
- ❑What are the “gaps”?
  2024 had 15, compared to previous average 2.5 and max of 7
- ❑ What are the consequences of not solving the problem?
  Reduced employee safety, $200K cost impact, decreased productivity, OSHA intervention
- ❑ Where does the problem occur?
  Site wide
- ❑ When does the problem occur?
  ???
- ❑ When did the problem start?
  In 2024

Exercise 9.1

Critique this problem statement using the checklist below. 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?
- ❑ 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

123

☹	😐	☺
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 ER, patients are waiting too long.	The average wait time for ER patients has increased from 1 hour to 2 hours.	In the last 6 months, the average wait time for ER patients during peak hours has increased from 2 hours to 4 hours.

123

Evolution of problem statements (cont'd)

124

☹	😐	☺
Regional account managers submit RFQs 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 \ quotation process charter*)

124

Student Files \ tool development charter

125

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.

125

Student Files \ Ti casting charter

126

"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.

126

Exercise 9.2

127

(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.

Exercise 9.2 (cont'd)

128

Problem Statement Outline/Critique

- ❑ What is happening?
- ❑ 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?

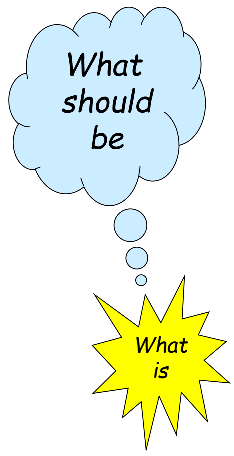
Problem Statement Guidelines

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

Examples of goal statements

129

- Reduce the number of reworks per tool by 50%.
- Meet the 3-day turn-around-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.



Project scope: the two dimensions

130

Value stream scope

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

Workflow scope

- Starts with an RFQ 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.

Examples of constraints and concerns

131

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 • . . .

131

Examples of assumptions

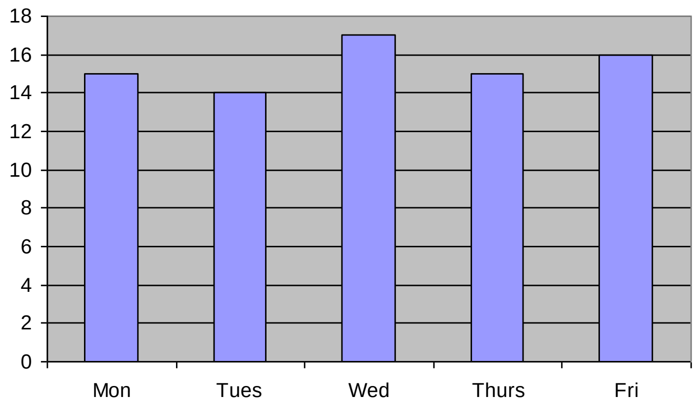
132

- 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
- . . .

132

Project metrics

133

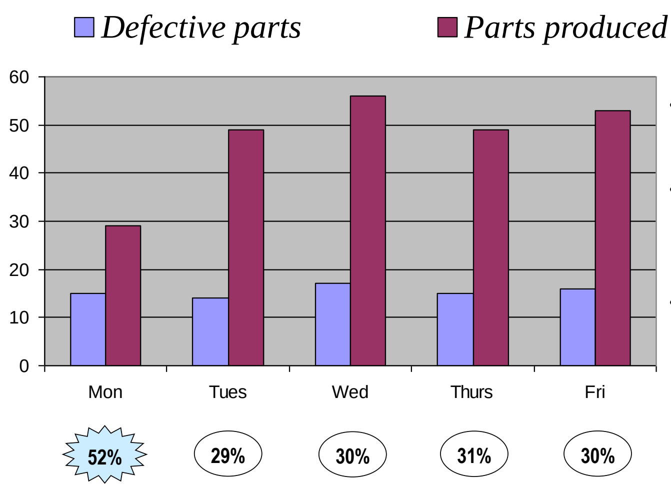


- Total number of defective parts last month, by day of week
- Can we conclude that Tuesdays are best and Wednesdays are worst?

133

Project metrics must be normalized!

134



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

134

Categories of Project Metrics

135

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

136

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?

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
- . . .

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

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

- 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

Setting goals for project metrics

- 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

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

Iteration between team and individual work

144

Team work

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

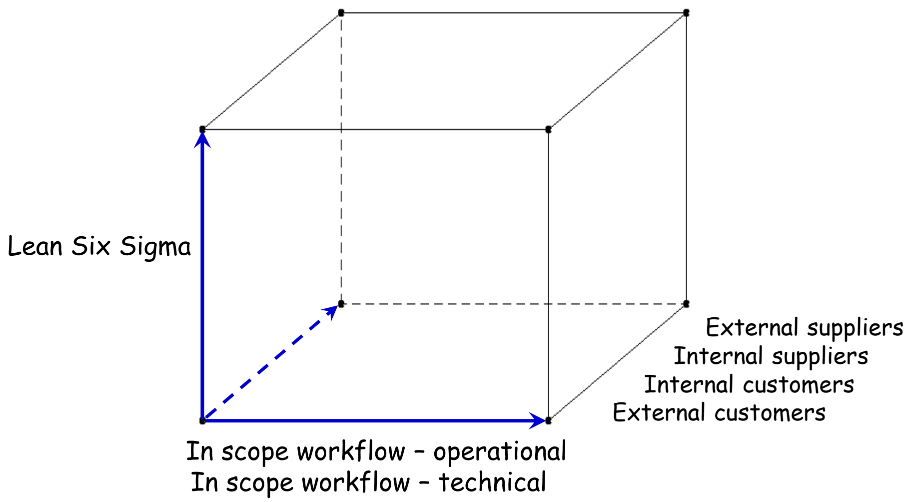
Individual work

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

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 above. 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 work flow must be represented within the team: process participants, customers, suppliers, and other stakeholders.
- Team members with little prior knowledge of the in–scope work flow 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 above. 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 above 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

.
.
.

149

Stakeholders

150

People with a vested interest in the project or its outcome

- 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 he/she has on the project and its outcome, the stronger his/her 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 shown above.

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

Criteria →

Stakeholders	Current position w.r.t. project	Needed position w.r.t. project	Gap between current and needed	Degree of influence	Degree affected	**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 above. 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.

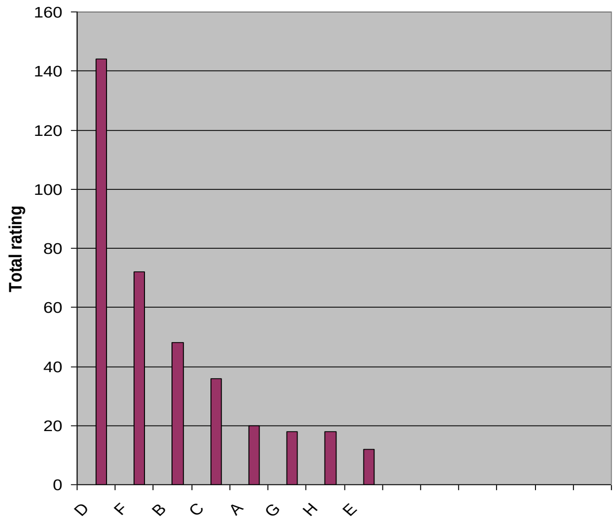
A template for this analysis is in *Student Files \ blank stakeholder analysis*.

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.)

155

PAINT your way into stakeholder support

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.)

156

157

Lean Six Sigma Green Belt Training

Supplement:
Stages of Team Development

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157

Effective Teams

158

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

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

Norming

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

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."

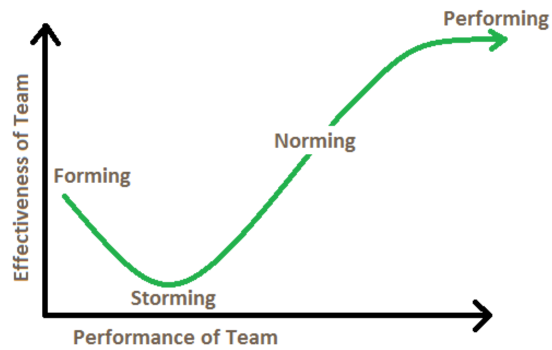
The Adjourning Phase involves team dissolution

- 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



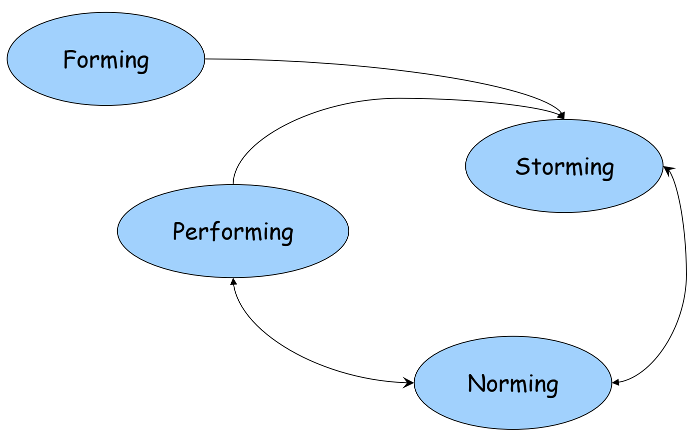
As may be expected, effectiveness is lowest during the Storming Phase but in the long run, successful navigation of this phase is critical to the team's success.

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

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.

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.

167

Stages of Team Development Activity (cont'd)

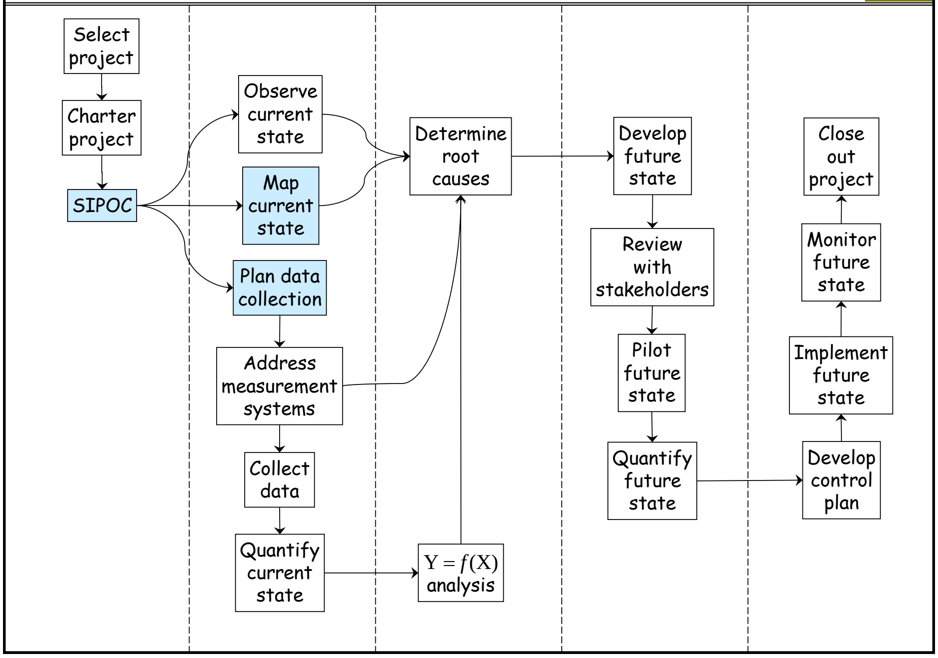
168

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?

168

10 Project Scope and SIPOC

169



Value stream scope

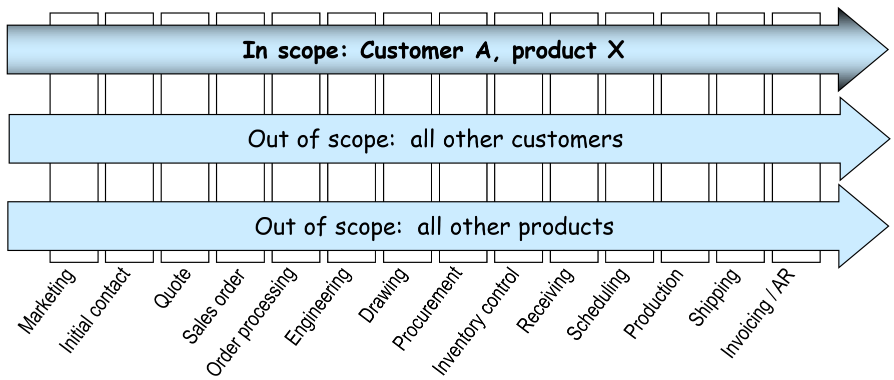
170

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

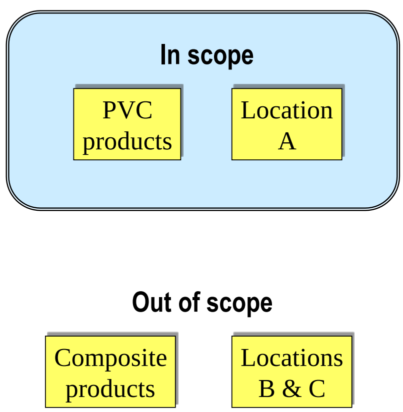
Value stream scope (cont'd)



171

Example 1 — value stream scope

Project to reduce cost and lead time of extrusion tool development



172

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?
- ✓ . . .

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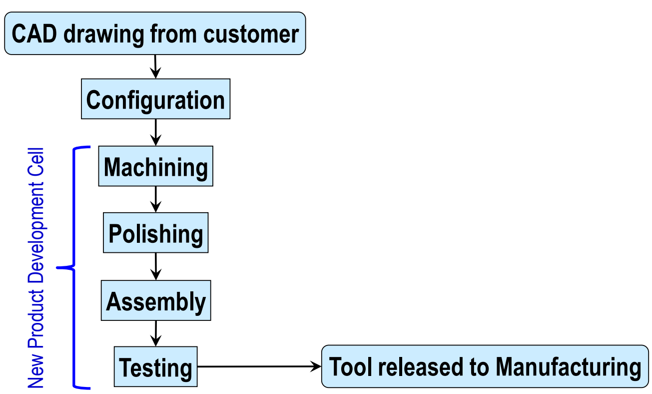
Example 1 — workflow scope

174

Project to reduce cost and lead time of extrusion tool development



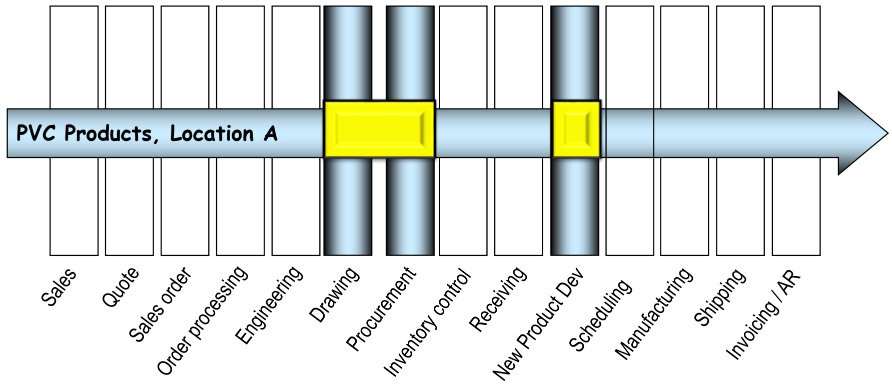
- *Manufacturing is out of scope*
- *The project is not chartered to analyze and improve Manufacturing*
- *What is the relationship between Manufacturing and the workflow scope?*

174

Example 1 — project scope

175

The *intersection* of value stream and workflow scope

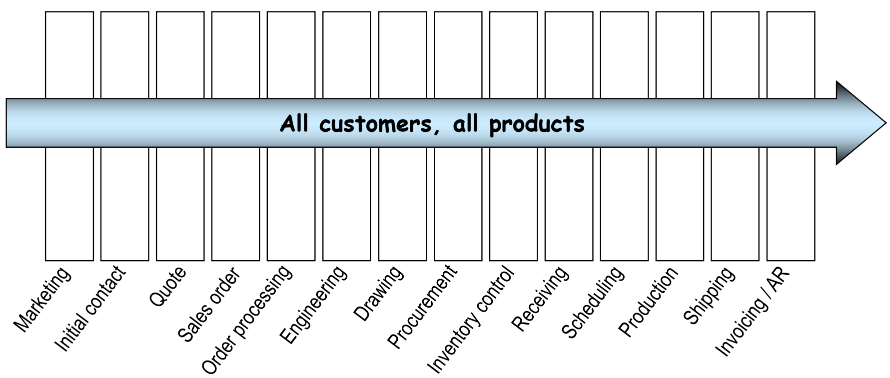


175

Example 2 — value stream scope

176

Project in Customer Service to address *order changes*



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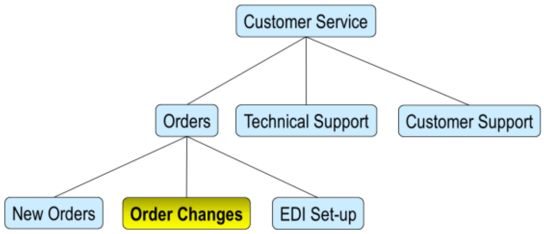
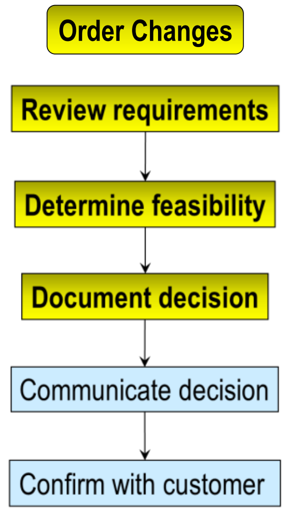
Example 2 — workflow scope

177



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

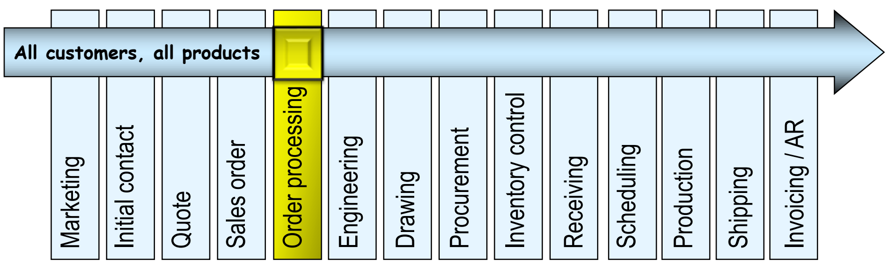


177

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 slide below for a typical example).

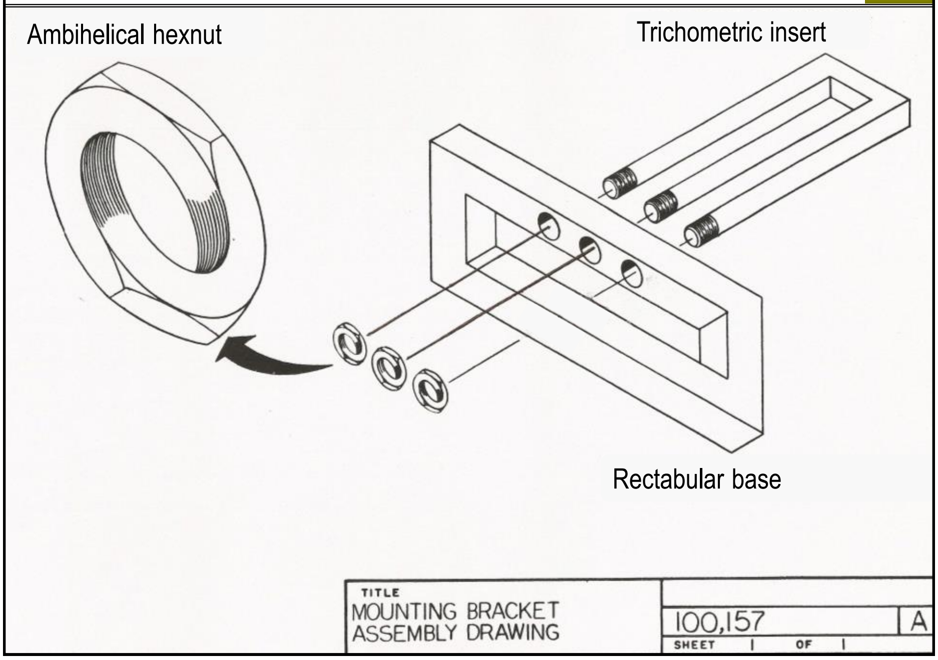
What is the value stream scope for this project?

What is the workflow scope for this project?

Open *Student Files \ MBDP charter* and update it by entering your description of the workflow scope; save your file for reference later in the course.

A non-standard mounting bracket

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 slide below.
- 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.

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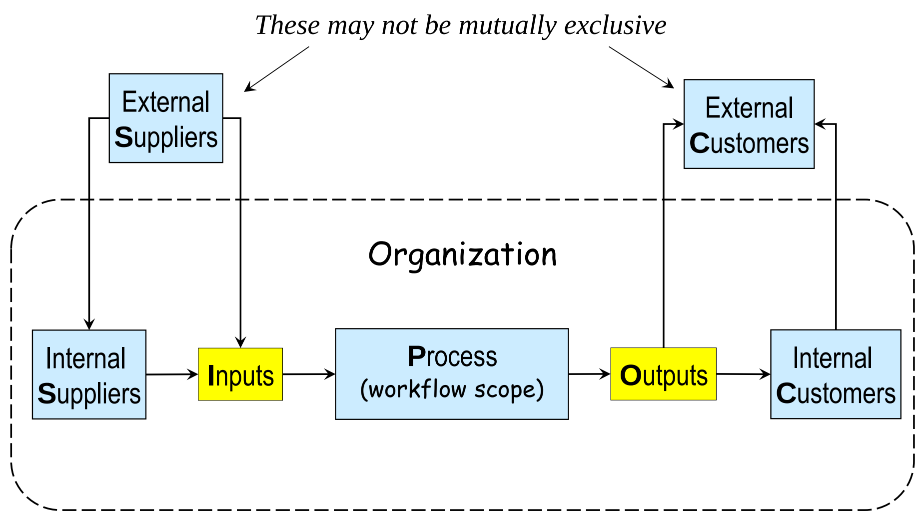
Graphical presentation of SIPOC

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 following three slides show the graphical SIPOC s for three case studies.

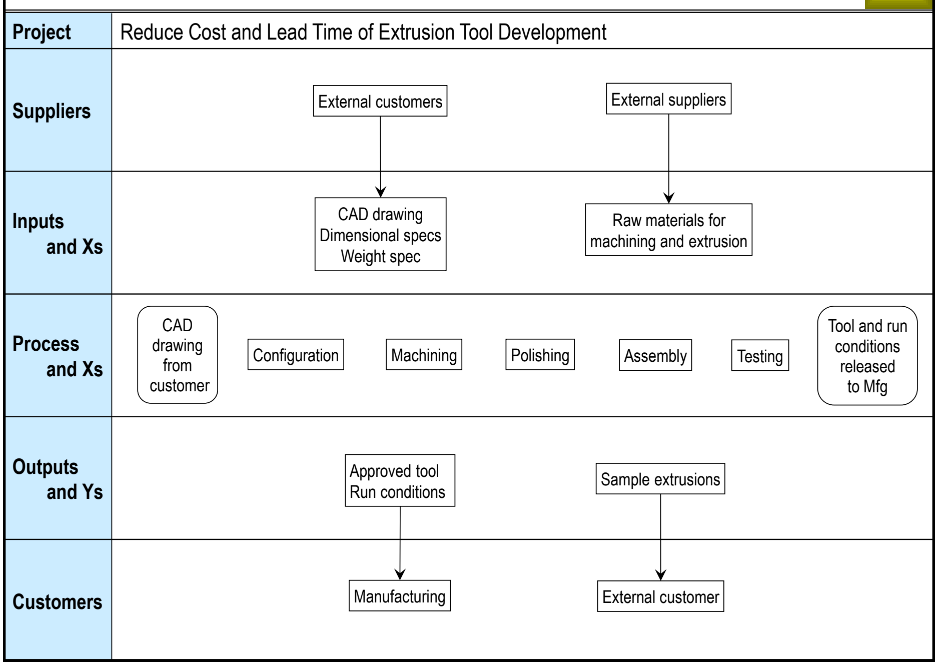
Electronic versions can be found in the *Student Files* folder:

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

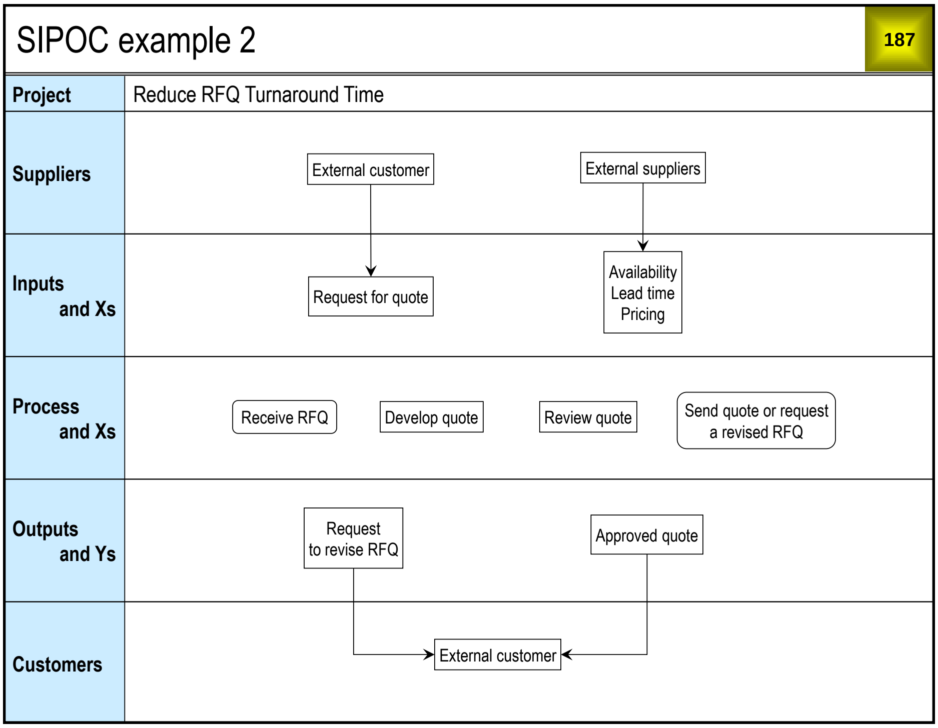
185

SIPOC example 1

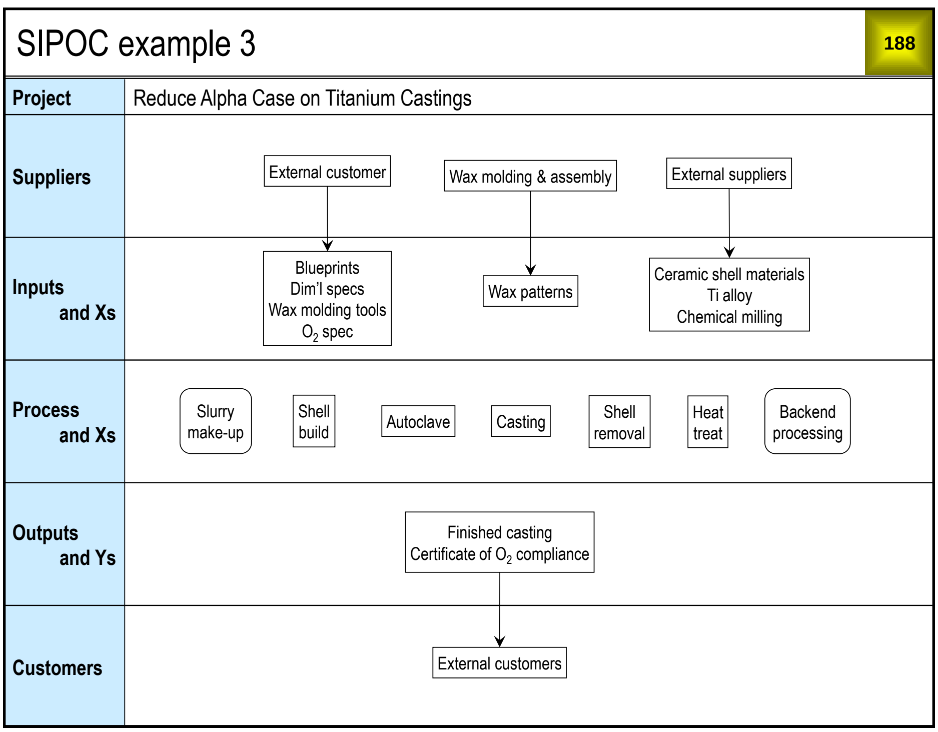
186



186


SIPOC example 2
187
Project
Reduce RFQ Turnaround Time
Suppliers
External customer
External suppliers
Inputs and Xs
Request for quote
Availability
Lead time
Pricing
Process and Xs
Receive RFQ
Develop quote
Review quote
Send quote or request a revised RFQ
Outputs and Ys
Request to revise RFQ
Approved quote
Customers
External customer

187


SIPOC example 3
188
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

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 below for an example). For background on the project and process, please refer to the following documents:

Student Files \ MBDP charter
Student Files \ 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.

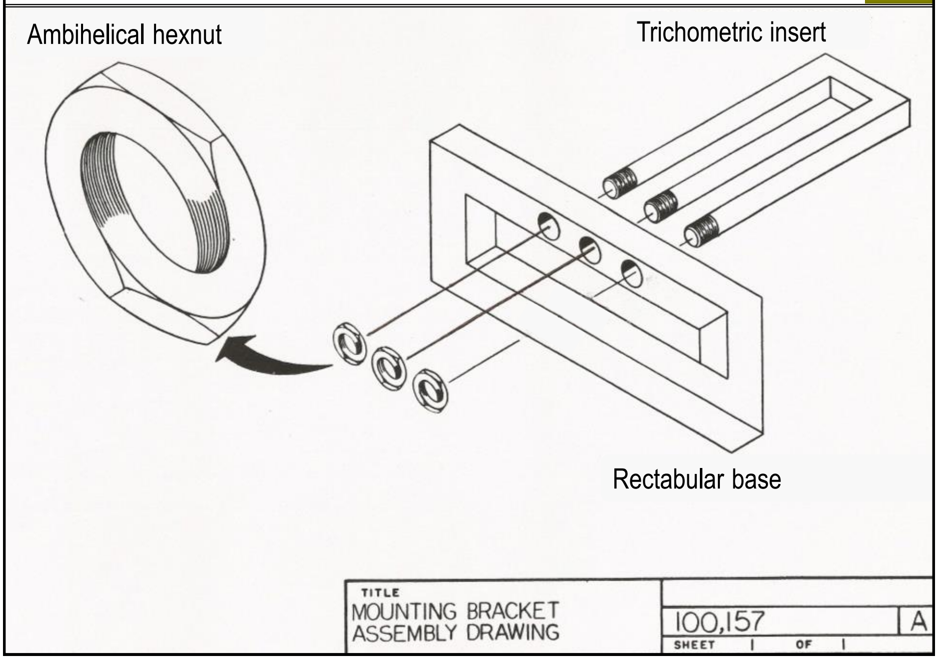
Do not fill in the X and Y variables shown on the *blank SIPOC* template (but do not delete their placeholders); we will discuss this topic later in the course.

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

189

A non-standard mounting bracket

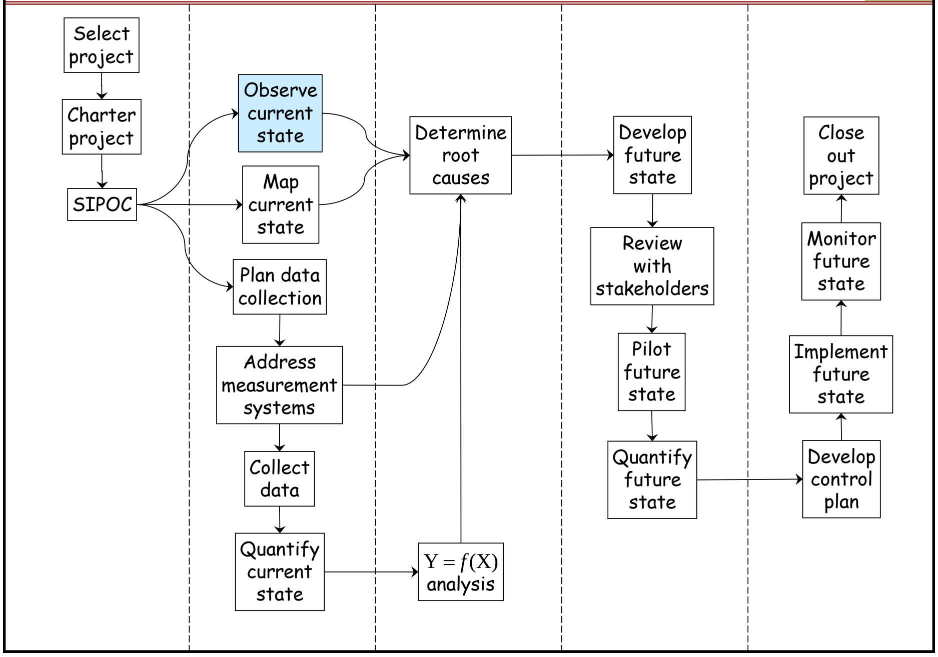
190



190

11 Observing the Current State

191



191

Guidelines

192

- 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

192

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			✓				✓

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.

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?" "Can you hear me in the back?" "So, you agree with the schedule change?" "Have we decided to meet on Fridays?" "We covered that earlier, didn't we?"
	• *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

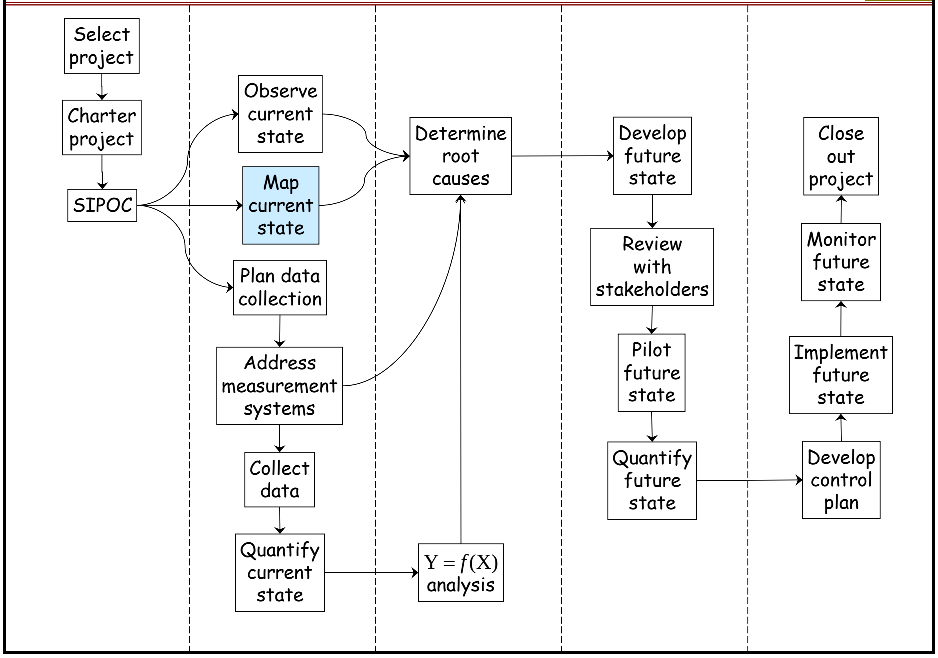
Observation log (cont'd)

202

Team member	Date	Location	Possible cause	Possible solution

202

12 Basic Process Mapping



Basic process mapping (cont'd)

Process mapping is easy to learn and produces useful documentation of the current state. It is also a great team building activity.

The key to successful application of any mapping technique is to focus on the appropriate *level of activity* for your project. In SIPOC we identify the first, last, and main intermediate steps of the in-scope workflow. This gives you a high-level process map.

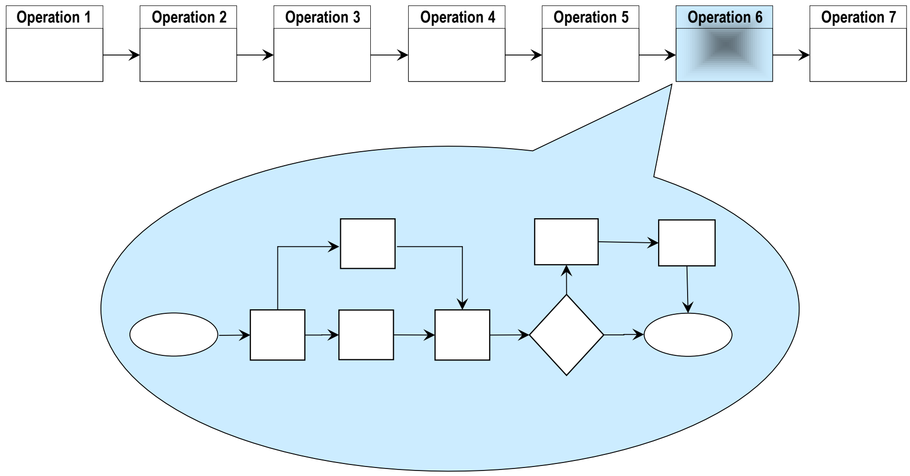
A high-level map is a good starting point for more detailed mapping. A basic process map, discussed in this section, shows individual tasks and decision points within the main steps. A cross functional or swimlane maps shows who is responsible for each task and decision. This and other common mapping formats are discussed in the next section.

A high-level map is also the usual starting point for value stream mapping (VSM). VSM combines visualization of what is happening with certain forms of data analysis. VSM will be discussed later in the program.

Basic process mapping (cont'd)

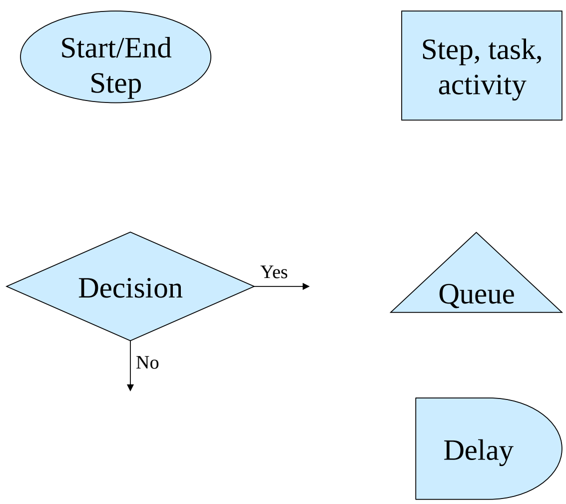
205

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



Standard (basic) process mapping symbols

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

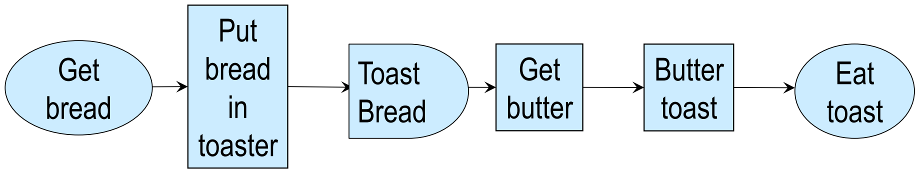
208

- ✓ 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

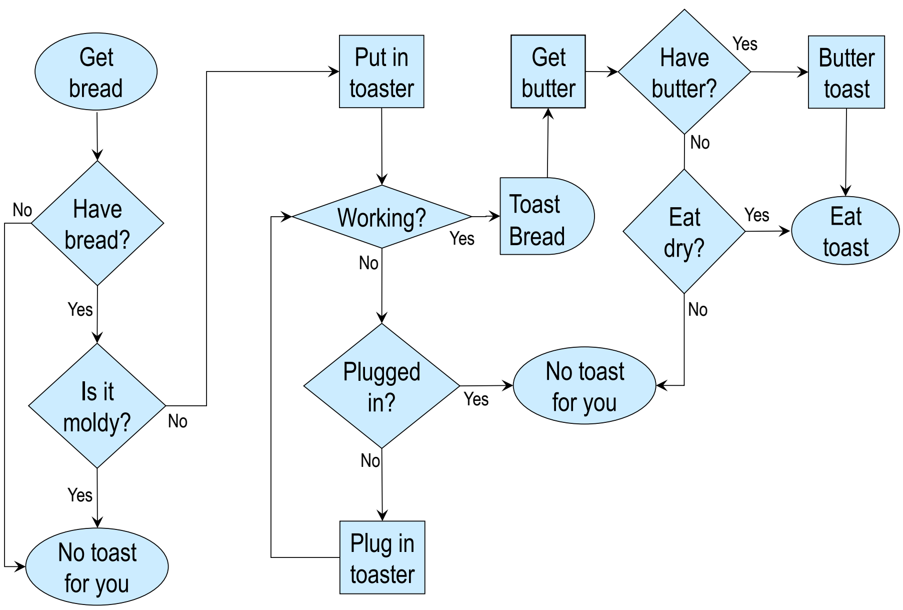
209



209

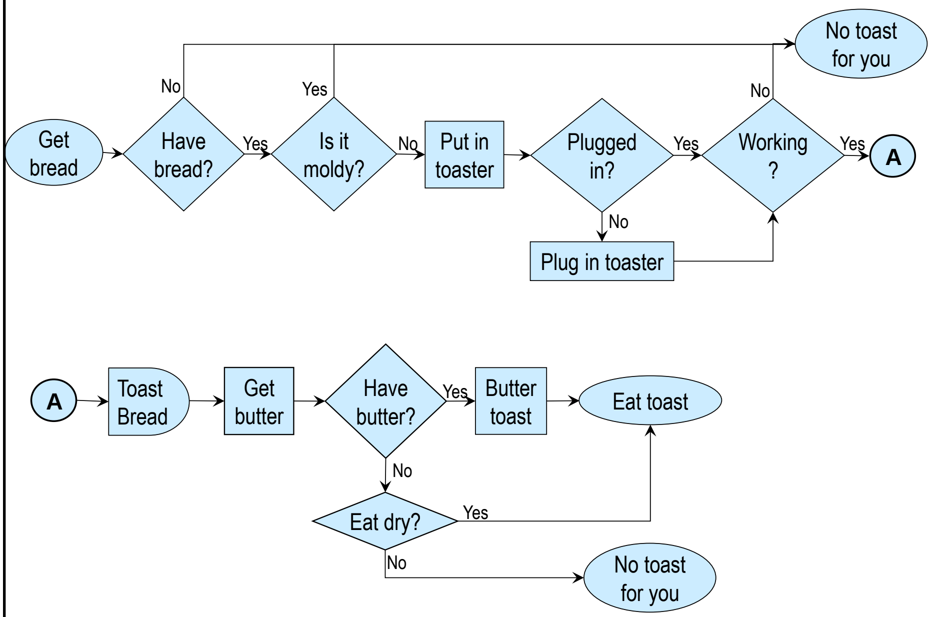
Decision steps show what really happens

210



Best practice: follow a qualitative timeline

211

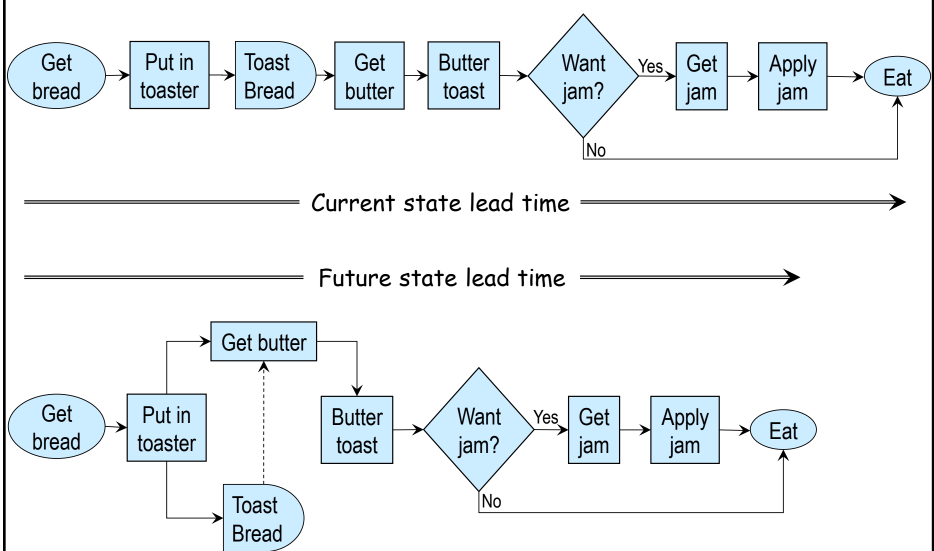


211

Parallel activities

212

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

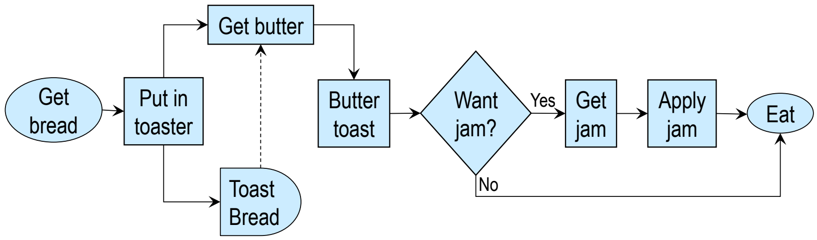


212

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 on this in small groups.

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

Use a separate sheet of paper to draw your map. Use a qualitative timeline!

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.

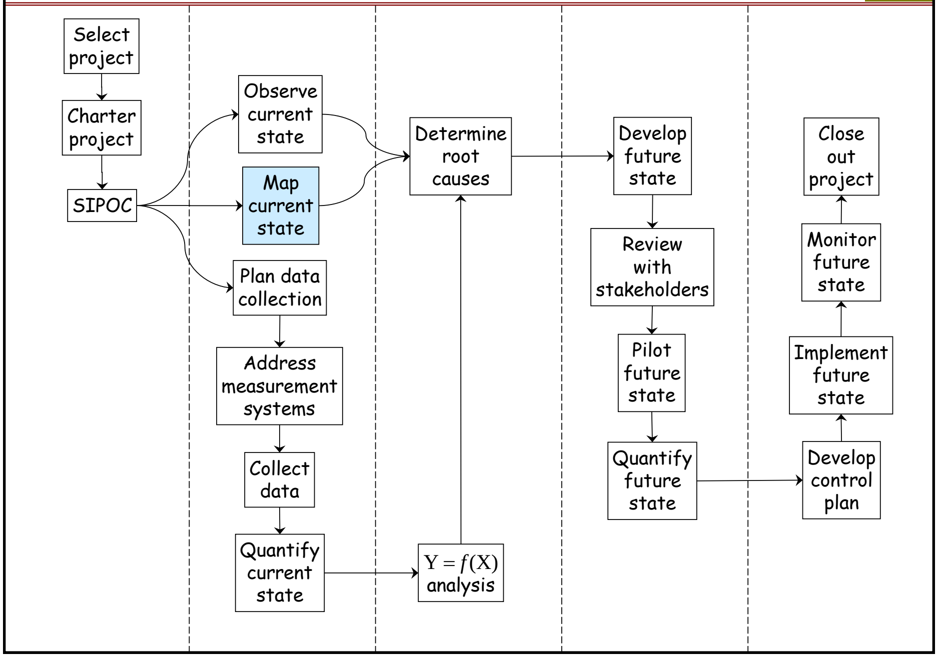
When Process 1 is completed, unload the material, and move on to Process 2. Process 2 requires Type 2 machines. If two Type 2 machines are available, load the A material into one machine, the B material into another, and run the two machines at the same time.

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.

13 Other Common Mapping Formats

217



217

Other common process mapping formats

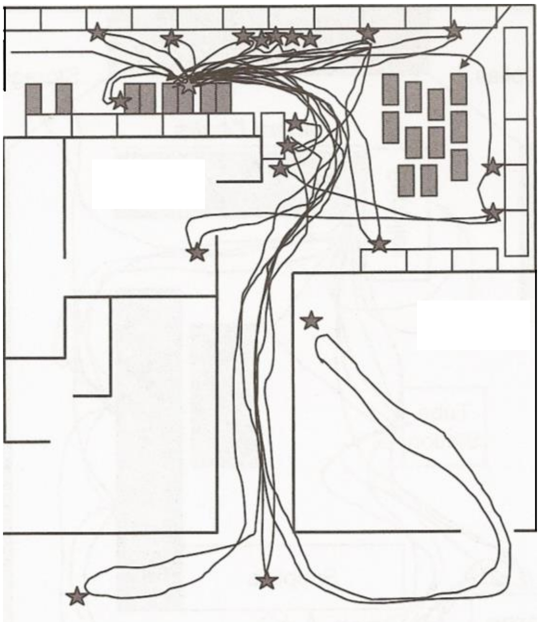
218

- Geographic (aka Spaghetti)
- Cross-functional (aka Swimlane)
- Topological

218

Spaghetti Diagram

219

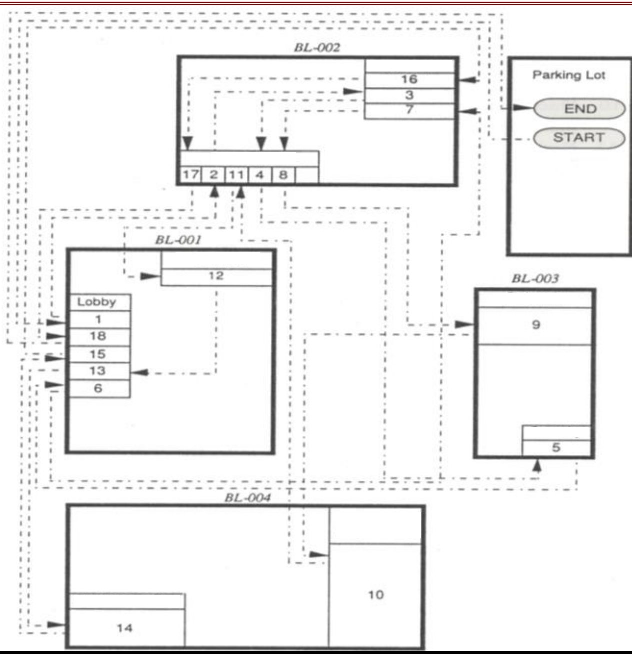


- Most useful in the Analyze Phase
- Requires a floor plan or scale drawing
- Shows typical travel patterns
- Quantify distance travelled
- Also known as a *geographic map*

219

Large scale spaghetti diagram

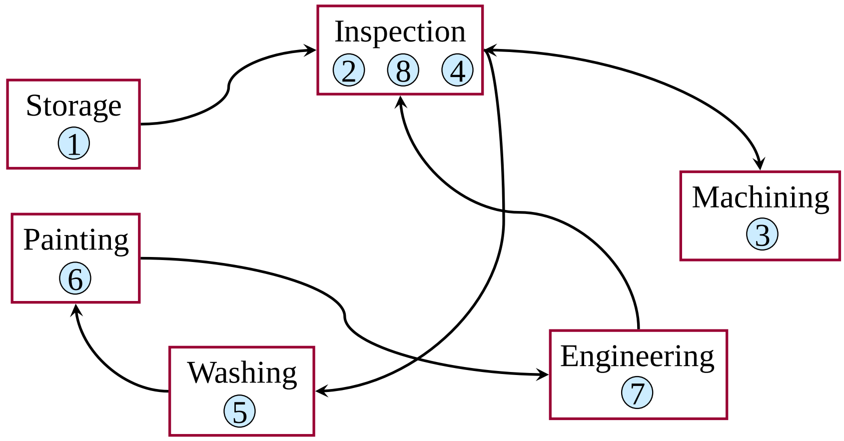
220



220

Spaghetti Diagram: current state

221

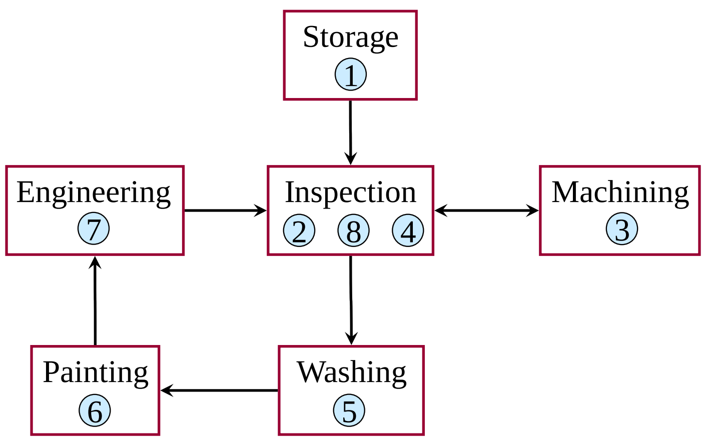


- Should rearrange to minimize transport
- Good opportunity for a Kaizen event

221

Spaghetti Diagram: future state

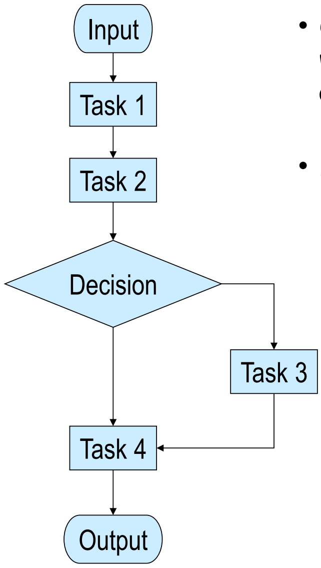
222



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?*

223

Basic process map (cont'd)

224

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

. . . but there is a better way!

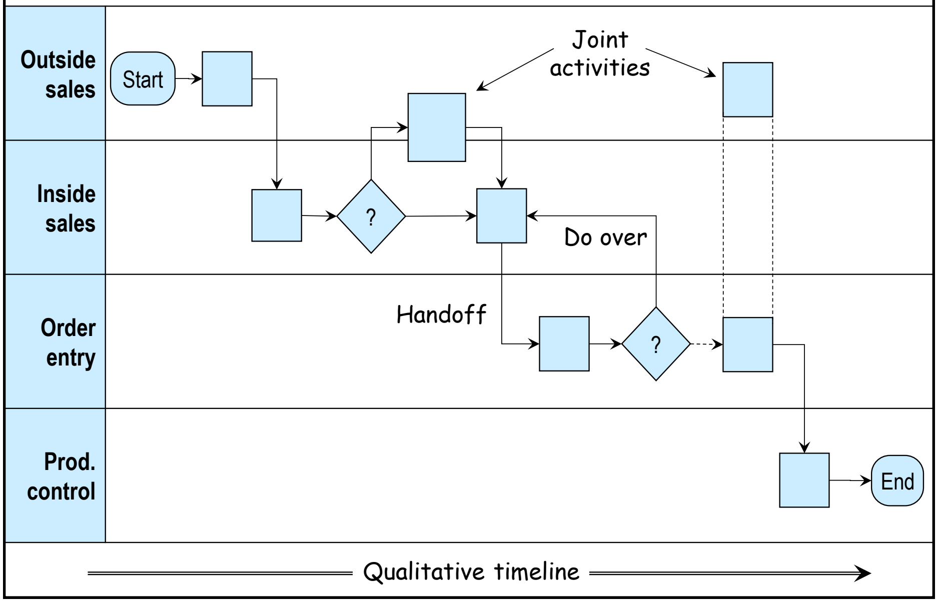
	Responsibility
Input	
Task 1	
Task 2	
Decision	
Task 3	
Task 4	
Output	

224

Swimlane Diagram

225

Also known as *cross-functional map*



Swimlane Diagram (cont'd)

226

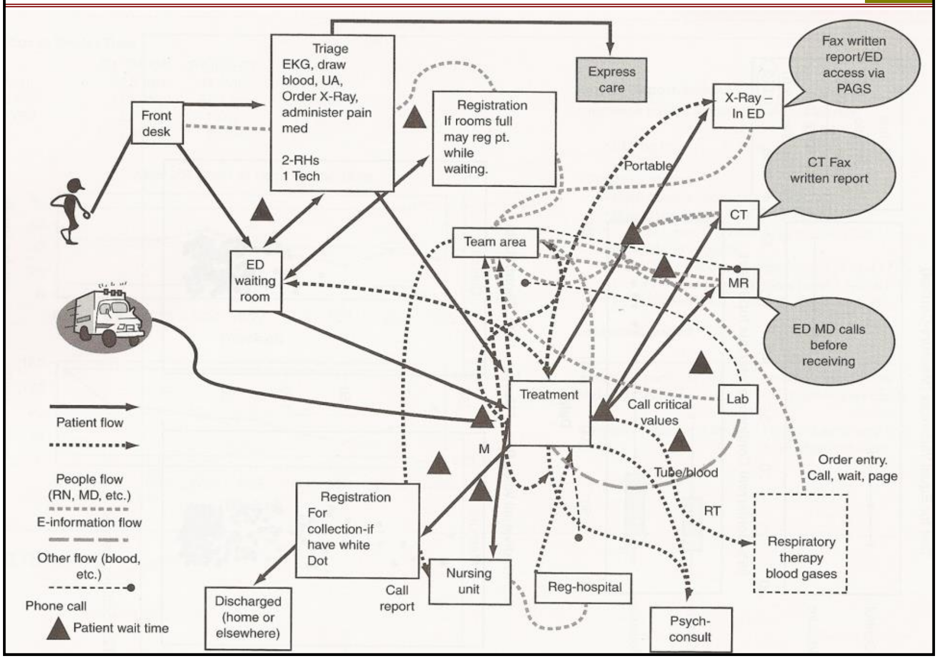
A swimlane diagram visually portrays the responsibilities for all process activities and decisions. In addition to showing responsibilities, swimlane diagrams are much better than simple maps for identifying opportunities for improvement.

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.

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.

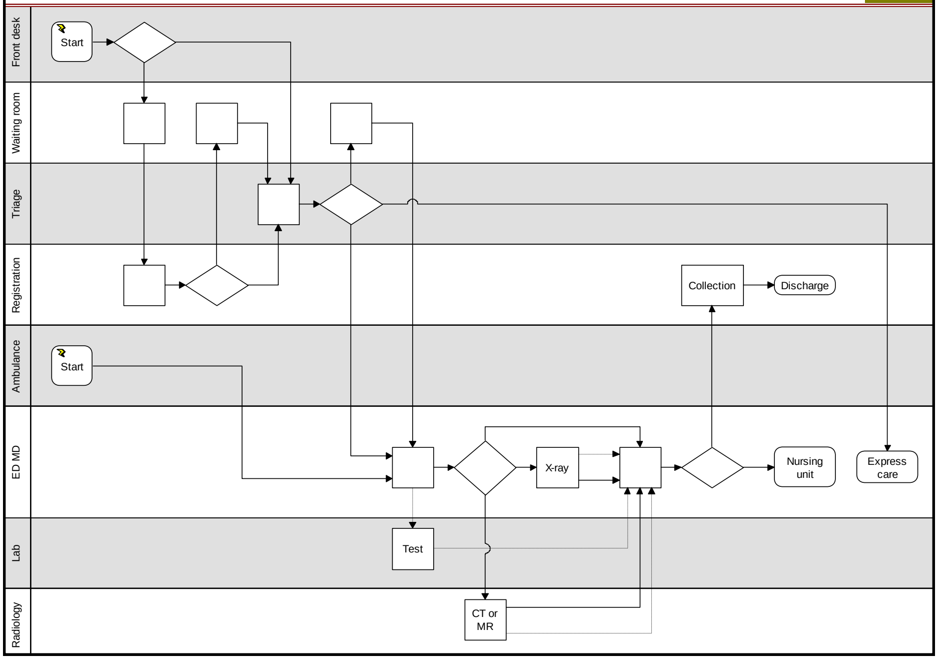
Like geographic maps, topological maps are extremely effective for conveying the complexity of a process. Also, the free form nature of topological mapping lends itself to team brainstorming.

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 \ 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.
(If using "sticky notes," make the swimlanes at least two sticky notes wide.)

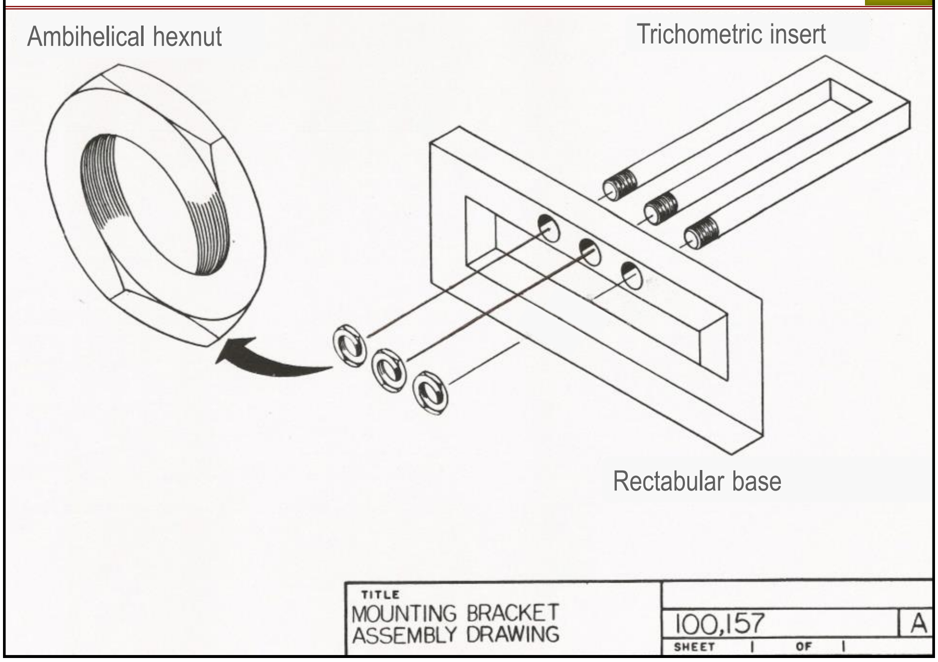
Add a sticky note for *each* step or decision in the process, although it's recommended to combine QE and ME in one lane.

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

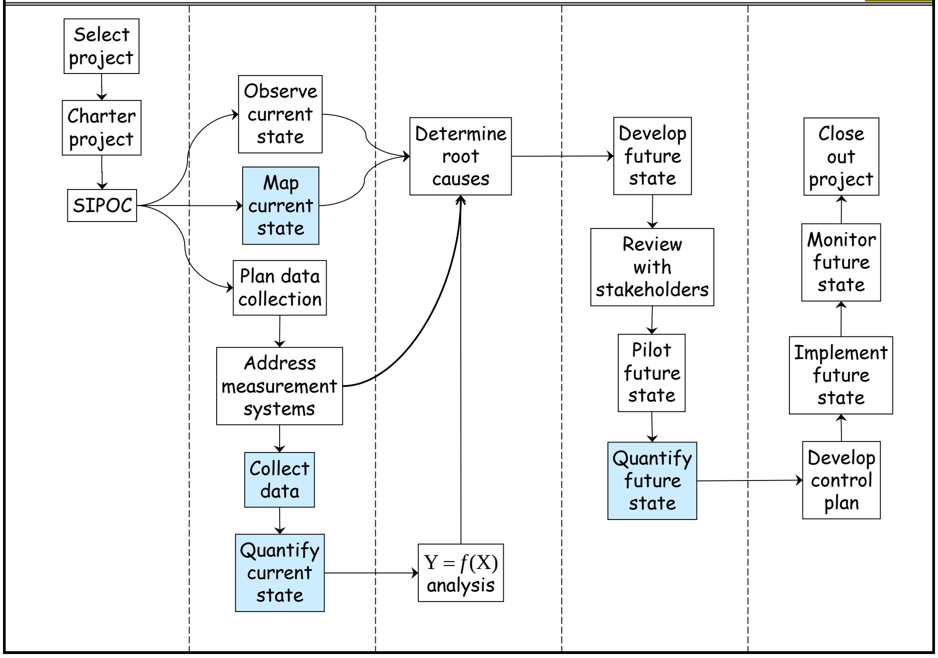
232



232

14 Value Stream Mapping

233



The nature of Value Stream Mapping

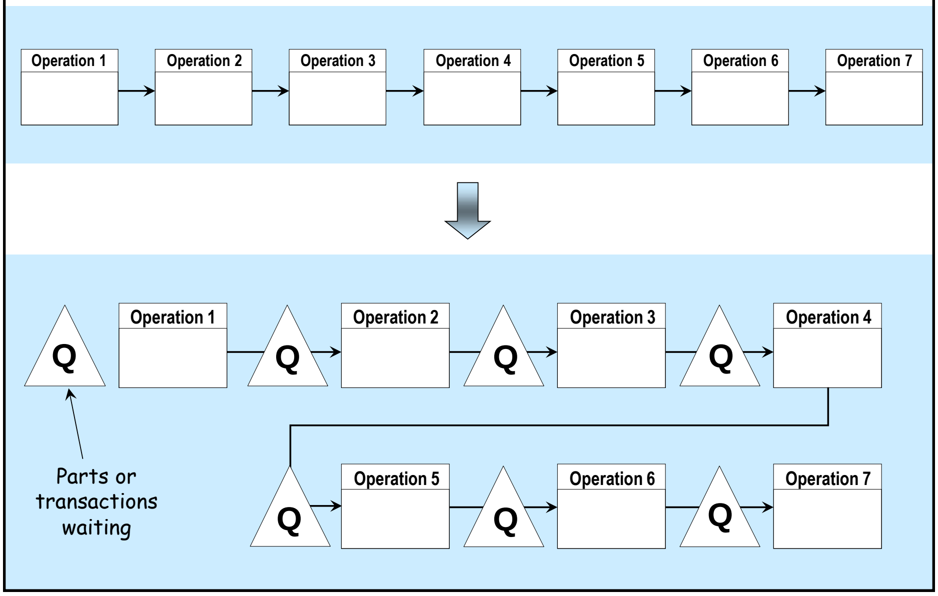
234

- 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

From SIPOC to VSM

235

High-level map from SIPOC



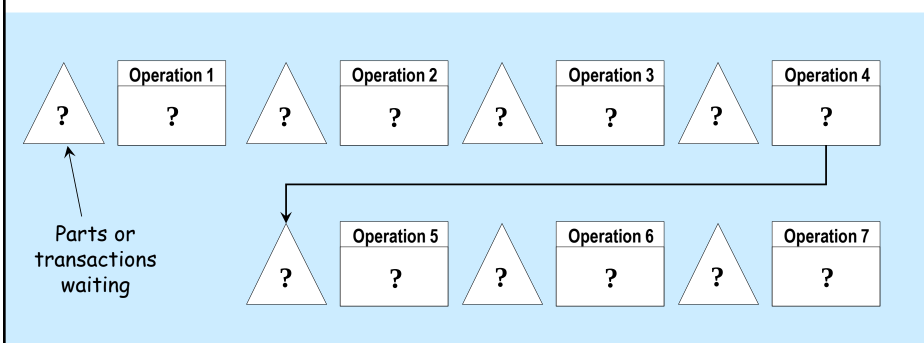
VSM, no data yet

236

What is the average lead time?

How much time is spent in each box or triangle?

How do we get this information?



Definitions

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

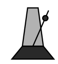
Definitions (cont'd)

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

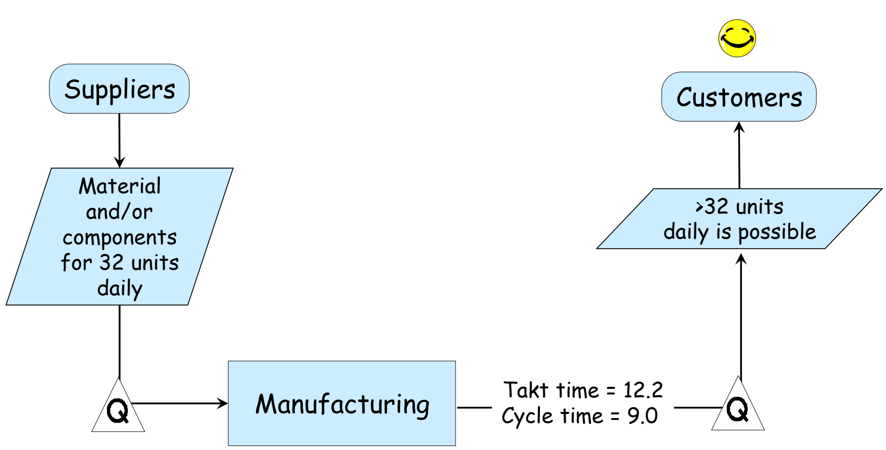
Based on this, the elapsed time in minutes between completed units was:

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

Cycle Time = 9 minutes (the fastest repeatable value)

Example 1 (cont'd)

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

245

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?

245

How do we get lead time data?

246

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

246

Little's law

247

Lead Time = (WIP) / (Throughput)

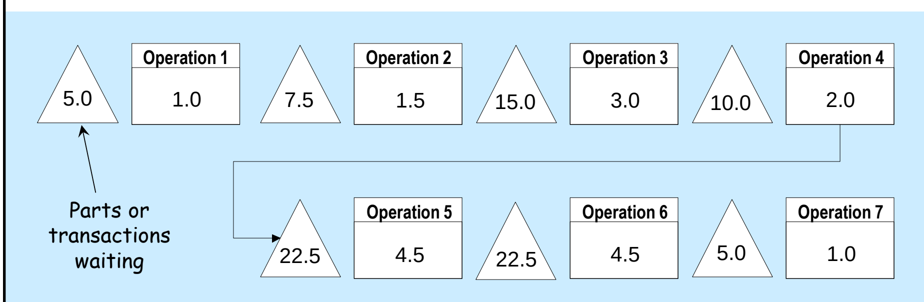
- WIP is easy to count during process observation
- If WIP varies, count multiple times and use average or min/max to show range in lead time
- Throughput is the quantity completed during an observation period. Period should be at least several days.
- Lead time = amount of time that passes between when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

247

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 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

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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

249

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

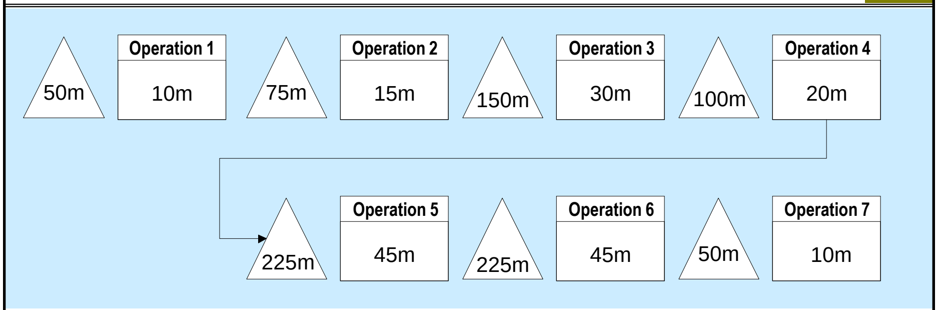
- For Queue 1 and Operation 1:

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

250

VSM with waiting and process times

251



Lead time = 1050 minutes or 17.5 hours

Waiting time = Sum of time in queue
= 50 + 75 + 150 + 100 + 225 + 225 + 50 + 10 = 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 raw materials be counted as WIP?

252

Exercise 14.3

Open *Data Sets* → *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.

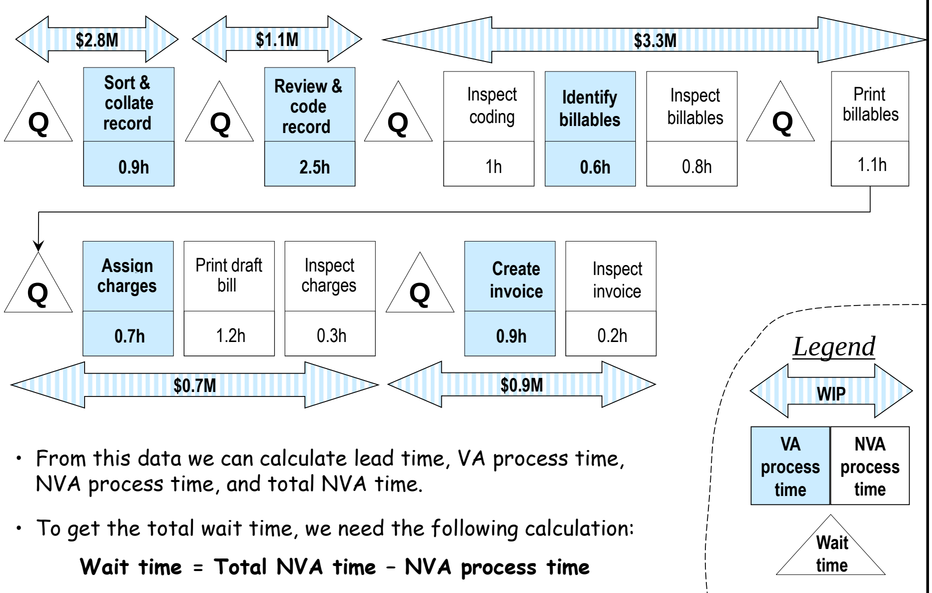
c) Where are the bottlenecks? Do these steps have anything in common?

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

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)

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.

Exercise 14.4 (cont'd)

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.

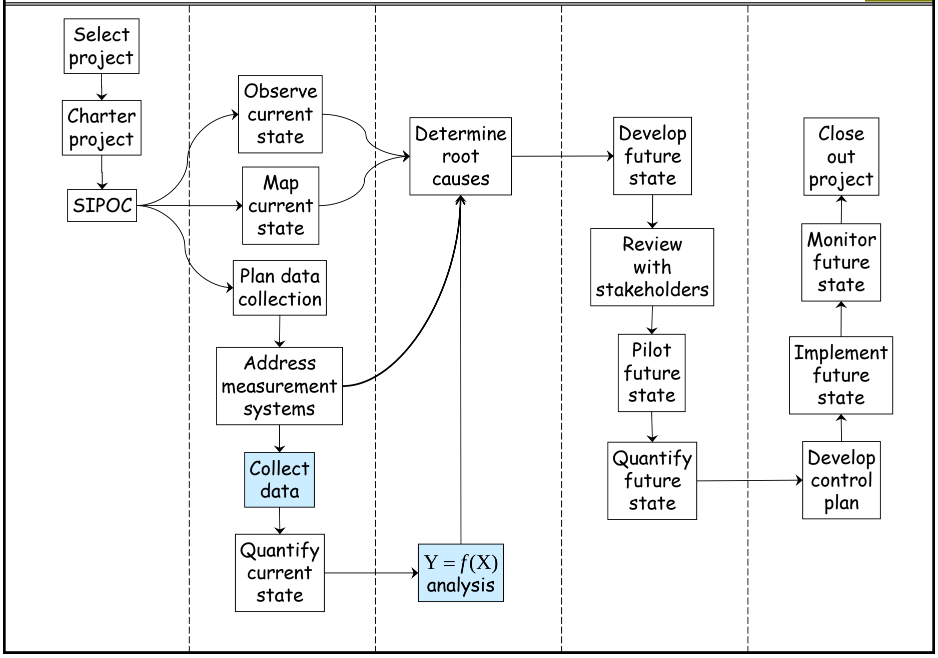
c) Total NVA Lead Time, NVA Process Time and Process Cycle Efficiency.

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?

15 X and Y Variables

257



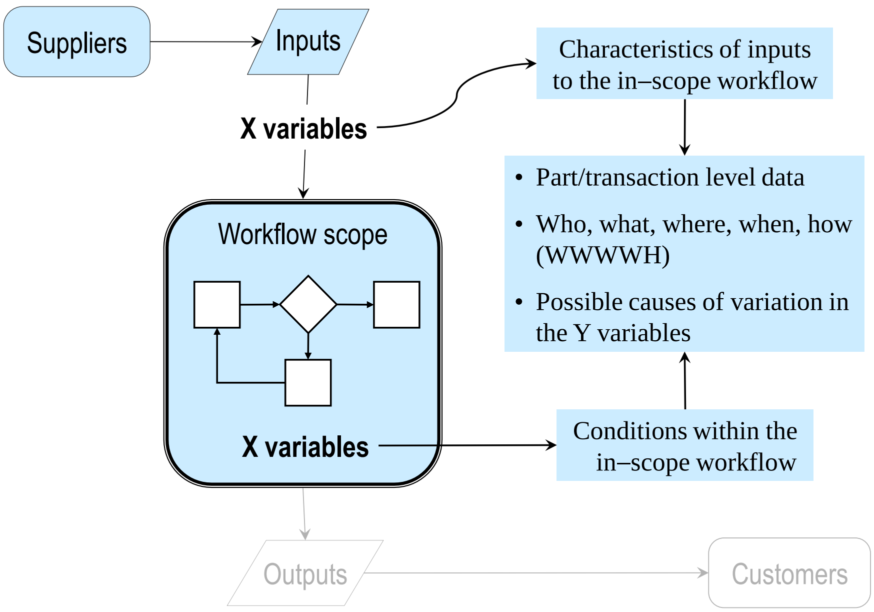
Topics

258

- X variables
- Fishbone Diagram
- Prioritizing X variables
- Y variables
- Operational definitions for data variables
- “Big Y” and “little y”

X variables

259

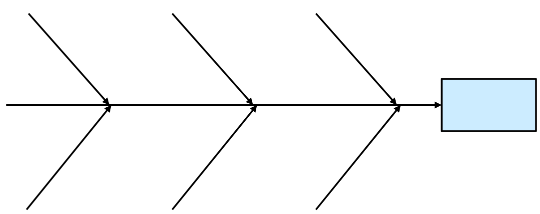


Fishbone Diagram

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



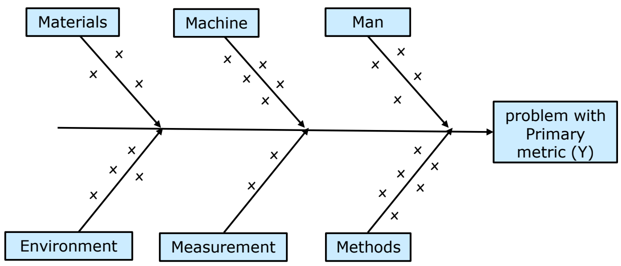
- The greater the number of X variables identified, the greater the chance of solving the problem. (Why?)

Fishbone Diagram (cont.)

261

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)

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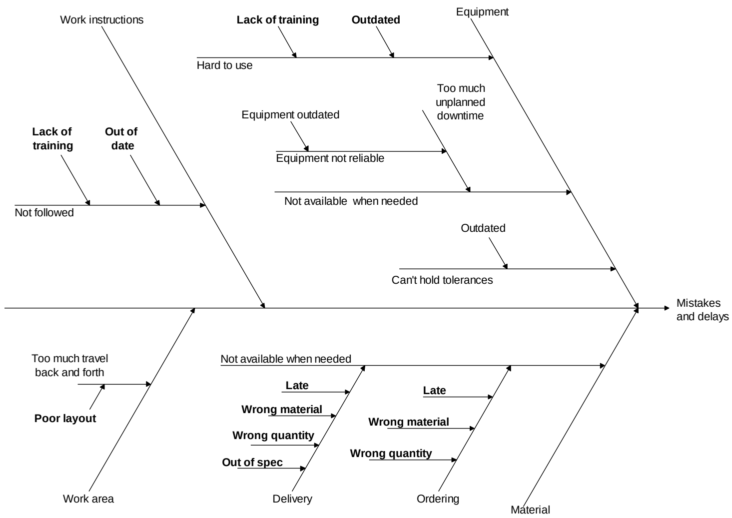

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Exercise 15.1

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 the *Student Files* folder:

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.

264

Prioritizing X variables for data collection

265

- X's are measurable characteristics of process inputs
- Who/what/where/when/how within the workflow scope
- These 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
- Once X variables are prioritized, they should be added to the SIPOC diagram

265

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 correlation with each Y variable: none (blank), low (L), medium (M), high (H)
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

266

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	Overall rankings
Relative weights	**2**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	
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

(Rows: X variables)

Degree of positive correlation of each item with each metric: None (blank) Low (L) Medium (M) High (H)

Items to be ranked sheet

Example (cont'd)

269

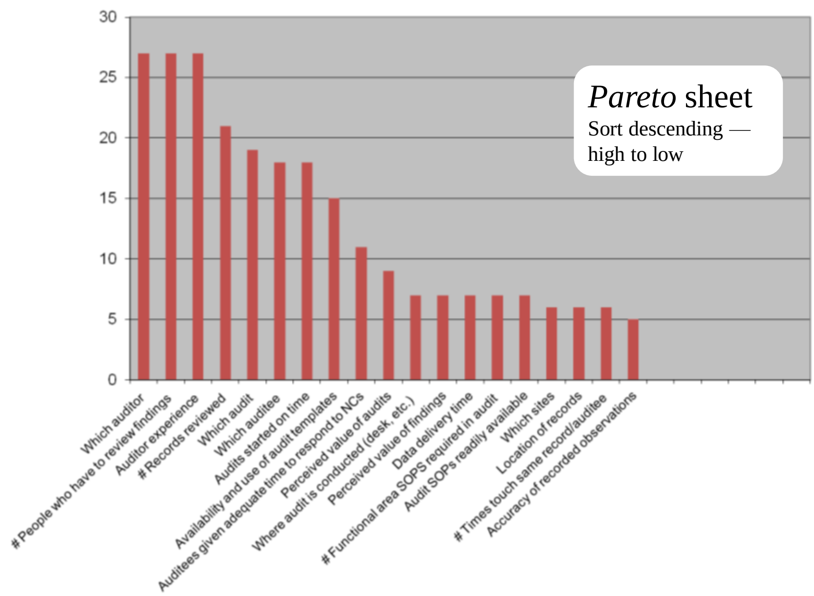
Paste items to be ranked	Paste overall rankings
Which auditor	27
# People who have to review findings	27
Auditor experience	27
# Records reviewed	21
Which audit	19
Which auditee	18
Audits started on time	18
Availability and use of audit templates	15
Auditees given adequate time to respond to NCs	11
Perceived value of audits	9
Where audit is conducted (desk, etc.)	7
Perceived value of findings	7
Data delivery time	7
# Functional area SOPS required in audit	7
Audit SOPs readily available	7
Which sites	6
Location of records	6
# Times touch same record/auditee	6
Accuracy of recorded observations	5

Pareto sheet

269

Example (cont'd)

270



270

Exercise 15.2

271

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

Prioritizing X's using Multi-voting

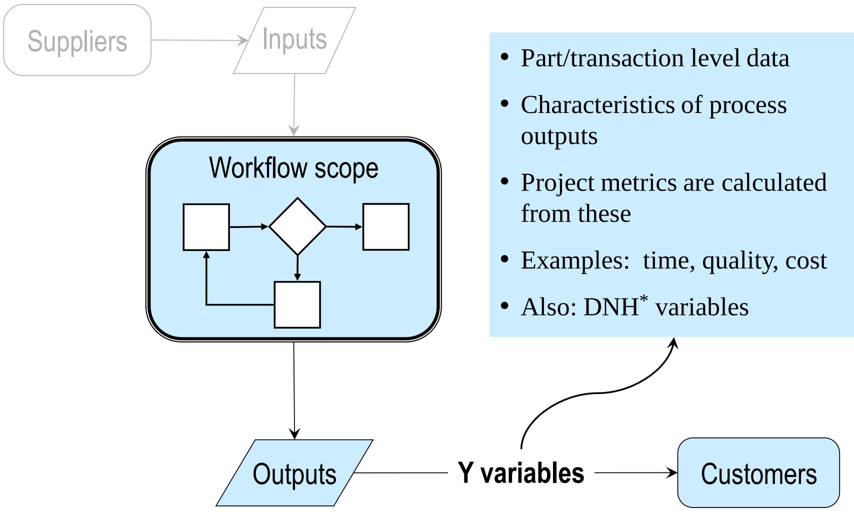
272

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

273



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

273

Y variables

274

- 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, pass or fail, quantitative measures of poor quality (including cost)
- The Y variables are the reason we are doing the project (Why?)

274

Operational definition for a Y variable

275

Examples of questions to be answered

- How, and from what basic quantities, will Y be calculated?
- What measurement system will be used?
- If Y is a lead time, what are the starting and stopping points?
- If Y is pass/fail, what are the possible defects?
- If you are going to count defects per opportunity, how are the opportunities defined?
- If Y is unplanned downtime, how will you record your data: hourly/daily/weekly summaries or event log?
- If there is existing data, can you use it with minor modifications to your operational definition(s)? (Data readily available will jump start your project. Use it whenever possible, even if minor adjustments to the project scope are needed.)

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Notes

276

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Case Study example of operational definition for a Y variable

277

Operational definition for a Y variable: *Case Study — Tool Development*

- ❑ How, and from what basic quantities, will Y be calculated?
  Y = Average number of reworks per tool, to be calculated from tally of reworks for a representative sample of in-scope tools.
- ❑ What measurement system will be used?
  Can pull number of reworks from the job order record in the ERP system, using record of routings between Tool Testers and Machining Group. Alternately, Tool Testers can maintain a spreadsheet of # of reworks per tool PN, by job order and dates.
- ❑ If Y is a lead time, what are the starting and stopping points?
  NA to this metric, but Average Order-to-sell time in days is another Y metric that will be calculated using the same sample described in the first question above. Start point will be date of Order Receipt, end point will be Shipment date to customer. Will calculate from ERP records, using (Ship Date – Order Date) + 1.
- ❑ If Y is pass/fail, what are the possible defects?
  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.

277

Case Study example of operational definition (cont'd)

278

Operational definition for a Y variable: *Case Study — Tool Development*

- ❑ If you are going to count defects per opportunity, how are the opportunities defined?
  As with the comment above, the inspection criteria would be used to define the defect opportunities.
- ❑ If Y is unplanned downtime, how will you record your data: hourly/daily/weekly summaries or event log?
  NA to this project. If we needed this data, we would access the Facilities department's maintenance/time logs kept for each piece of equipment.
- ❑ If there is existing data, can you use it with minor modifications to your operational definition(s)? (Data readily available will jump start your project. Use it whenever possible, even if minor adjustments to the project scope are needed.)
  There is existing data for reworks per tool available in the ERP system. We will work with IT to create a report for extracting this data in a useable format.

278

Exercise 15.3

279

Working with one or two others from your company, if possible:

1. Give an operational definition for PO-PD in the Mounting Bracket Development Process (MBDP) project. Your definition should address the relevant questions on the previous slide.

2. Give an operational definition for one of the Y variables for your project. Your definition should address the relevant questions on the previous slide.

279

"Big Y" and "little y"

280

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

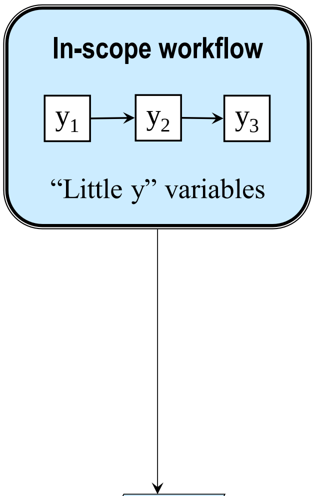
PO: Sales/PE
Design Spec: PE
Design Spec: ME/QE
Drawing: Drafting/PE
Drawing: ME/QE
Proto

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

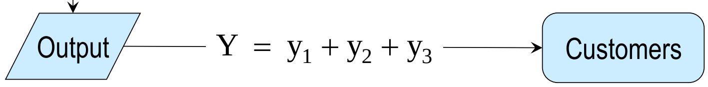
280

"Big Y" and "little y" (cont'd)

281



- 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
- "Big Y" is the sum of "little y" over all elements
- This is what the *customers* care about

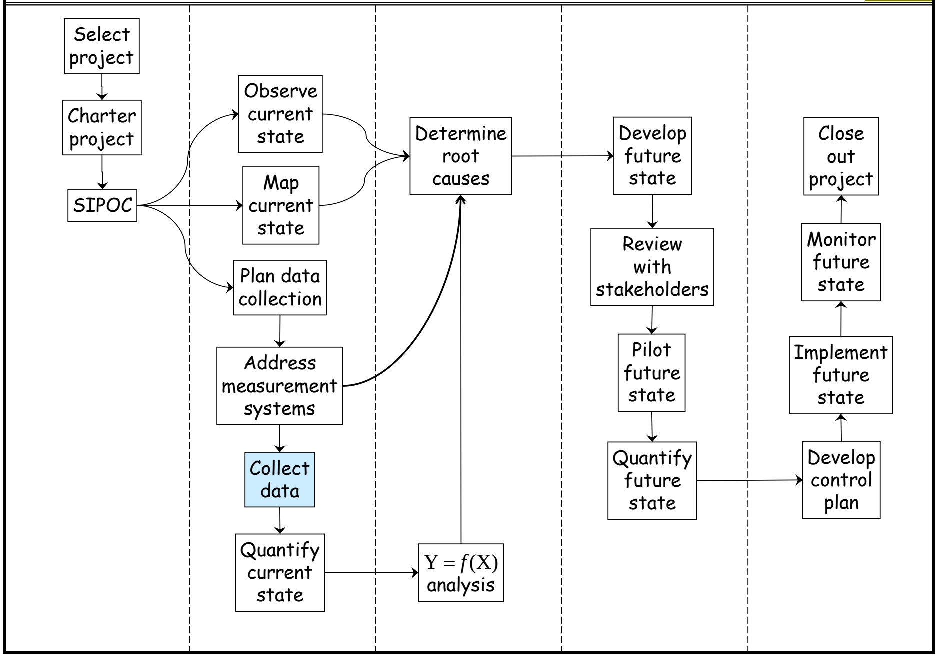


Pitfall: setting goals for each "little y"

282

- 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?

16 Data Collection



Purposes of data collection

- 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

Population sampling

285

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

285

Example: opinion poll

286

Population of registered voters

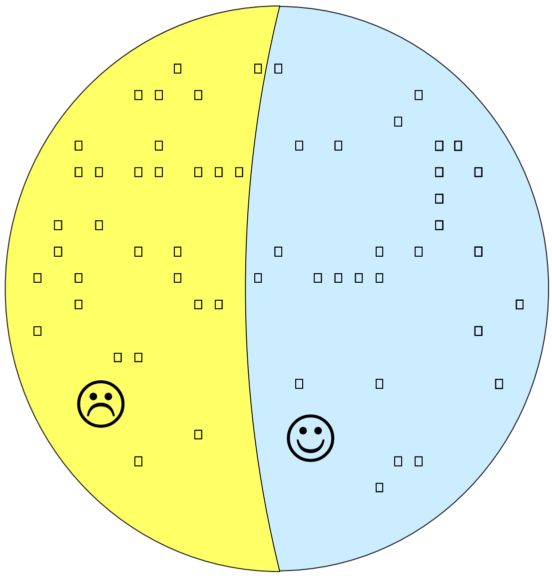
"Do you support the President's policy on _____ ?"

We want to determine the percentages

286

The sample must be representative

287



287

Representative sampling (cont'd)

288

- 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*

288

Exercise 16.1

289

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 slide below.

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 presidential candidate	Generate telephone numbers at random, call those people

Exercise 16.1 (cont'd)

290

(a)

(b)

(c)

(d)

(e)

Incorrect interpretation of survey data

291

"Do you support the President's policy on _____?"

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

Infotainment Nightly "News"

"According to a recent survey, the majority of registered voters support the President's policy."

291

Interpretation of survey data (cont'd)

292

- 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 President's policy

292

Must quantify the uncertainty

293

"Do you support the President's policy on _____?"

Rational Public Radio

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

Quantifying uncertainty (cont'd)

294

- "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 President's policy is between 48% and 54%"
- The data fails to demonstrate a majority on *either* side of the question

Process sampling

295

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

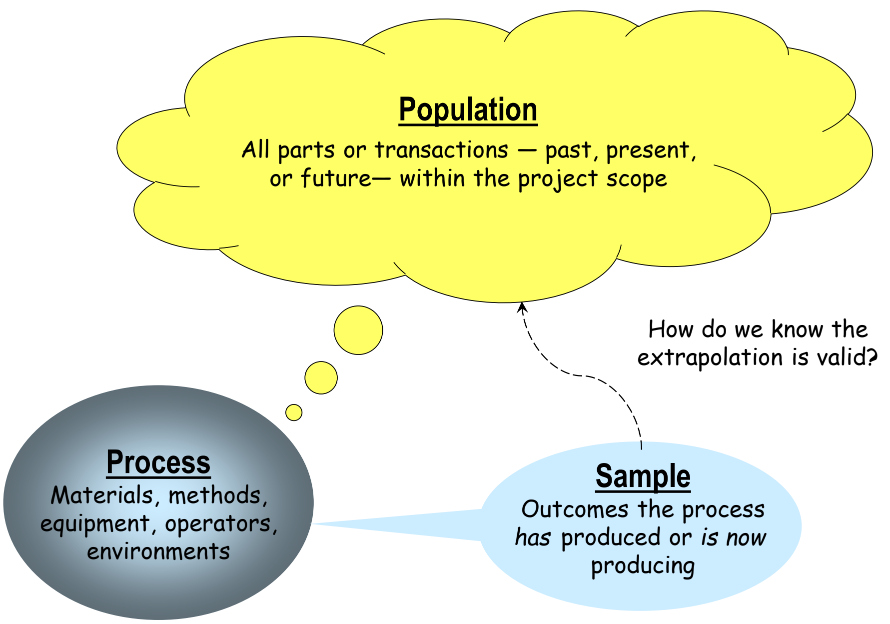
- ✓ Manufacturing process
- ✓ Service process
- ✓ Business process
- ✓ Transactional process
- ✓ Decision process
- ✓ Design process

For any process, there is an associated *population*

295

Process sampling (cont'd)

296



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Process sampling for LSS projects

297

- 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 slide below)

Typical sources of variation

298

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

299

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.

299

Exercise 16.2

300

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

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

300

Sample size

301

- 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.

301

Sample size calculation: opinion poll example

302

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. 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.

302

Sample size (cont'd)

303

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 desireable. 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	N
0.05	384
0.04	600
0.03	1067
0.02	2401
0.01	9604

303

Sample size calculation: process applications

304

- In process applications, ϕ represents the fraction defective
- In this case, the margin of error on the high side is of greatest interest:

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

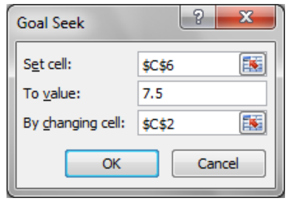
- To do a sample size calculation, we must provide two inputs:
  - a) A guess for ϕ_{sample}
  - b) An acceptable upper bound on ϕ (giving the desired MOE, which is the difference between this upper bound and ϕ_{sample})
- Open *Student Files* → *calculator - sample size* → *% Defective*

304

Example

305

- 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* → *What If Analysis* → *Goal Seek* → set up as shown to the right → 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

Exercise 16.3

306

We want to get an accurate estimate of the population % defective. Find the required sample size in the following scenarios.

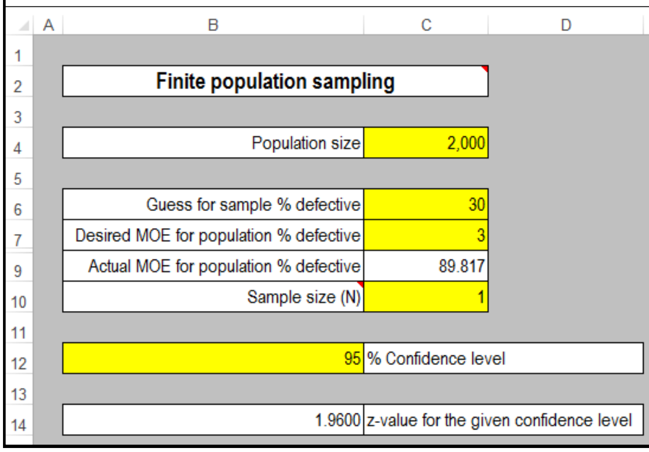
	Guess for sample % defective	Desired upper bound on population % defective	Sample size
(a)	10	20	
(b)	10	15	
(c)	10	13	
(d)	1	4	
(e)	1	3	
(f)	1	2	

Finite population sampling

307

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

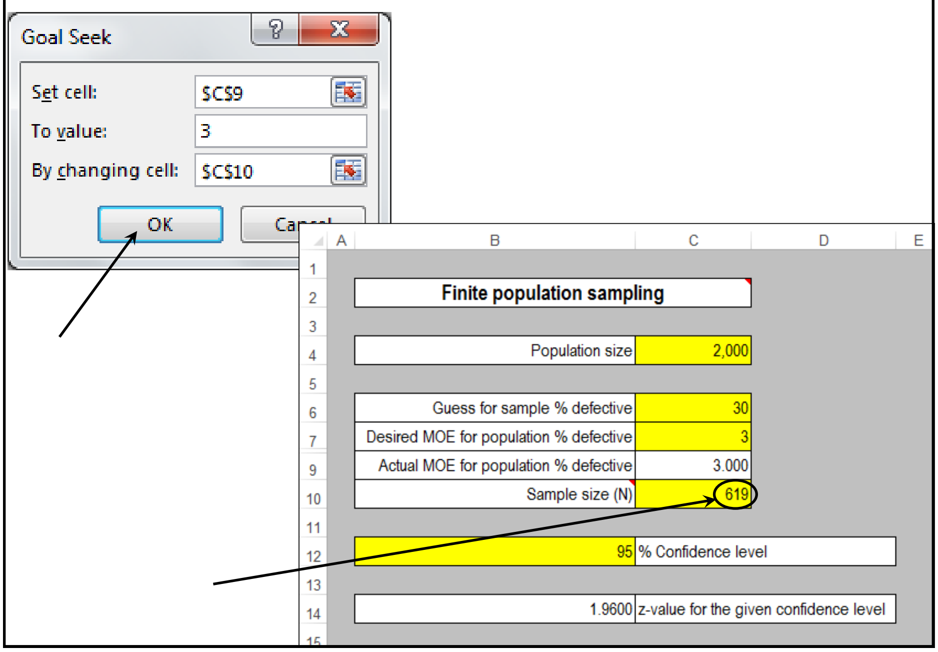


Data
↓
What If Analysis
↓
Goal Seek
↓
Set up as shown on the next slide

307

Finite population sampling (cont'd)

308



308

Sample size for estimating a population mean

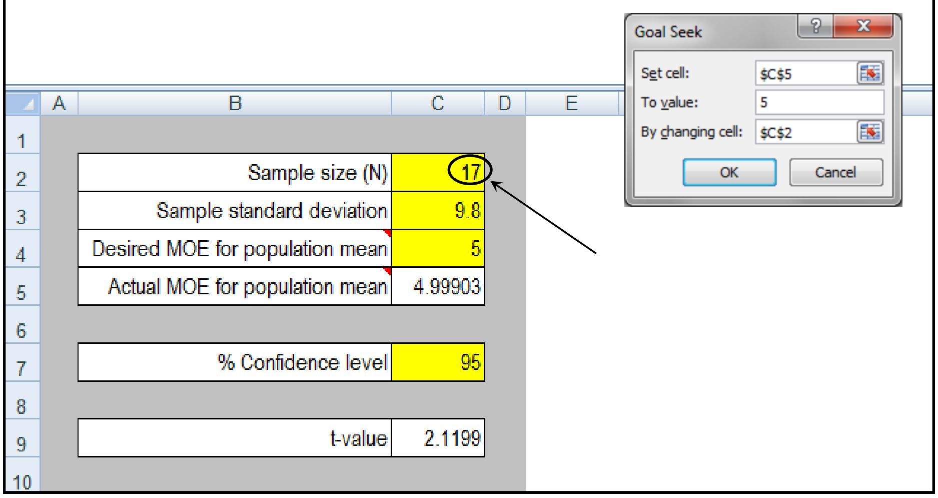
309

- This 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
- Go to the sheet *Pop. mean for quant. Y* → enter the value 2 in cell C2, 9.8 in C3, and 5 in C4
- Select *Data* → *What If Analysis* → *Goal Seek*

Sample size for population mean (cont'd)

310

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



Exercise 16.4

311

a) For the previous example, calculate the sample size assuming we want our MOE to be 5% of the mean instead of 10%.

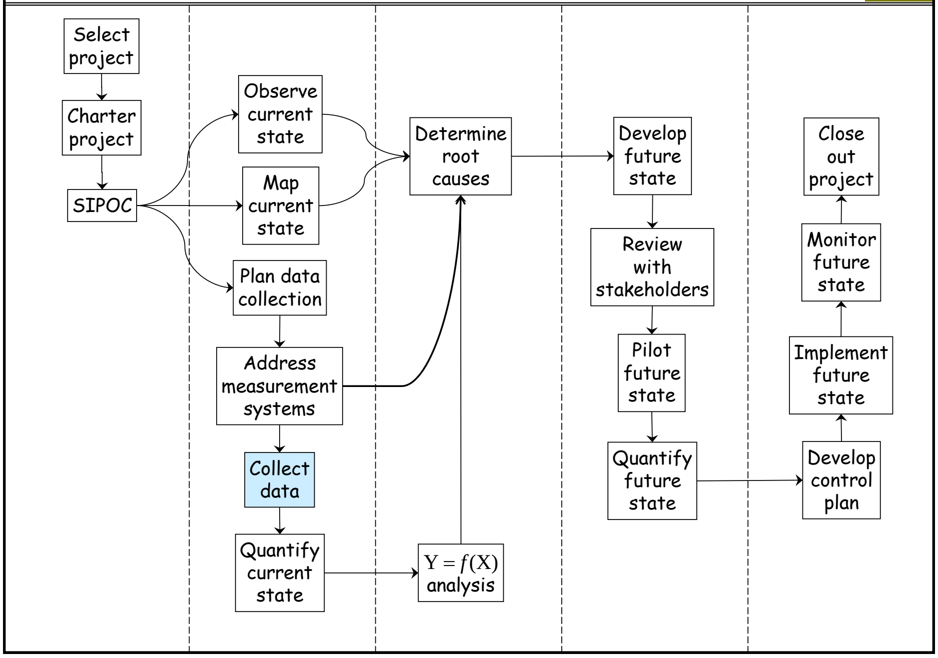
b) Calculate the sample size assuming we want MOE to be 1% of the mean.

Notes

312

17 Data Formatting

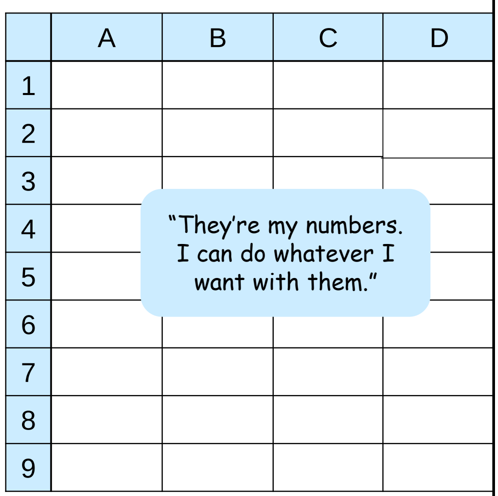
313



The spreadsheet: a truly marvelous invention

314

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



Standard data matrix format

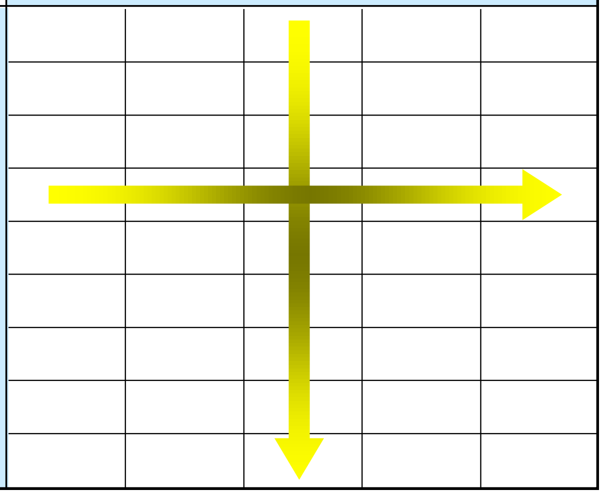
315

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*



315

Data matrix example 1

316

← *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

316

Data matrix example 2

317

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

317

Data matrix example 3

318

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

318

Data matrix example 4

319

← 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 17.1 (a)

320

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 17.1 (b)

321

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.

Exercise 17.1 (c)

322

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.

Exercise 17.1 (d)

323

DI water 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

. . .

⋮

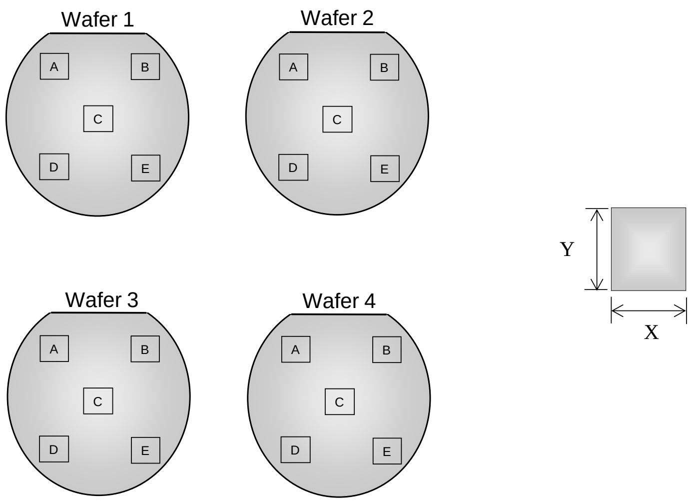
Is this a valid data matrix?

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

Notes

324

Exercise 17.2



Exercise 17.2 (cont'd)

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

327

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

327

Data collection forms (cont'd)

328

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.

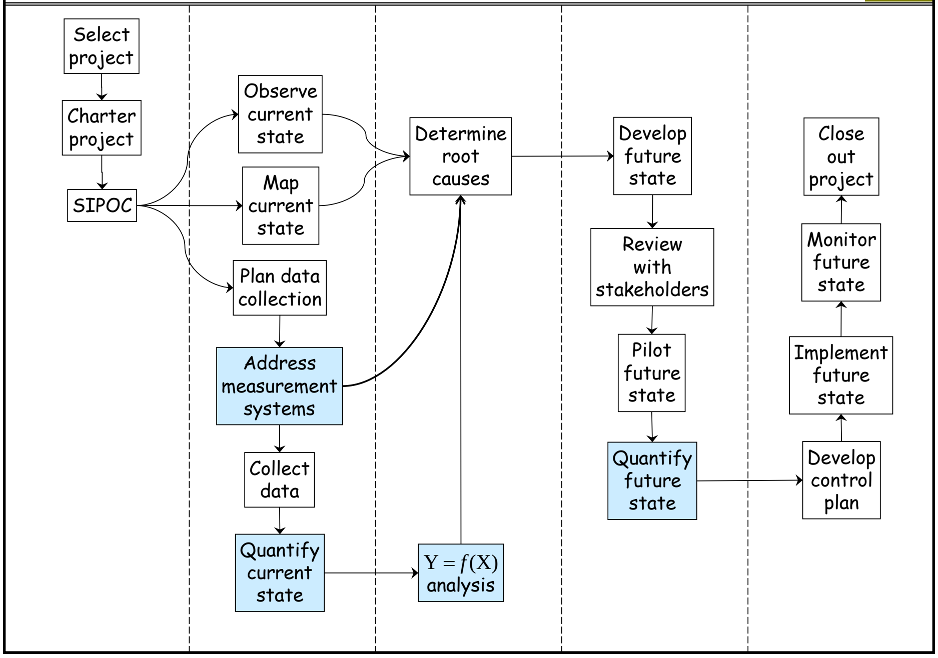
Try to fit all the variables for which you want data collected on one page. Try to make the spaces big enough to write in. These things may work against each other. If there are too many columns to fit into portrait mode, use landscape mode instead. Do not include variables that can be calculated from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

328

18 Types of Data

329



329

Summary of data types

330

	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, . . .

330

Quantitative Y variables

331

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

332

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

- Deionized 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?

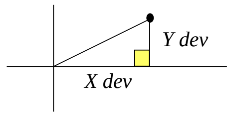
Quantitative Y variables

333

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

333

Quantitative Y variables

334

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

334

Quantitative Y variables

335

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
- If the number of units is always 1, this is count data
- **Date**: quantitative or categorical?

335

Quantitative Y variables

336

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

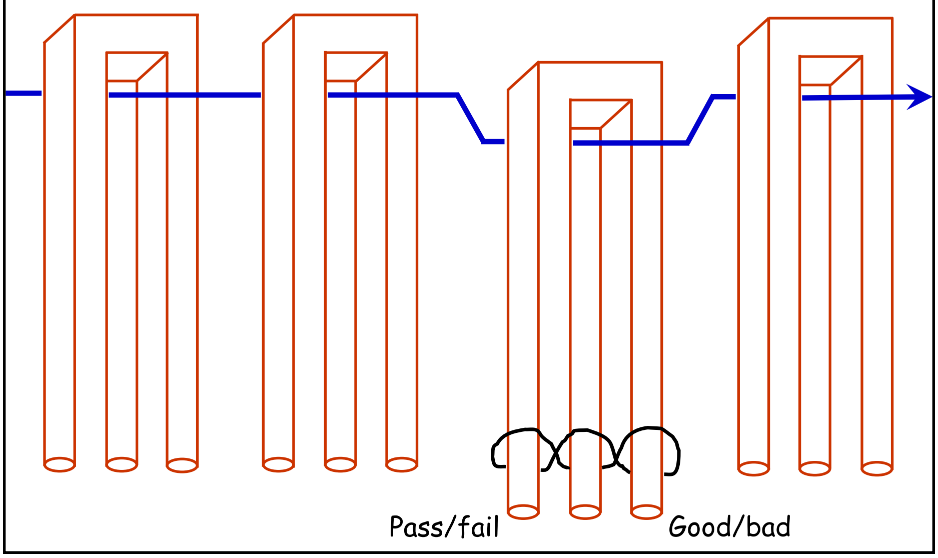
*The Excel function NETWORKDAYS subtracts out the weekends

336

Pass/fail Y variable

337

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

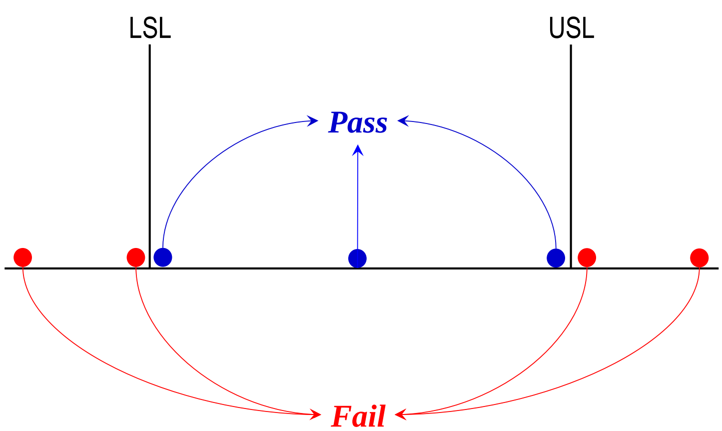


337

Pass/fail Y variable

338

Can be derived from quantitative data and spec limits



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

338

Pass/fail Y variable

339

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

Pass/fail Y variables

340

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

Tabulated defect data

341

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?

341

Categorical Y variable

342

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?

342

Exercise 18.1

343

Pretend the data shown below 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 18.1 (cont'd)

344

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 Dl	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 Dl	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 Dl	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 18.2

345

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

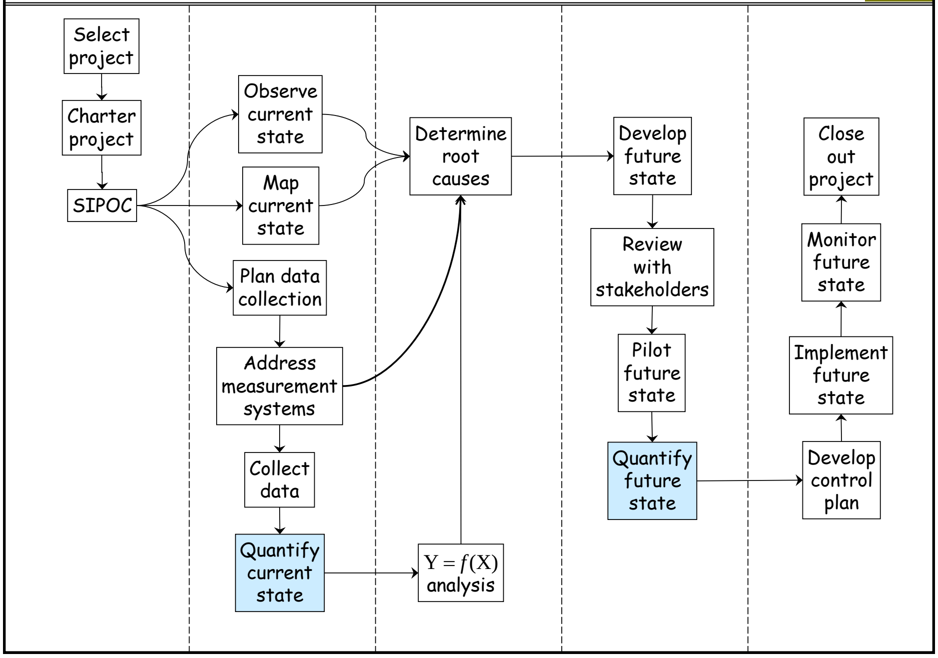
(b) Which useful statistical project metrics can be calculated from a pass/fail Y variable?

Notes

346

19 Basic Statistics and Normal Distribution

347



Basic statistic summary for continuous (quantitative) data

348

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

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

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

$$N = 8$$

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

Minimum = 76

Maximum = 92

Basic statistics (cont'd)

349

Sample standard deviation =

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

$$= 5.04$$

349

Average and standard deviation in Excel

350

C2 | =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 | =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					

350

Open *Student Files* → *anatomy of STDEV*

351

	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**

351

Anatomy of STDEV (cont'd)

352

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.

352

Exercise 19.1

353

a) Open *Data Sets* → *solution properties*. Calculate the average and standard deviation for *Spec grav*. Save your work.

b) Open *Data Sets* → *ED patient visits*. Calculate the average and standard deviation of *Visits*. Save your work.

Notes

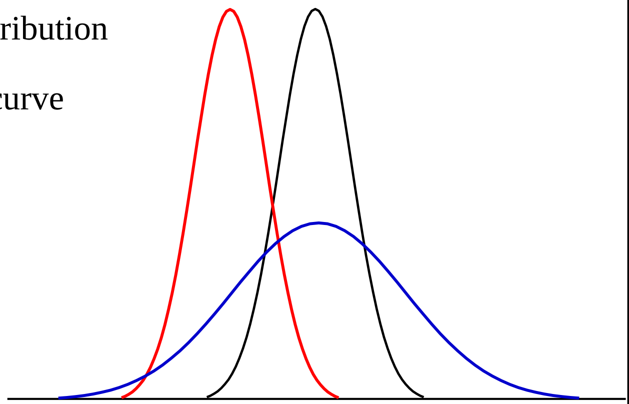
354

The Normal Distribution

355

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

355

Normal distribution (cont'd)

356

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.

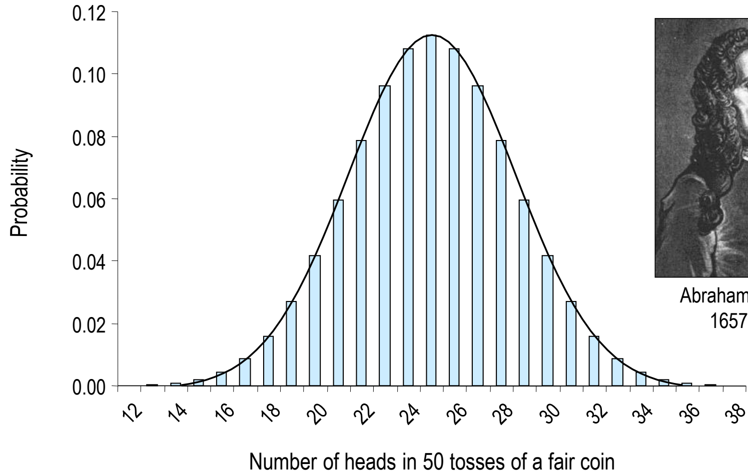
I guess life really isn't fair.

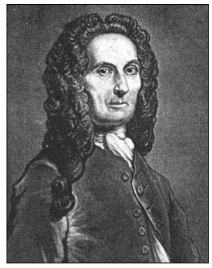
356

Origin of the Normal distribution

357

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

Origin of Normal distribution (cont'd)

358

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).

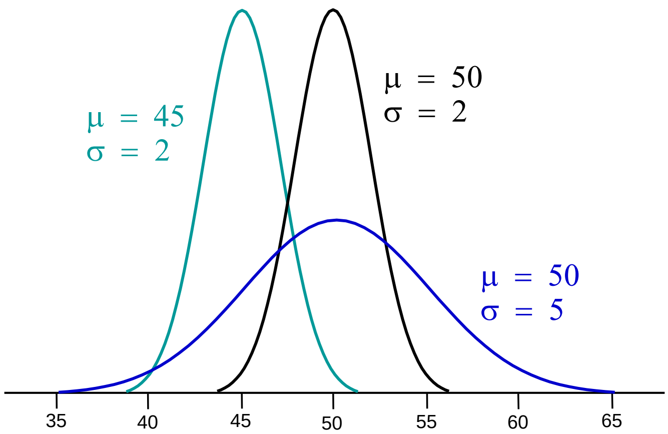
Over the next 200 years, de Moivre's discovery was extended far beyond coin tossing. Today, we know that many quantitative measurements are sums of large numbers of small, independent, possibly unobservable contributing factors. Measurements of this type in a stable population will follow the Normal 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 measure-ments.

The bell shaped curve

359

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



Bell-shaped curve (cont'd)

360

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 above, 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.

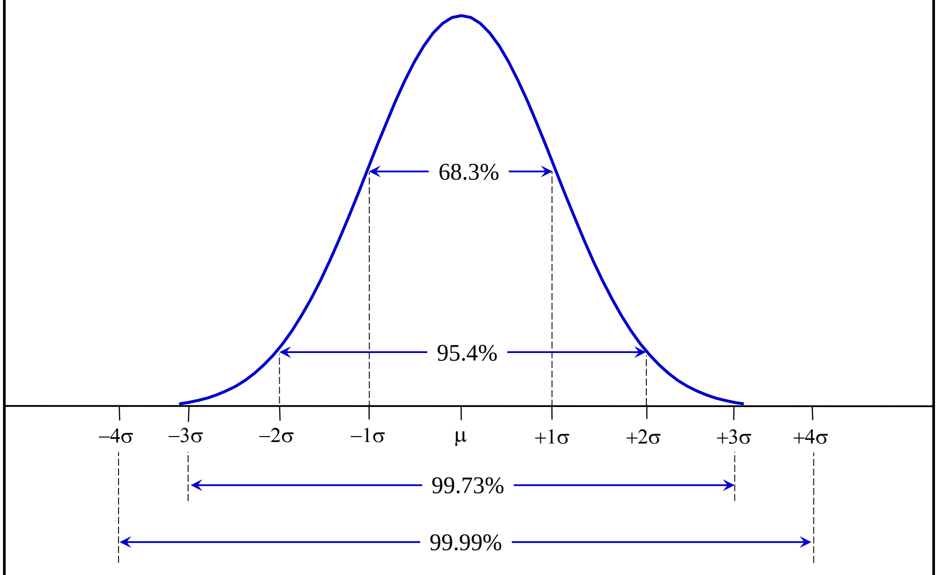
The formula for the bell shaped curve is given below. In this equation, $f(y)$ is the height of the curve above the value y on the horizontal axis.

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

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

361



361

Area under curve (cont'd)

362

For a Normal population:

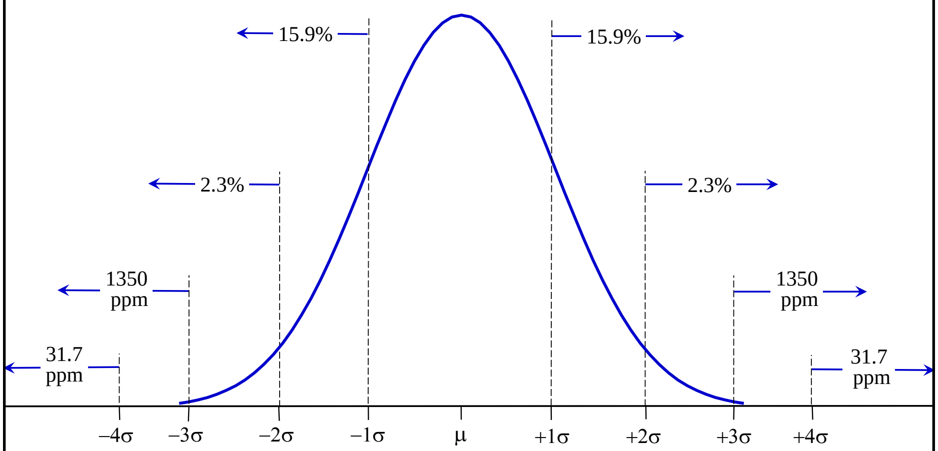
- The 1.960σ limits contain 95% of the population.
- The 2σ limits contain 95.45% of the population.
- The 2.576σ limits contain 99% of a Normal population
- The 3σ limits contain 99.73% of the population.

362

Area under curve = % of population

363

Usually we care mostly about % *beyond* certain points



363

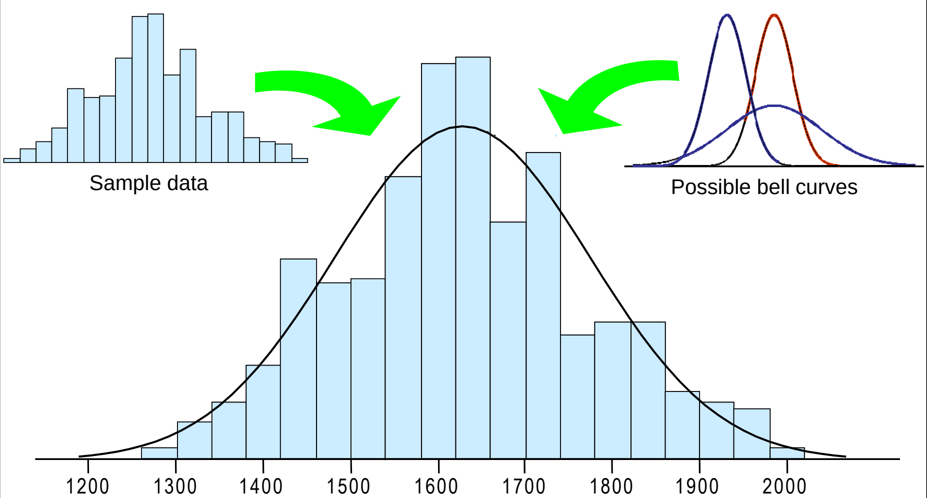
Fitting the bell curve to data

364

Sample mean (1628.7) → μ

Sample standard deviation (142.8) → σ

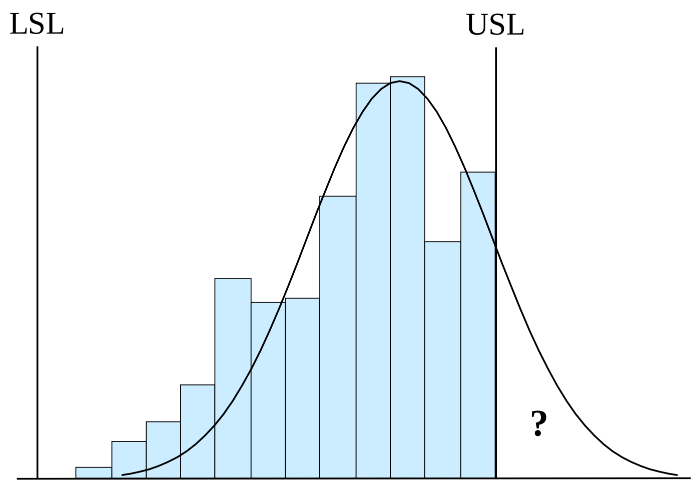
$$f(y) = \frac{1}{\sqrt{2\pi}} \frac{1}{\sigma} e^{-\frac{1}{2}\left(\frac{y-\mu}{\sigma}\right)^2}$$



364

Why use fitted distributions?

365



365

Why distributions? (cont'd)

366

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 above, 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.

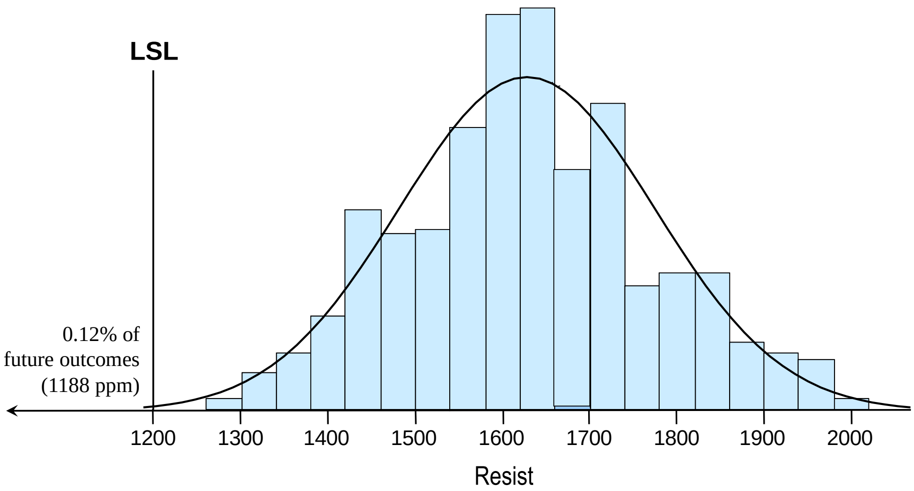
A distribution curve pays no attention to spec limits and will always produce a positive value for % defective or DPPM. This gives an estimate of the supplier's first pass yield. In the example shown above, it is obvious that the first pass yield is far below 100%.

366

Using the Normal curve to predict % defective or DPPM

367

Allows extrapolation (☺ ☹)



367

% below 1500

368

Student Files → calculator - Normal distribution

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

LSL	1500
USL	
Mean	1628.7
Standard deviation	142.8

	LSL	USL	Total
Population % out of spec	18.37	0.00	18.37
Population PPM out of spec	183725	0	183725

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.*

368

% below 1500 or above 1800

369

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*.

Exercise 19.2

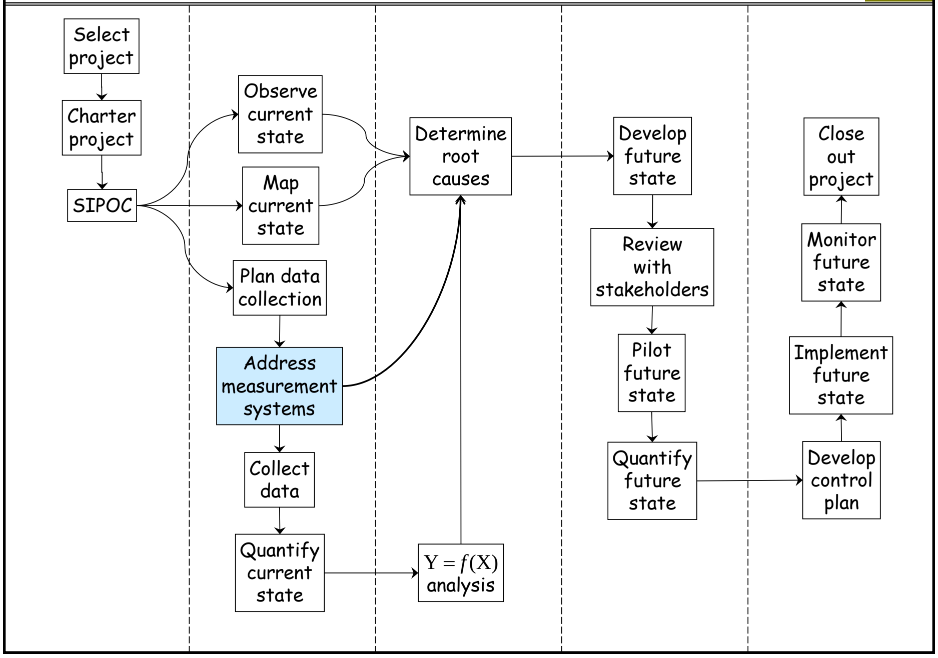
370

a) Open *Data Sets → solution properties*. Use the mean and standard deviation you calculated in Exercise 19.1 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 Exercise 19.1 to find the % or PPM for which *Visits* is either less than 2700 or greater than 3300.

20 Measurement Variation

371



Topics

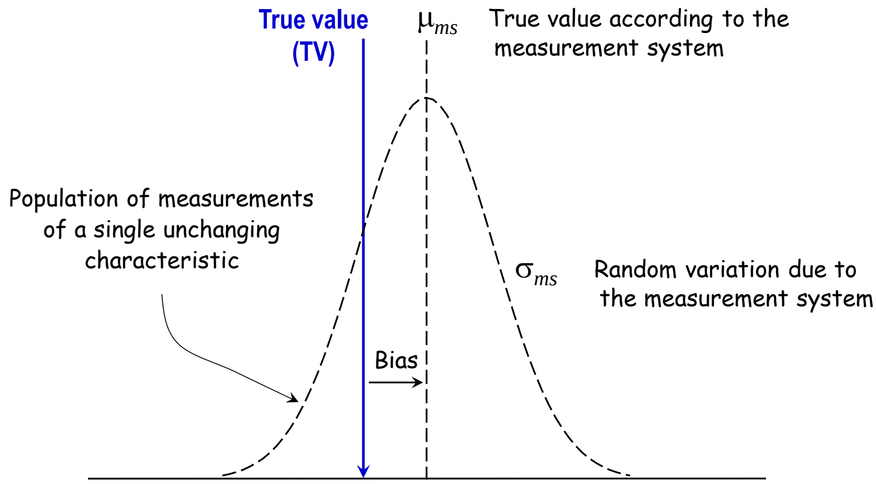
372

- 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.

Population model for measurement variation

373



Measurement error = Systematic error (bias) + Random error

Population model (cont'd)

374

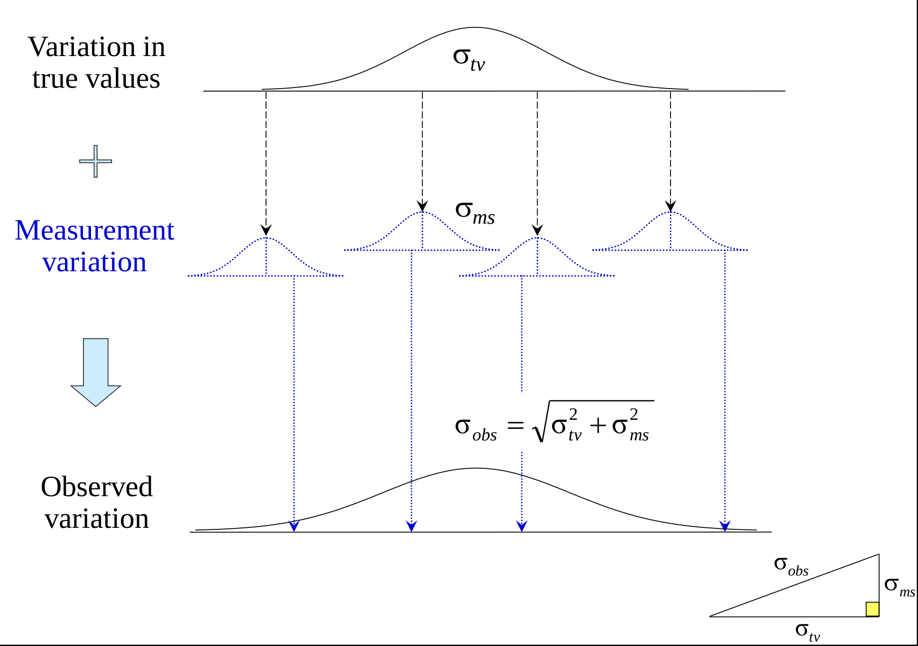
- The purpose of calibration is to eliminate gage bias
- Calibration requires standards (measurable items whose true values are known) or a calibrated second gage of higher accuracy
- The primary objective of quantitative measurement system analysis (MSA) is to determine the variation contributed by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

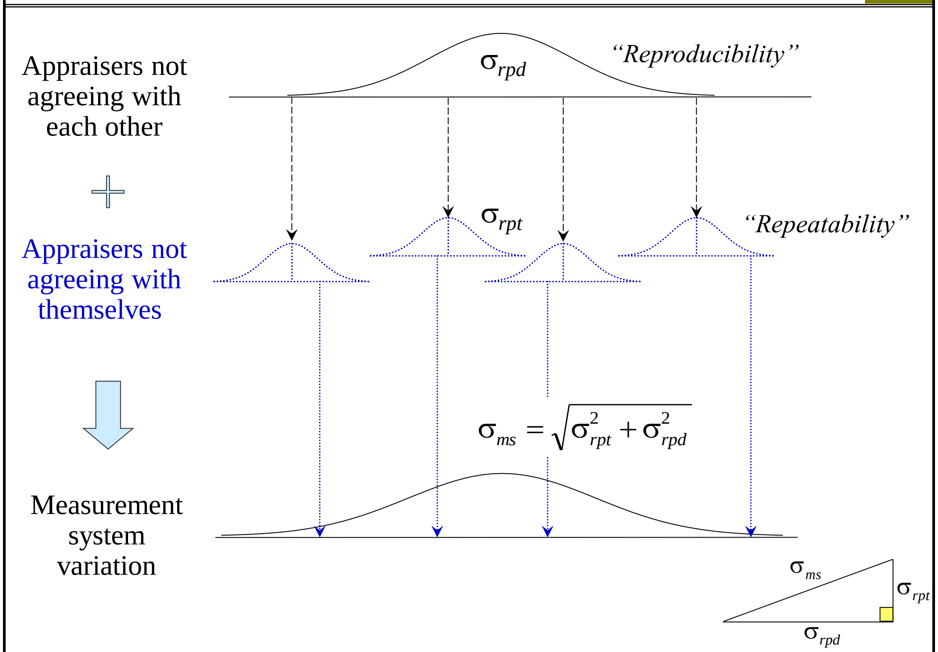
375



375

Components of *measurement system variation*

376



376

STDEV revisited

377

	A	B	C	D	E	F	G	H	I	J
1			**Data**		**Average**		**Difference**			
2			9.61		9.691		-0.081			
3			9.71		9.691		0.019			
4			9.54		9.691		-0.151			
5			9.67		9.691		-0.021			
6			9.75		9.691		0.059			
7			9.49		9.691		-0.201			
8			9.55		9.691		-0.141			
9			9.42	=	9.691	+	-0.271		Sum =	0.00000000
10			9.58		9.691		-0.111			
11			9.61		9.691		-0.081			
12			9.87		9.691		0.179			
13			9.93		9.691		0.239			
14			9.81		9.691		0.119			
15			9.89		9.691		0.199			
16			9.94		9.691		0.249			
17	Degrees of freedom (DF)		15	=	1	+	14			
18	Sum of squares (SS)		1409.220	=	1408.829	+	0.391			
19	Mean square (MS)		*(SS / DF)*				0.028			
20	Square root of MS						**0.167**			

↑
Sample standard deviation
(STDEV)

377

STDEV (cont'd)

378

The slide above 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.

378

MSA with one appraiser (cont'd)

379

	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 of measurement variation

379

MSA with one appraiser (cont'd)

380

The slide above 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 × 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.

380

MSA with one appraiser (cont'd)

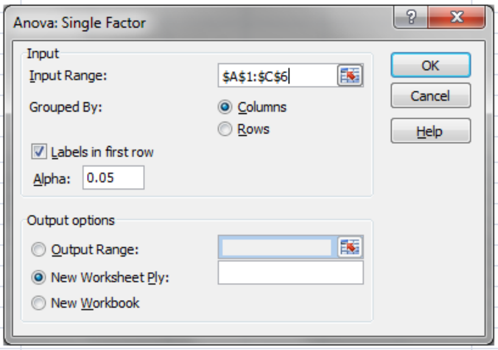
381

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*

381

MSA with one appraiser (cont'd)

382

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**

382

MSA with one appraiser (cont'd)

383

	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**

383

Exercise 20.1

384

Open file *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.

384

Degrees of freedom for MSA with one appraiser

385

- 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

Exercise 20.2

386

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

	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

387

- 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)

387

Example

388

- 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

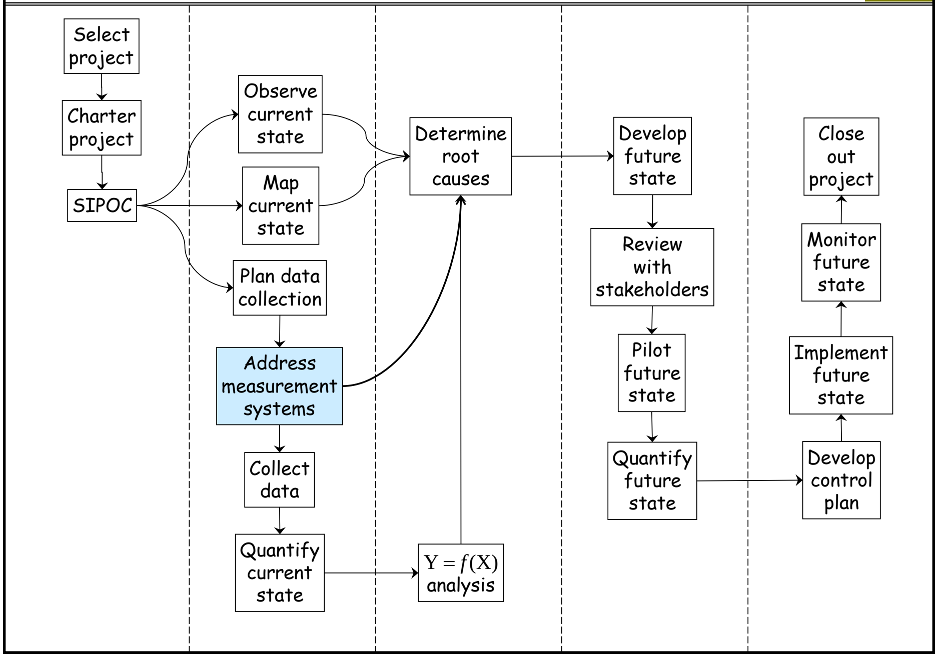
Exercise 20.3

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

388

21 Measurement System Analysis

389



Topics

390

- 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

391

- 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

391

Measurement system

392

- 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

392

Impact of measurement variation

393

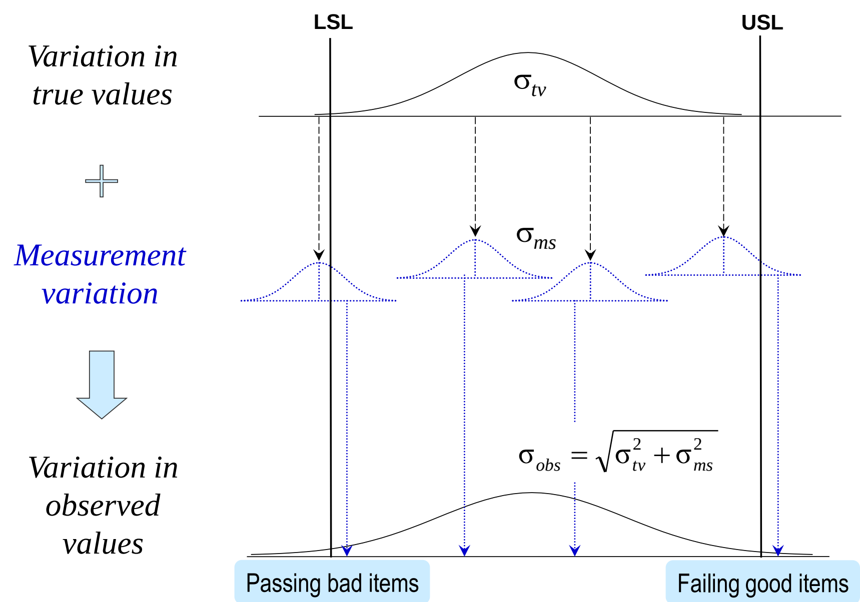
Action taken

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

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

Impact of measurement variation (cont'd)

394



Measurement system analysis (MSA)

395

- 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

395

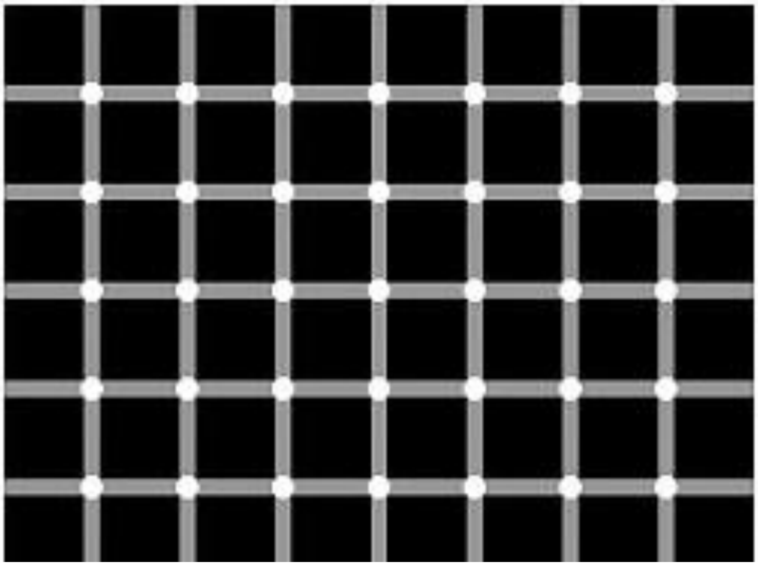
Common corrective actions

396

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

396

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

399

% 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

399

Acceptability criteria for "percent" metrics

400

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

400

Designing a quantitative MSA

401

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.

401

Designing a quantitative MSA (cont'd)

402

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.

402

Examples of step 3

403

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
# Opportunities for appraiser cross-agreement	20
Total sample size	90

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

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

403

Examples of step 3

404

A better plan

Number of items	15
Number of appraisers	3
Number of sessions	2
# Opportunities for appraiser self-agreement	45
# Opportunities for appraiser cross-agreement	30
Total sample size	90

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

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

404

Examples of step 3

405

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

405

Conducting a quantitative MSA

406

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.

406

Analyzing a quantitative MSA

407

- Open *Data Sets* → *msa velocity gage*
- Measurements are of Drop Velocity
- This is the data format required for continuous MSA 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?

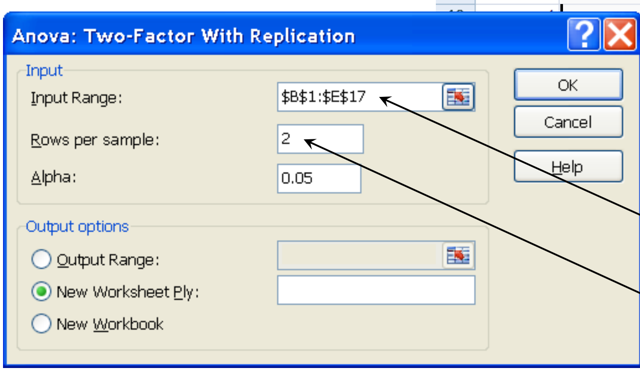
What do the numbers in cell range C2:E2 represent:
part variation, measurement variation, or observed variation?

Worked example

408

1. **Sort the data by *Part*** as shown to the right (the Excel procedure needs this).
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
[illegible]	[illegible]	6	10.15	10.12	10.16
[illegible]	[illegible]	6	10.31	10.08	10.18
[illegible]	[illegible]	7	9.96	9.87	9.97
[illegible]	[illegible]	7	10.05	9.96	9.97
[illegible]	[illegible]	8	9.80	9.72	9.72
[illegible]	[illegible]	8	9.87	9.74	9.78



Place cursor here, highlight this range

Enter the number of sessions here

Example (cont'd)

409

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)

410

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)

411

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

$3\sigma_{ms} = 0.2179$

	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					

		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				

Reproducibility is the dominant component, but not by much.

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

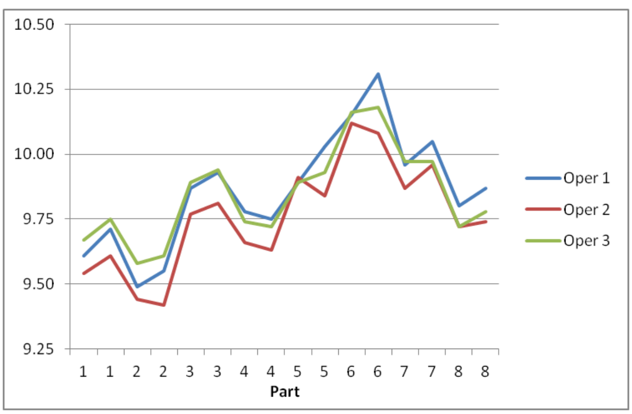
$$\%Tol = 100 \times \frac{3\sigma_{ms}}{1.65} = 13.2\%$$

Example (cont'd)

412

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

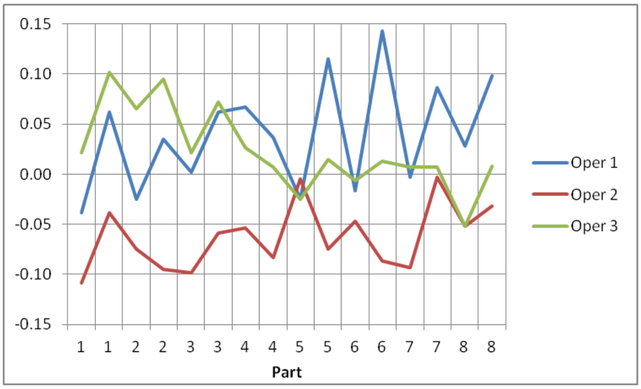
10. This is what a good one looks like. The operator curves are close together and roughly parallel, showing they are getting similar measurements for each part.



Example (cont'd)

413

- 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.



413

Interpreting $3\sigma_{ms}$

414

- In this example, $3\sigma_{ms} = 0.2179$
- For a given measurement *m*, the true value lies in the interval

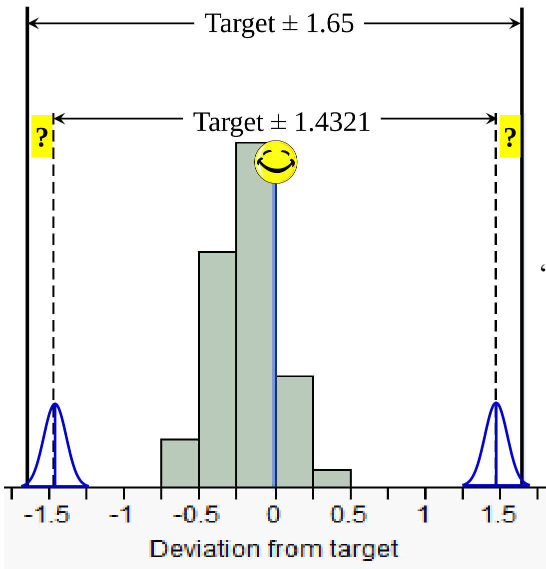
  $$m \pm 0.2179$$

  with 99.7% confidence
- The tolerance for drop velocity is ± 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)

414

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

415



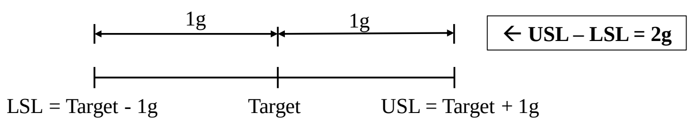
These are also known as "Guard Bands"

Exercise 21.1

416

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 21.2

417

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″. 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. Who seems to be the greatest opportunity for improvement?

Exercise 21.3

418

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 temperatures to determine the effect of temperature 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 temperature on measurement variation?

Exercise 21.4

419

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?

419

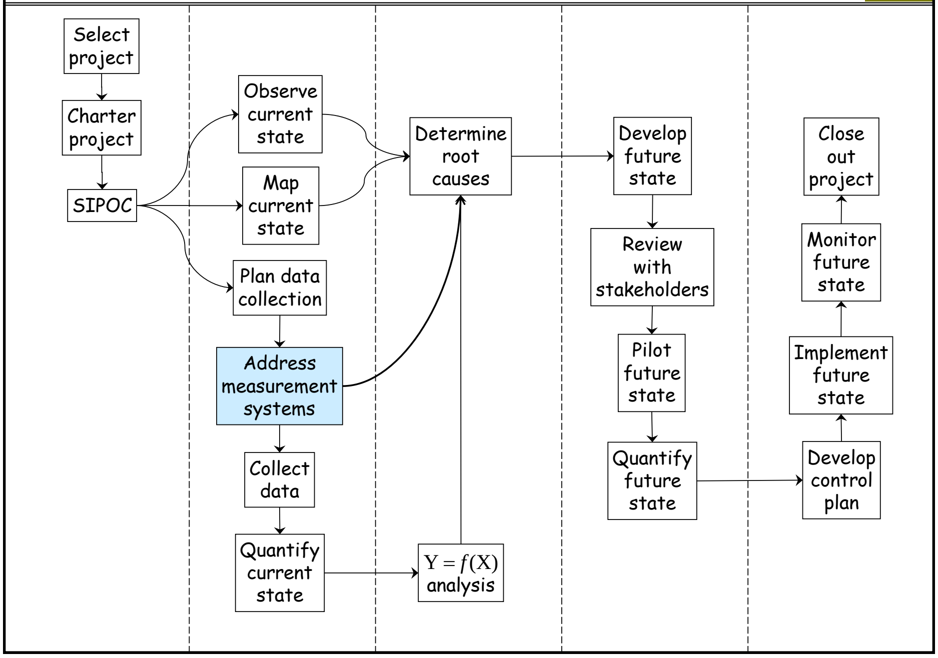
Notes

420

420

22 Categorical MSA

421



421

Categorical MSA

422

- 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)

422

Designing a categorical MSA

423

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.

423

Designing a categorical MSA (cont'd)

424

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.

424

Examples of step 3

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

Examples of step 3

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

Conducting a categorical MSA*

427

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

427

Analyzing a categorical MSA

428

- 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

428

Worked example

429

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

429

Example (cont'd)

430

- 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)

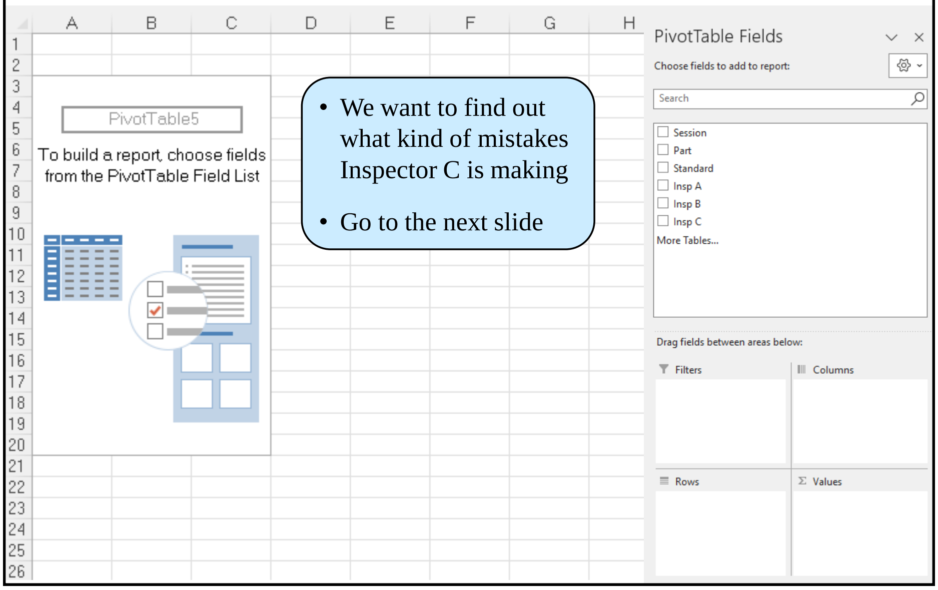
	A	B	C	D	E	F	G	H	I	J
1	Session	Part	Standard	Insp A	Insp B	Insp C	A	B	C	
143	3	42	F	F	F	F	1	1	1	
144	3	43	P	P	P	F	1	1	0	
145	3	44	P	P	P	P	1	1	1	
146	3	45	F	F	F	F	1	1	1	
147	3	46	P	P	P	P	1	1	1	
148	3	47	P	P	P	P	1	1	1	
149	3	48	F	F	F	F	1	1	1	
150	3	49	P	P	P	P	1	1	1	
151	3	50	F	F	F	F	1	1	1	
152							94.7%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

430

Example (cont'd)

431

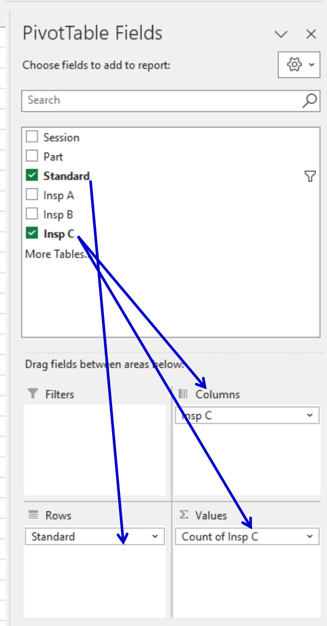
Highlight columns A-F → select the *Insert* ribbon → select *PivotTable* → OK



431

Example (cont'd)

432



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.

432

Example (cont'd)

433

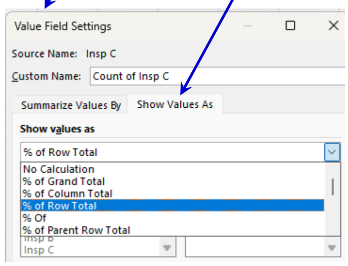
Count of Insp C	Column Labels		
Row Labels	F	P	Grand Total
F	87.50%	12.50%	100.00%
P	8.82%	91.18%	100.00%
Grand Total	34.00%	66.00%	100.00%

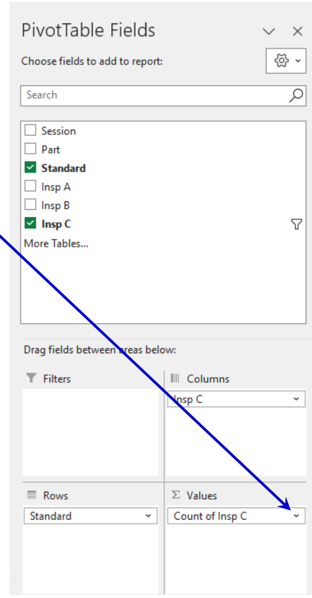
- Inspector C passed 12.5% of the bad parts
- and failed 8.8% of the good parts
- Inspector C needs further training to reduce both types of errors

Click dropdown on *Count of Insp C >*

Value Field Settings >

Show Values As >
% of row total





Exercise 22.1

434

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.

Exercise 22.2

435

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 22.3

436

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.

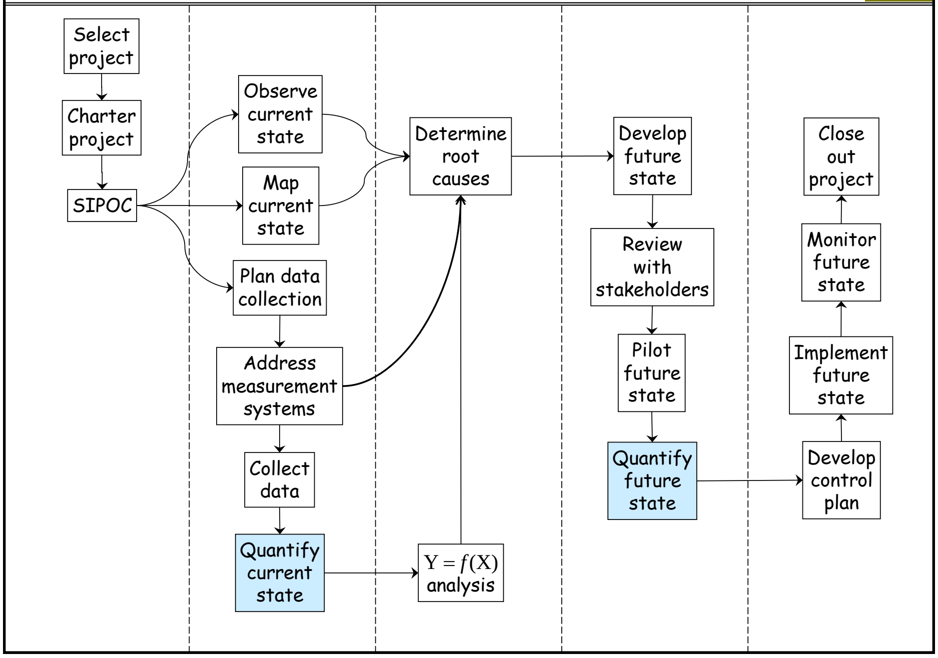
a) Calculate the % agreement by appraiser and overall.

b) Which inspector offers the greatest opportunity for improvement? Make a pivot table to determine the particular error this inspector often makes.

c) Save your work.

23 Establishing Baselines – Pass/fail Y

437



Topics

438

- 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

439

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	690	3457445	3	Fail	Op curr out of range
13	3/1/06 6:19 AM					
14	3/1/06 6:20 AM					
15	3/1/06 6:21 AM					
16	3/1/06 6:22 AM					
17	3/1/06 6:22 AM					
18	3/1/06 6:24 AM					nge
19	3/1/06 6:24 AM					Test
20	3/1/06 6:25 AM					
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	

- Part level data (not tabulated)
- Y variables = *Result, Failure Reason*
- X variables = *Date, Time, P/N, Tester*

439

% Defective (cont’d)

440

	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	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.

440

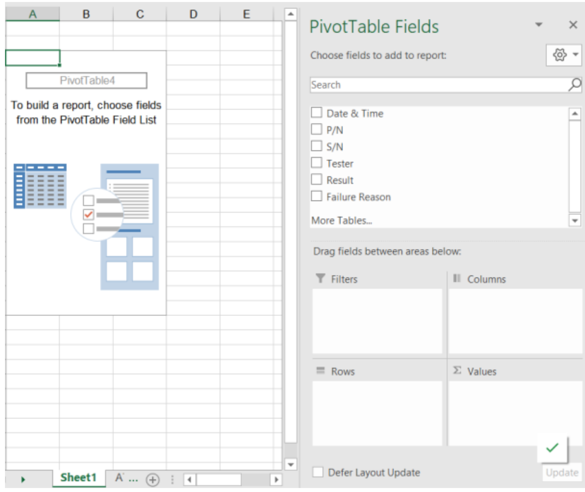
% Defective (cont'd)

441

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

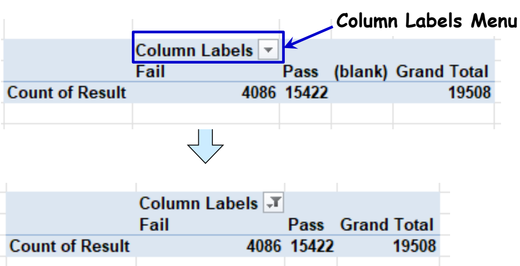
5. Drag/drop *Result* into the *Values* box

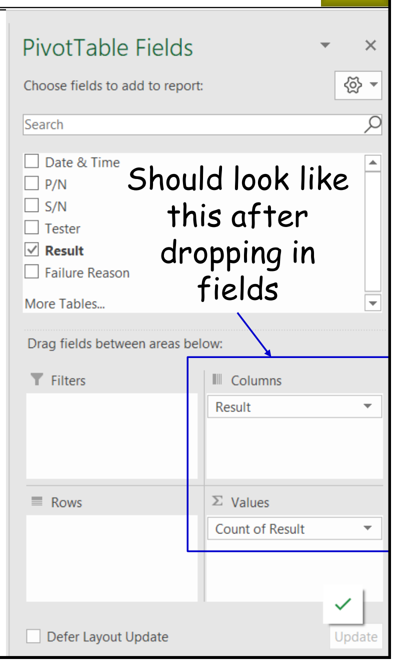
6. Go to the next slide.



% Defective (cont'd)

442





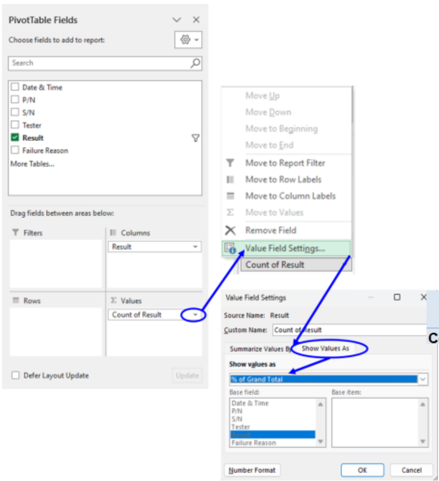
7. Pull down the *Column Labels* menu (shown above)

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

9. Go to the next slide.

% Defective (cont'd)

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



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

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

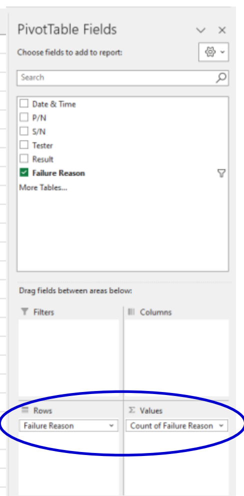
Format for reporting:

Project metric	% Defective
Baseline value	20.9%

Pareto analysis of failure reasons

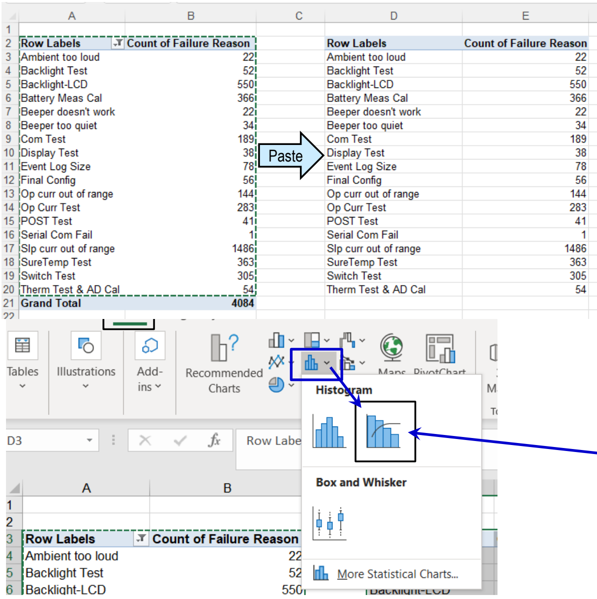
Menu

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**



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

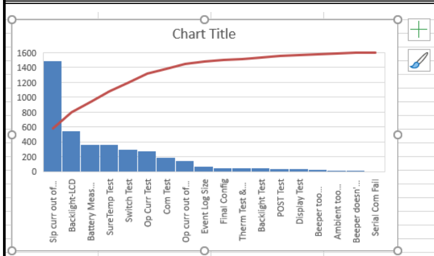
Pareto analysis of failure reasons (cont'd)



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

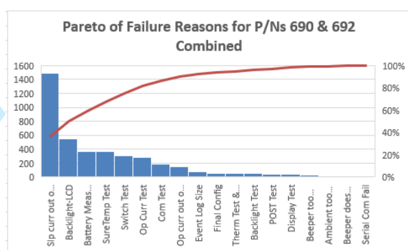
5. Copy Pivot table except for the Grand Total
6. Paste one column to the right
7. Highlight entire table you just pasted
8. Select *Insert* > Charts Section > *Insert Statistic Chart* dropdown > *Pareto*
9. Go to the next slide

Pareto analysis of failure reasons (cont'd)



Click the "+" button to edit chart elements

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



Exercise 23.1

447

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)

448

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

449

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

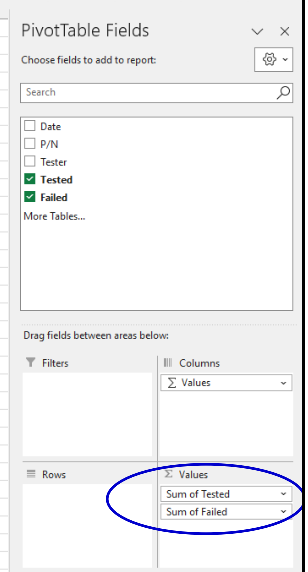
	A	B	C	D	E
1	Date	P/N	Tester	Tested	Failed
2	3/1/2006	690	3	166	12
3	3/1/2006	692	1	142	13
4	3/1/2006	692	2	183	34
5	3/1/2006	692	3	1	0
6	3/2/2006	690	1	155	20
7	3/2/2006	690	2	168	12
8	3/2/2006	690	3	24	4
9	3/2/2006	692	3	107	14
10	3/3/2006	690	1	87	10
11	3/3/2006	690	2	19	9
12	3/3/2006	690	3	5	2
13	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

% Defective from tabulated data (cont'd)

450

- 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
3	Sum of Tested	Sum of Failed
4	19509	4087
6	% Defective=	20.9%



Pareto analysis from tabulated data

451

- 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 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

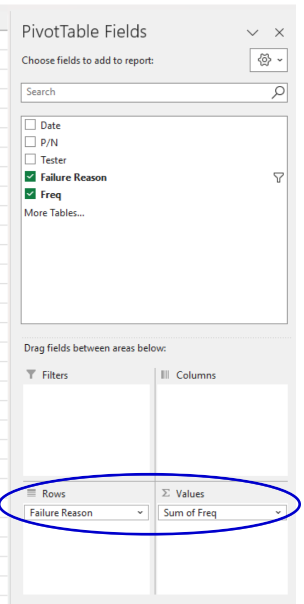
451

Pareto from tabulated data (cont'd)

452

- Insert a pivot table
- Set it up as shown here
- Sort the failure reasons in descending order by number of occurrences
- The Pareto chart will turn out the same as the one previously generated from the "raw" data

	A	B
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



452

Exercise 23.2

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*. Find the % failing. Save your work.

Exercise 23.2 (cont'd)

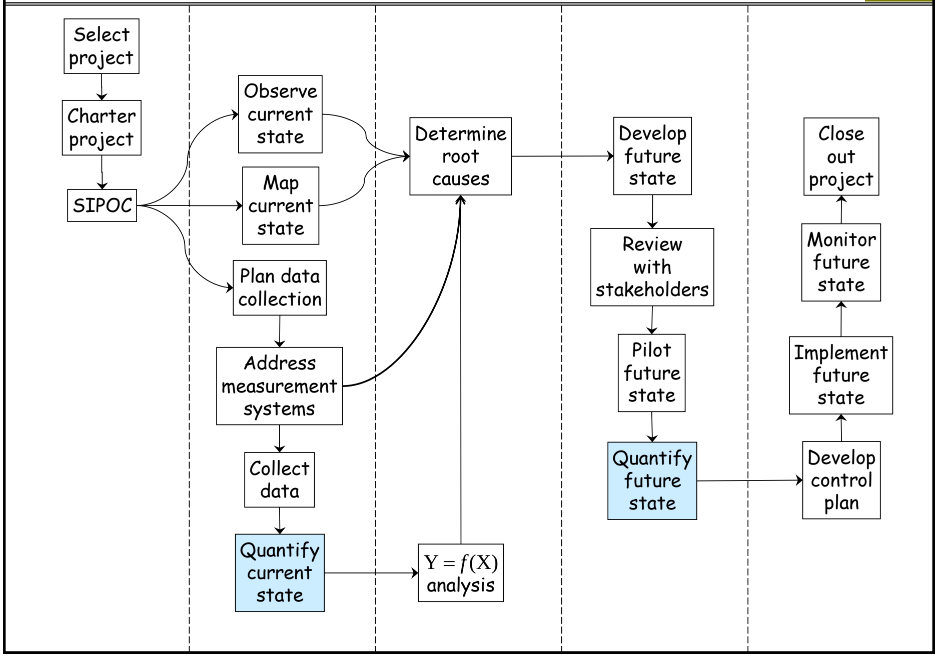
d) Open *unplanned downtime log*. Create a Pareto chart of *Problem area* by total downtime. Save your work.

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

455



455

Topics

456

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

456

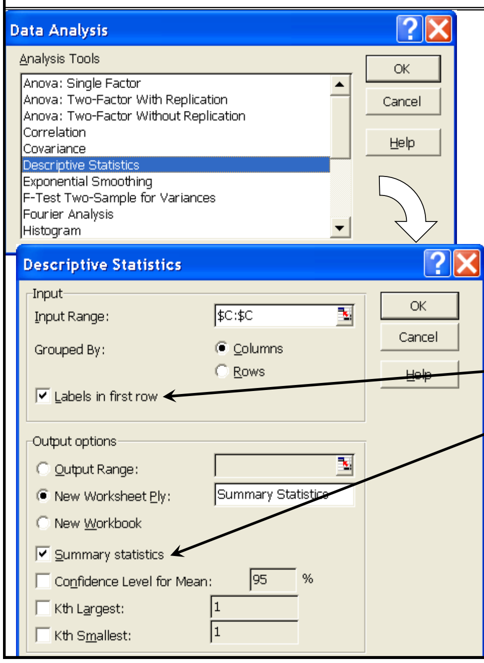
Basic statistical summary

- Open *Data Sets* → *DI water*
- Measurements 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		

457

Basic statistical summary (cont'd)



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

458

Basic statistical summary (cont'd)

459

	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

- Edit down to the "vital few"
- Correct the default numerical formats

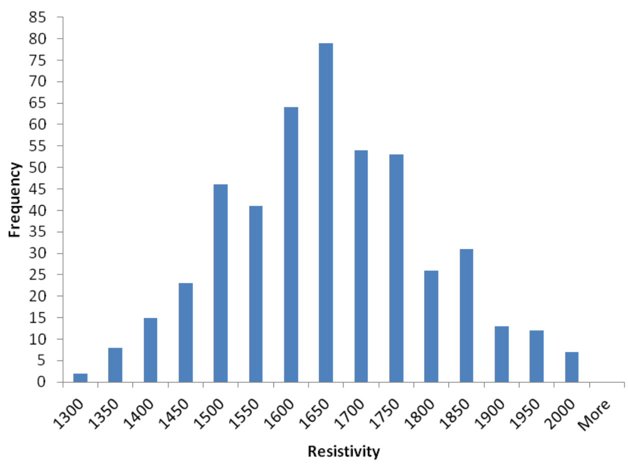
	A	B
1	*Resist*	
2		
3	Mean	1628.8
4	Standard Deviation	142.9
5	Minimum	1267
6	Maximum	2000
7	Count	474
8		
9		
10		
11		
12		
13		
14		
15		

Project metric	Average Resistivity
Baseline value	1628.8

Frequency histogram

460

A statistical graphic for displaying variation in quantitative data



Histogram (cont'd)

461

- 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

461

Histogram (cont'd)

462

Excel path to create Histogram:

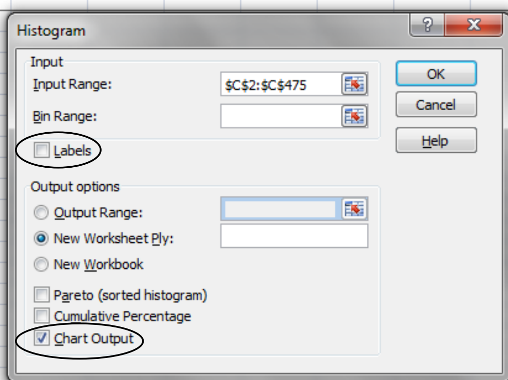
Data → *Data Analysis* → *Histogram*

462

Histogram Setup: *Data → Data Analysis → Histogram*

463

	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



Grab the data range only

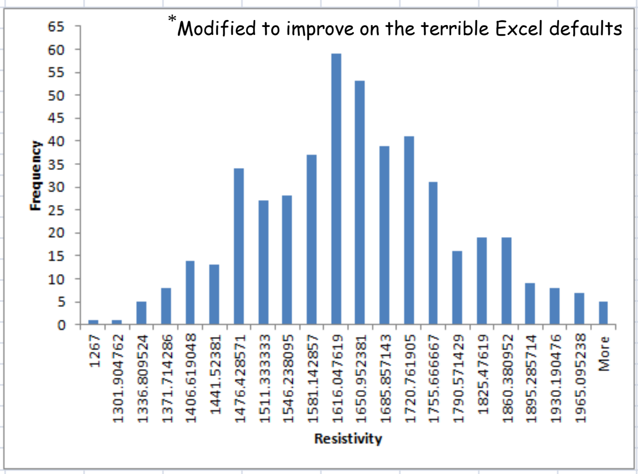
Use: Ctrl-Shft-▼ to grab whole column

463

Histogram output*

464

	Bin	Frequency
2	1267	1
3	1301.905	1
4	1336.81	5
5	1371.714	8
6	1406.619	14
7	1441.524	13
8	1476.429	34
9	1511.333	27
10	1546.238	28
11	1581.143	37
12	1616.048	59
13	1650.952	53
14	1685.857	39
15	1720.762	41
16	1755.667	31
17	1790.571	16
18	1825.476	19
19	1860.381	19
20	1895.286	9
21	1930.19	8
22	1965.095	7
23	More	5



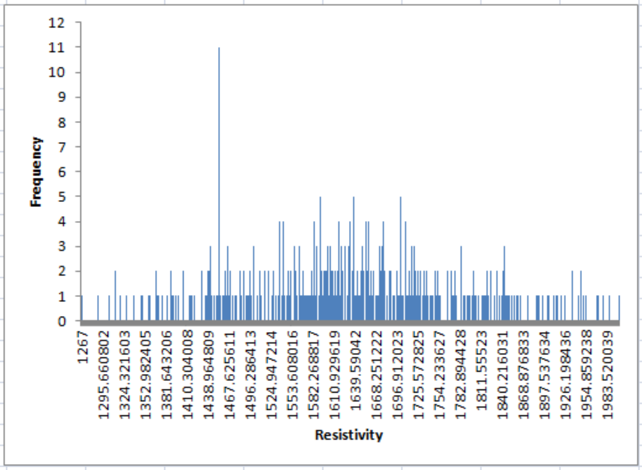
The numeric format for the bin endpoints should not vary

464

Histogram output that you don't want

465

Row	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

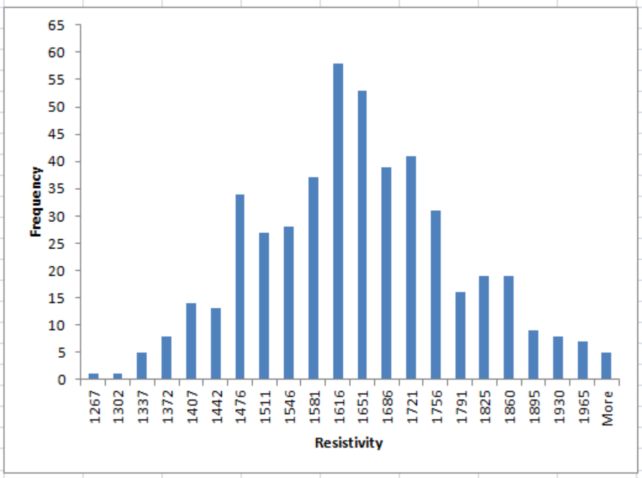


If you get a graph that looks like this, you selected the entire column, not just the data.

Histogram (cont'd)

466

Row	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

% Defective from quantitative data

467

	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

467

Percent less than 1500

468

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")

468

Percent less than 1500 (cont'd)

469

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

469

Percent less than 1500 (cont'd)

470

- Run a pivot table on the new column
- 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 (refer to instructions in Module 23)

	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%

470

Percent greater than 1800

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

Percent greater than 1800 (cont’d)

- 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%

Exercise 24.1

473

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.

Exercise 24.2

474

Open *Data Sets* → *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.

(e) Save your work.

* *Student Files* → *quotation process charter*

Exercise 24.3

475

Open the file *Data Sets* → *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* → *MBDP charter*

475

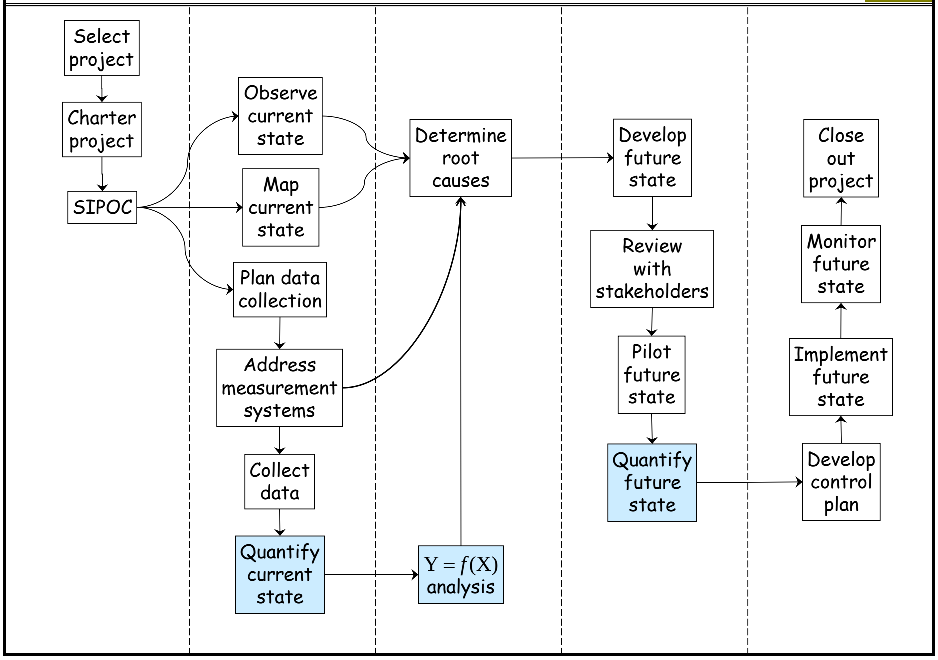
Notes

476

476

25 Plotting Data Over Time

477



477

Why plot data over time?

478

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

478

Example 1: Plotting quantitative data

479

Data Sets → DI water

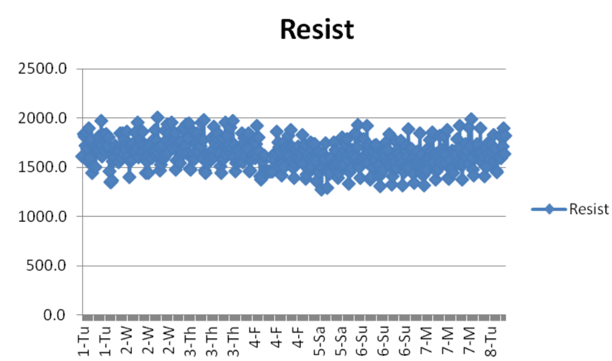
- De–ionized water is used in machining and cutting operations
- Y = electrical resistivity (*Resist*)
- Want lower conductivity, so higher Y is better
- Baseline data was collected over 8 days, 3 measurements per hour
- Want to make a time plot

	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	

Example 1 (cont'd)

480

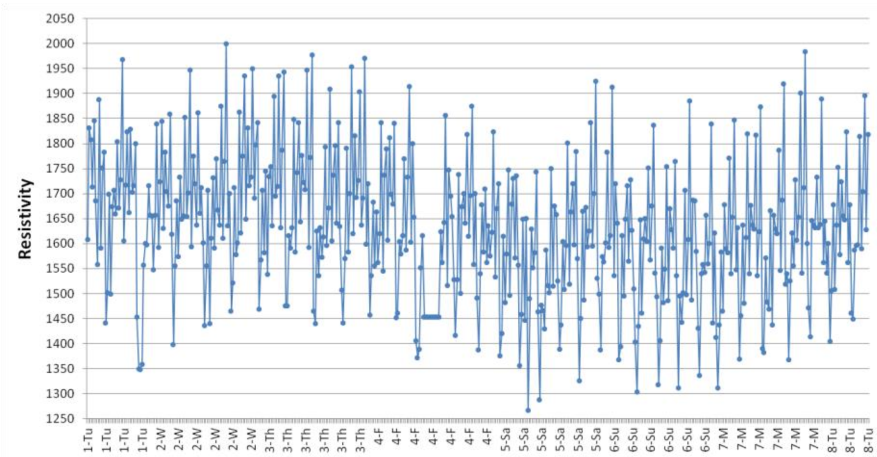
1. Select column C, then select column A while holding down the **Ctrl** key
2. Insert a line chart ("Line with Markers")
3. Behold: your typically terrible default Excel chart
4. Desperately needs "graphical 5S"



Example 1 (cont'd)

481

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)

482

- 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 above — what are they?

Example 2: Plotting quantitative data

483

Open *Data Sets* → *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

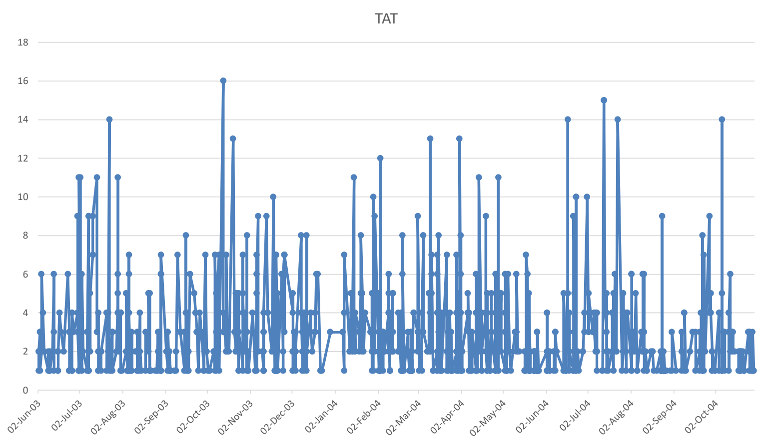
=YEAR(D2)+MONTH(D2)/100

=IF(H2>3,"Fail","Pass")

Example 2 (cont'd)

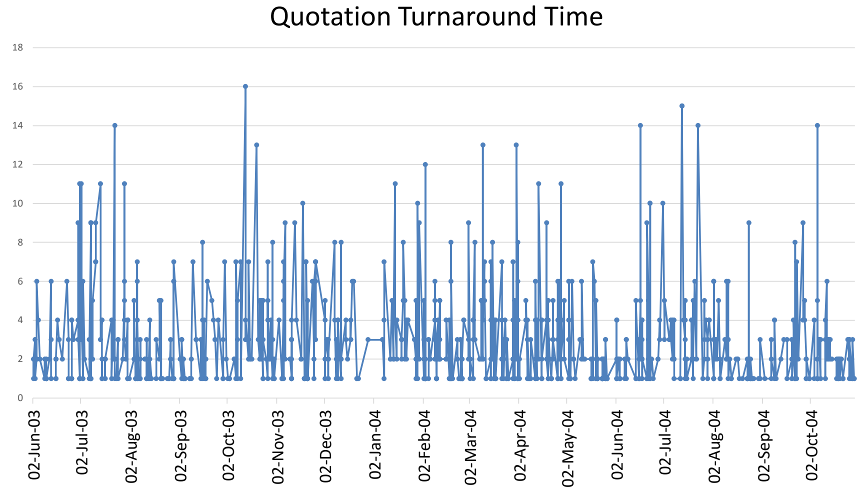
484

1. Select column H, then select column D while holding down the **Ctrl** key
2. Insert a line chart ("Line with Markers")



Example 2 (cont'd)

485



Changes in variation, no discernable changes in the mean

Example 3: Plotting pass/fail data

486

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					Dp 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)

- 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

Example 3: (cont'd)

	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

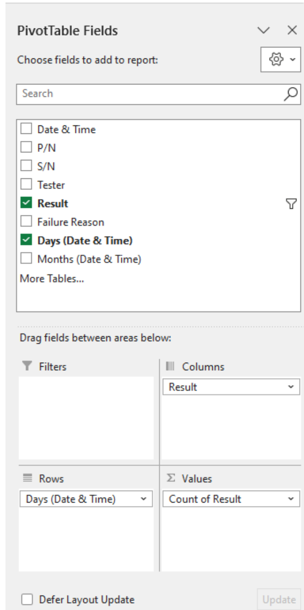
1. Select columns A-F
2. Insert a *PivotTable* (see next slide)

Example 3 (cont'd)

489

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

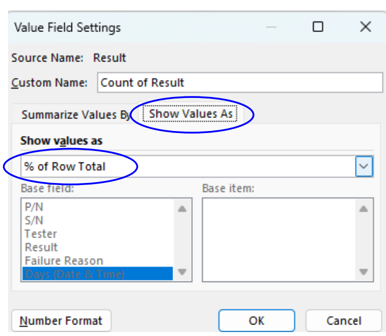


Example 3 (cont'd)

490

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

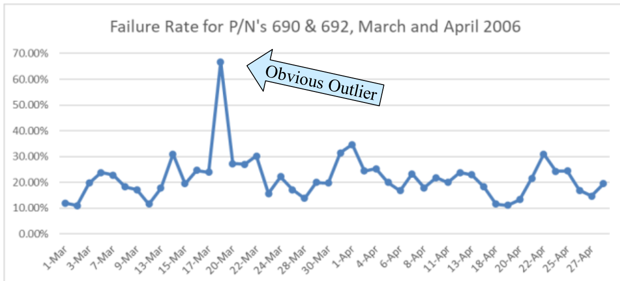


Example 3 (cont'd)

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%

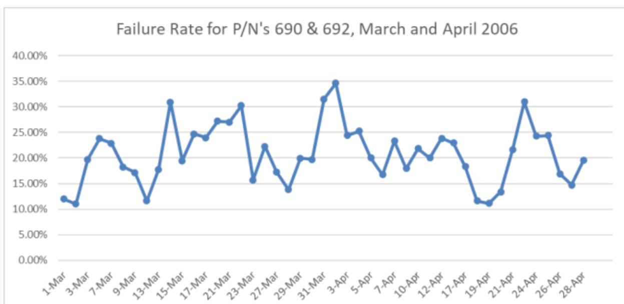
8. Next, *Copy* and *Paste* the *Count of Result Row Labels* and the *Fail %* columns to a blank area of the worksheet.

9. Click in any *Fail* data cell and *Insert* a *Line Chart with Markers*



Example 3 (cont'd)

- 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

493

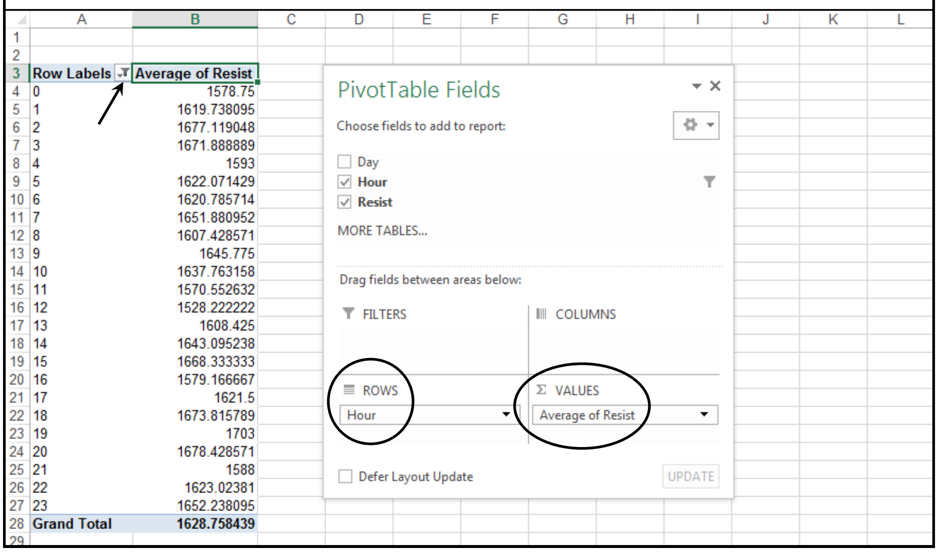
- Can also plot *summary statistics* by time period
- Average, % too high, % too low, etc.
- May give a clearer picture of certain patterns of variation

493

Example 4 (cont'd)

494

1. Let's plot average resistivity by hour of day
2. Insert a pivot table, set it up as shown below



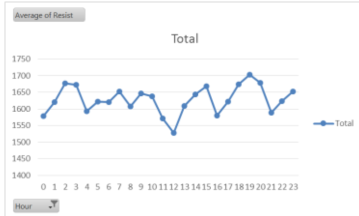
Row Labels	Average of Resist
0	1578.75
1	1619.738095
2	1677.119048
3	1671.888889
4	1593
5	1622.071429
6	1620.785714
7	1651.880952
8	1607.428571
9	1645.775
10	1637.763158
11	1570.552632
12	1528.222222
13	1608.425
14	1643.095238
15	1668.333333
16	1579.166667
17	1621.5
18	1673.815789
19	1703
20	1678.428571
21	1588
22	1623.02381
23	1652.238095
Grand Total	**1628.758439**

494

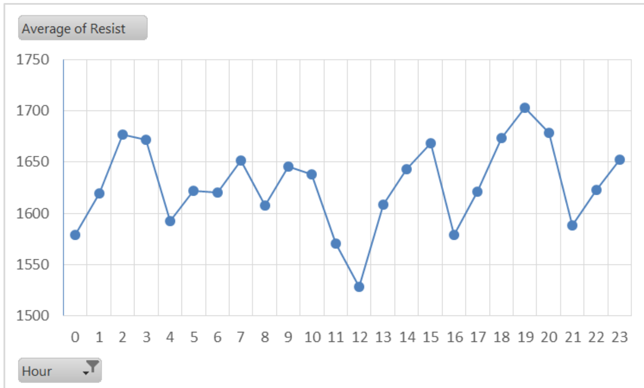
Example 4 (cont'd)

495

With the *Pivot Table Fields* dialog still 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



Exercise 25.1

496

Open *Data Sets* → *quotation process current state*. Create the following charts. Make them look the way they should.

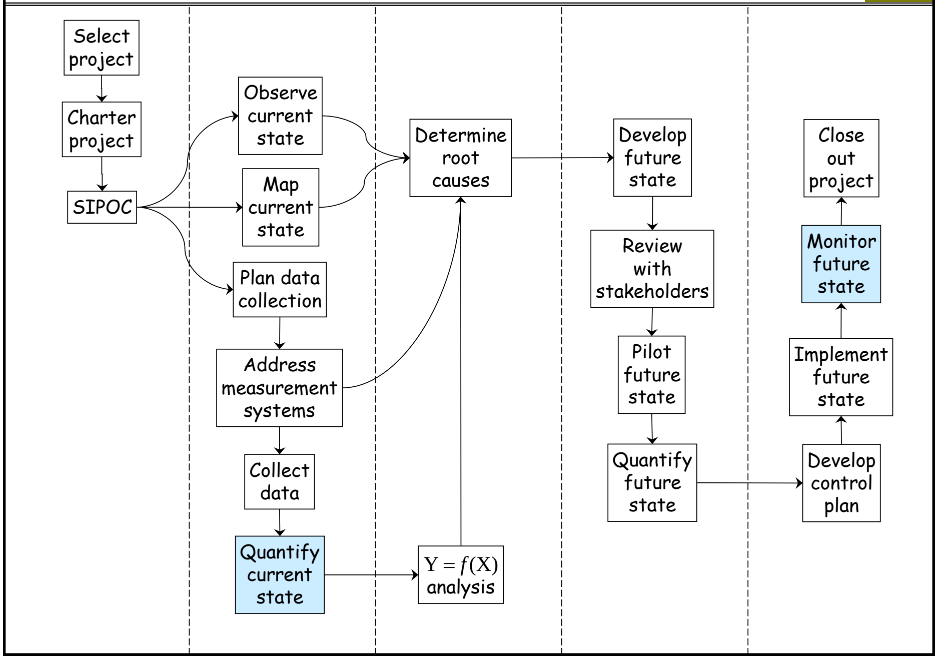
a) Monthly % TAT > 3.

b) Monthly PO hit rate (% Yes).

c) Close and save the data set.

26 Process Capability Indices

497



497

Topics

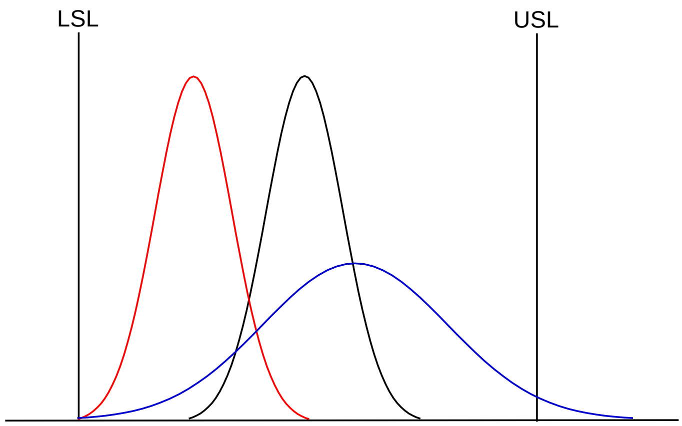
498

- Purpose of Process Capability Indices
- Commonly used indices
- Important assumptions for validity

498

Process capability indices

499



- 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

Process capability indices (cont’d)

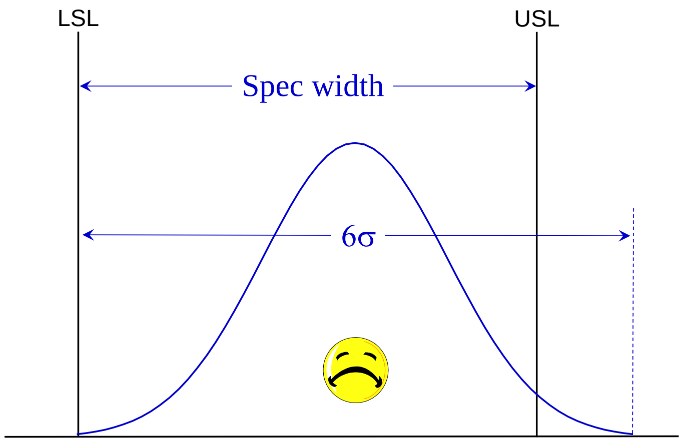
500

- Do your organization’s external customers ask for process capability reporting?
- Are there internal requirements or needs for process capability reporting?

C_p index

501

$$C_p = \frac{\text{Spec width}}{6\sigma}$$



In this case, C_p is less than 1

C_p (cont'd)

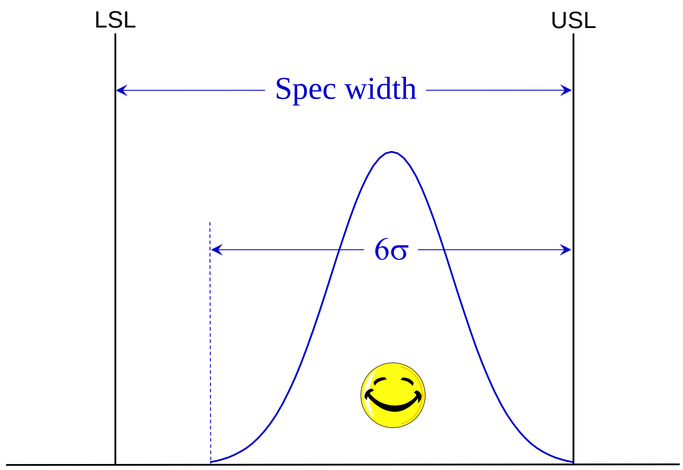
502

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)

503



In this case, C_p is greater than 1, but what's a potential problem here?

503

C_p (cont'd)

504

In the example above, 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.

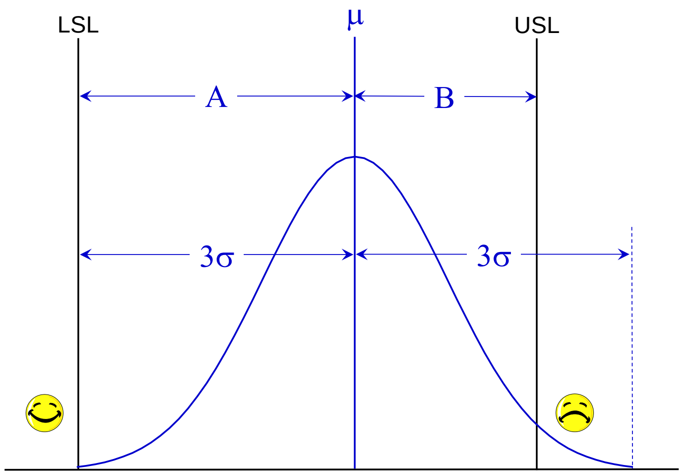
If the process mean does not equal the midpoint of the specification range, C_p represents the capability that could be attained by moving the process mean to the midpoint.

504

C_{pl} and C_{pu} indices

505

$$C_{pl} = \text{"}C_p \text{ lower"} = \frac{A}{3\sigma} \qquad C_{pu} = \text{"}C_p \text{ upper"} = \frac{B}{3\sigma}$$



505

C_{pl} and C_{pu} (cont'd)

506

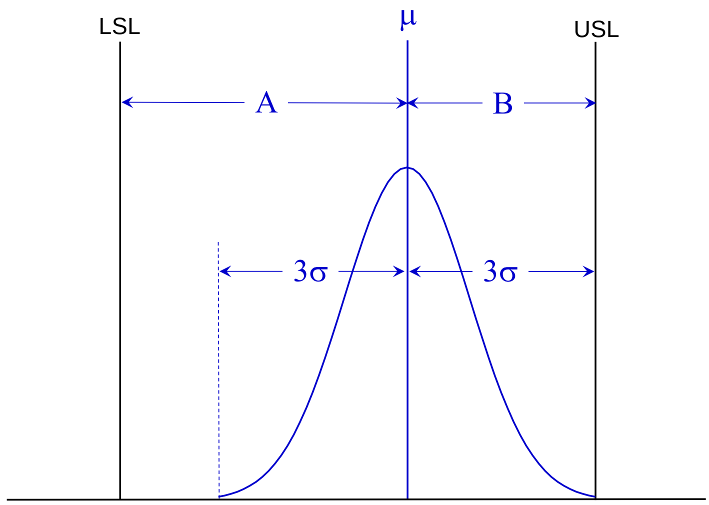
The indices C_{pl} and C_{pu}, pronounced "C_p lower" and "C_p upper", were introduced to overcome the deficiency of C_p. They depend on both the mean and standard deviation of the process. If we know both C_{pl} and C_{pu} we can determine the first pass yield of the process.

Like the C_p index, C_{pl} and C_{pu} 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.

506

C_{pl} and C_{pu} (cont'd)

507



C_{pl} is greater than 1, C_{pu} is equal to 1

507

C_{pl} and C_{pu} (cont'd)

508

C_{pk} is equal to 1 in the example above. If improvement is needed, the opportunity is on the high side.

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?

508

Guidelines

509

- 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.

509

Important assumptions in Process Capability

510

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.*

510

Formulas (Normal distribution)

511

$$C_{pl} = \frac{\mu - LSL}{3\sigma} \qquad C_{pu} = \frac{USL - \mu}{3\sigma}$$

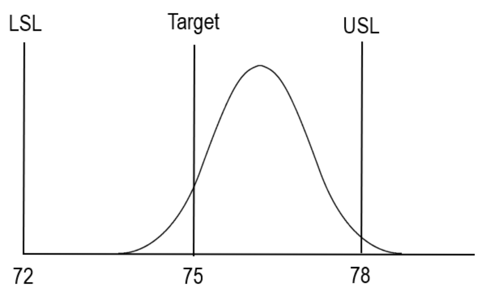
$$C_p = \frac{C_{pl} + C_{pu}}{2} = \frac{USL - LSL}{6\sigma}$$

$$C_{pk} = \min(C_{pl}, C_{pu})$$

511

Example: Calculating Process Capability indices

512



For this distribution, the mean = 76 and the standard deviation = 1.

$$C_p = \frac{USL - LSL}{6\sigma} = \frac{78-72}{6*1} = \frac{6}{6} = 1.0$$

$$C_{pl} = \frac{\mu - LSL}{3\sigma} = \frac{76-72}{3*1} = \frac{4}{3} = 1.33$$

$$C_{pu} = \frac{USL - \mu}{3\sigma} = \frac{78-76}{3*1} = \frac{2}{3} = 0.67$$

$$C_{pk} = \min(C_{pu}, C_{pl}) = 0.67$$

512

Exercise 26.1

513

(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?

514

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

515

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

515

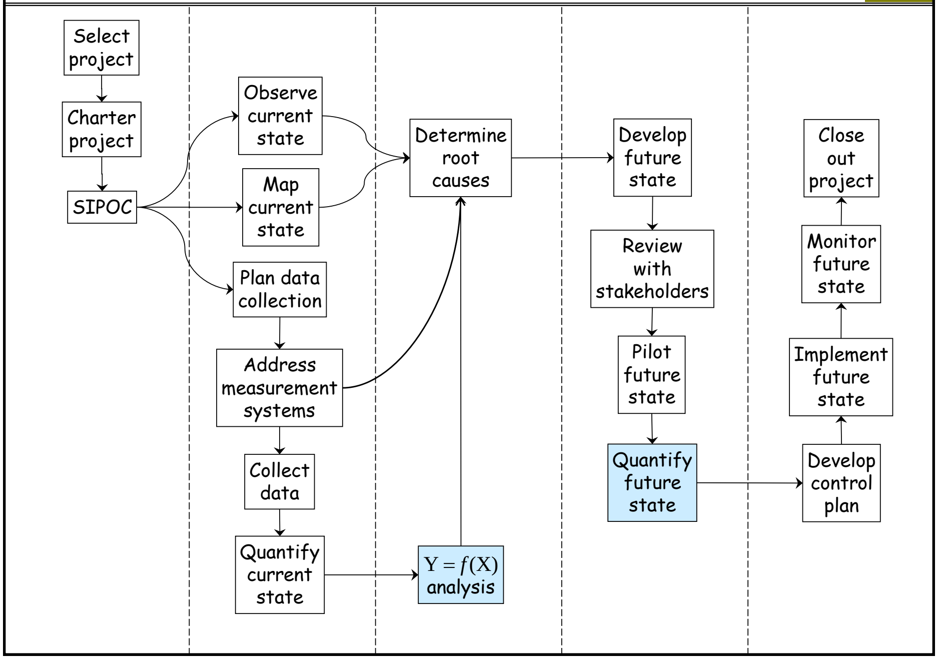
Notes

516

516

27 Testing for Statistical Significance

517



517

Topics

518

- Comparing populations with quantitative Y
- Comparing populations with categorical (pass/fail) Y
- Correlating quantitative X and Y variables

518

Comparing populations with quantitative Y

519

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)

519

Comparing populations with categorical (pass/fail) Y

520

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)

520

Correlating quantitative Y and X variables

521

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

521

The role of the X variable in significance testing

522

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

522

Excel tools for significance testing

523

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)

523

Exercise 27.1

524

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

524

Exercise 27.1 (cont'd)

525

(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)

526

(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)

527

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

528

Comparing samples with quantitative Y

Standard data matrix format ↓ Data format required for Anova: Single Factor ↓

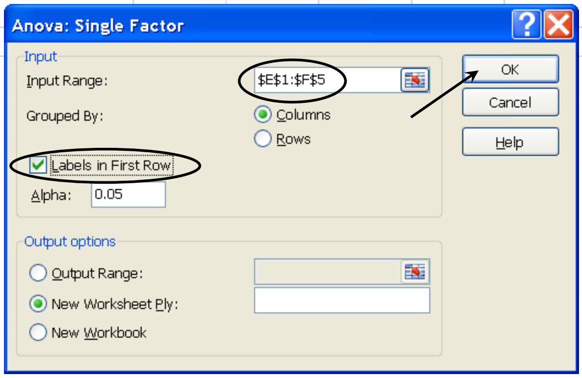
	A	B	C	D	E	F	G	H
1	**Molding machine**	**Part diams**			**A**	**B**		
2	A	27.5			27.5	31.0		
3	A	29.0			29.0	29.0		
4	A	28.0			28.0	31.5		
5	A	29.5			29.5	30.0		
6	B	31.0						
7	B	29.0						
8	B	31.5						
9	B	30.0						
10								

- 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 (cont'd)

529

	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

529

Significance testing: example 1 (cont'd)

530

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 Varia*	*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

530

Significance testing: example 1 (cont'd)

531

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 the sample's mean difference would be this large if they were from the same population
	The probability that machines A and B produce the same average diameter. The sample is used to infer a difference in the machine's performance.

531

Interpreting P values - "Statistical Standard of Evidence"

532

P value	Evidence that samples are different, or variables are correlated	Confidence level (CL)
1.00 – 0.15	None	None
0.15 – 0.05	Some	85% ≤ CL < 95%
0.05 – 0.01	Strong	95% ≤ CL < 99%
0.01 – 0.0001	Very strong	CL ≥ 99%

532

Significance testing: example 1 (cont'd)

533

	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

533

Notes on p-values, confidence, and false-positives

534

Even people that work with data regularly often misinterpret the meaning of a p-value. The technical definition of a p-value is:

- The odds that the difference between samples would be this large or larger if the two samples were taken from the same population.

This unwieldy definition means that we try to think of the p-value in a way that makes more sense in the context of what we are studying. People will often think of the p-value as meaning "The odds that the difference I'm seeing isn't real". They think a p-value of 0.05 means that there is only a 5% chance that what they've measured isn't a real difference between populations, or that there is a 95% chance that the difference is real. This is a mostly harmless short-hand, but other misinterpretations are more problematic.

534

Notes on p-values, confidence, and false-positives (cont'd)

535

Sometimes people believe that a p-value of 0.05 means that there is only a 5% chance that their result is a false-positive. Here's an example to explain why that is dangerous.

Say you are working on a process that is having a quality problem. You have no idea what the source of the problem is so you decide to study all of the variables you can identify, and you come up with 20. When the analysis is finished, you identify 4 with a p-value of 0.05 or less. That seems really great, but remember, since you were looking for p-values of 0.05 or better, you would expect to get 0.05*20 = 1 significant variable by chance alone. Since you found 4 significant variables, you can expect a false positive rate of ¼ = 25%. If these variables are difficult, expensive, or risky to change, you'll want to know which one isn't real.

Key take-away

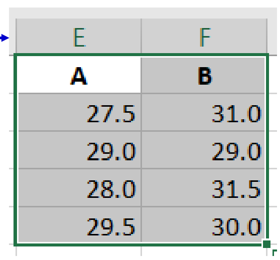
If in doubt, always repeat your study with another sample set!

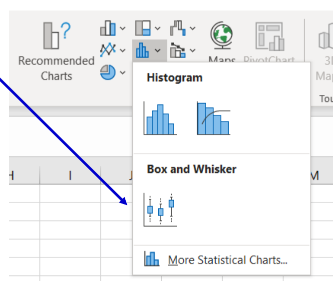
535

Displaying the data graphically using Box and Whisker Plots

536

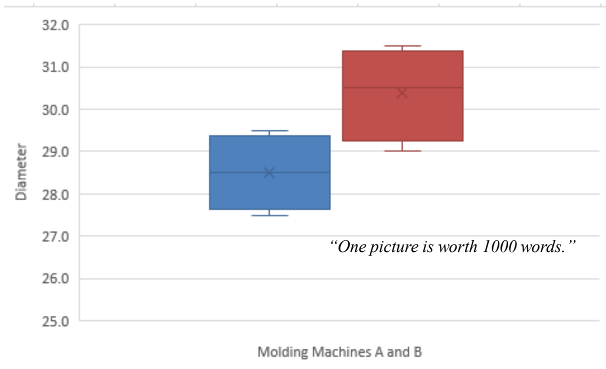
1. Highlight the two columns for molding Machines A&B
2. Navigate to the Insert Ribbon and then the Charts section
3. Choose the Insert Statistics Chart dropdown and then the Box and Whisker plot





Displaying the data graphically Using Box and Whisker Plots

537

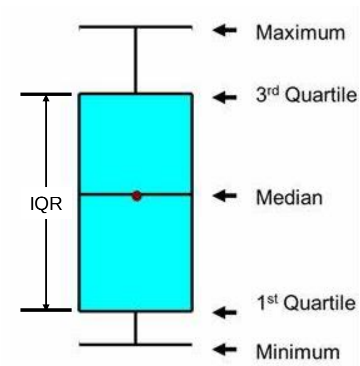


- Edit legends, titles, etc. as desired.
- Rule of thumb – if the median line for one data set is outside of the box of the other data set, then the two samples are significantly different
- If we wanted to reduce the overall variation in diameter, would we focus on within or between machine variation first? What follow up action is needed here?

537

Anatomy of a Box and Whisker Plot

538



- 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 is drawn at Q2 (50%).
- The Mean (aka Average) may also be marked.
- The Inner Quartile Range (IQR) provides a robust measure of spread.
- Outliers are defined as data falling outside the range Q1 – (1.5)IQR and Q3 + (1.5)IQR.

538

Significance testing: example 2

539

Comparing samples with pass/fail Y

- Our project objective was to reduce % defective by 50%
- Based on the data, it looks like we didn't quite make it
- But did we make a statistically significant improvement?

Process	Sample size	No. Failed	% Defective
Current state	500	147	29.4%
Future state pilot	50	8	16.0%

Significance testing: example 2 (cont'd)

540

- Open *Student Files* → *calculator - chi square test*
- Fill out the *2 groups* sheet as shown

	A	B	C	D	E	K	L
1		Defective?		Sample	%		
2	Group labels	Yes	No	size	Defective	P-value	
3	Current	147	353	500	29.40	0.0446	
4	Future	8	42	50	16.00		
5	Totals	155	395	550			
6							

Hid columns F-I

- Strong evidence of an improvement!

Interpreting P values - "Statistical Standard of Evidence"

541

P value	Evidence that samples are different or variables are correlated	Confidence level (CL)
1.00 – 0.15	None	None
0.15 – 0.05	Some	85% ≤ CL < 95%
0.05 – 0.01	Strong	95% ≤ CL < 99%
0.01 – 0.0001	Very strong	CL ≥ 99%

541

Significance testing: example 3

542

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

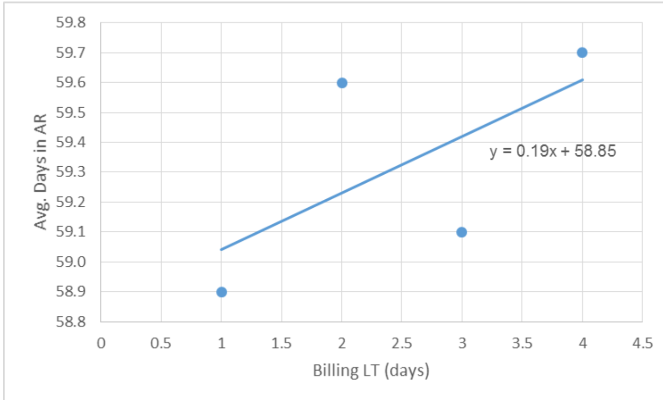
542

Significance testing: example 3 (cont'd)

543

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

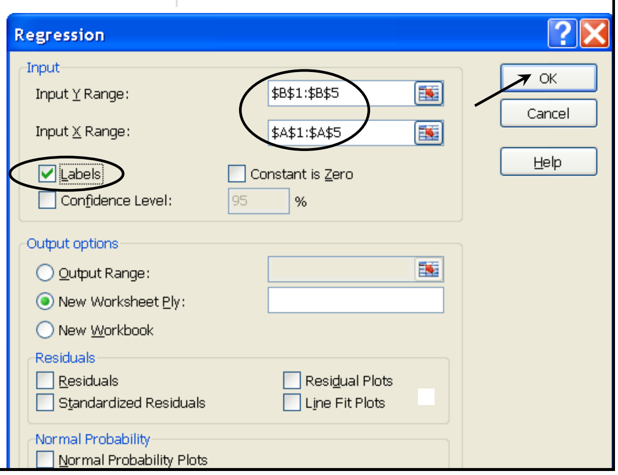


Significance testing: example 3 (cont'd)

544

	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			

Data
↓
Data Analysis
↓
Regression
↓
set up as shown
↓
OK



Significance testing: example 3 (cont'd)

545

Default Excel output

SUMMARY OUTPUT

Regression Statistics	
Multiple F	0.6351
R Square	0.403352
Adjusted I	0.105028
Standard E	0.365377
Observati	4

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regressio	1	0.1805	0.1805	1.35206	0.364900043
Residual	2	0.267	0.1335		
Total	3	0.4475			

← **This is the p-value**

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	58.85	0.447493	131.5104	5.78E-05	56.92459295	60.77541	56.92459	60.77541
Billing LT (	0.19	0.163401	1.162781	0.3649	-0.513059249	0.893059	-0.51306	0.893059

P value	The probability that the slope of the line for the sample would be this large if there was truly no relationship (i.e. if the real slope is zero)
	The probability of no correlation between billing lead time and days in accounts receivable

Interpreting P values - "Statistical Standard of Evidence"

546

P value	Evidence that samples are different or variables are correlated	Confidence level (CL)
1.00 – 0.15	None	None
0.15 – 0.05	Some	85% ≤ CL < 95%
0.05 – 0.01	Strong	95% ≤ CL < 99%
0.01 – 0.0001	Very strong	CL ≥ 99%

Interpreting P values (and other stuff)

547

SUMMARY OUTPUT

Regression Statistics	
Adjusted R Square	**0.1050**
Residual standard deviation	**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	0.18	0.18	1.35	**0.3649**
Residual	2	0.27	0.13		
Total	3	0.45			

- 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

547

Exercise 27.2

548

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.

548

Exercise 27.3

549

Open *Data Sets* → *defects per unit*. Is the average DPU for March the same as it was for February?

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) Close and save the data set.

549

Exercise 27.4

550

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) Go to the next exercise, but keep the data set open.

550

Exercise 27.5

551

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) Close and save the data set.

Exercise 27.6

552

Based on the data given below, did our project achieve a significant reduction in % defective?

	Sample size	No. defective	% Defective
Current state	500	147	29.4%
Future state pilot	10	1	10.0%

a) Perform the appropriate analysis.

b) Give the P value and its interpretation in terms of standards of evidence.

Exercise 27.7

553

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) Close and save the data set.

Exercise 27.8

554

Open *Data Sets* → *lead time*. Did our project achieve a significant reduction in average lead time?

a) Identify the data types for the X and Y variables, then perform the appropriate analysis.

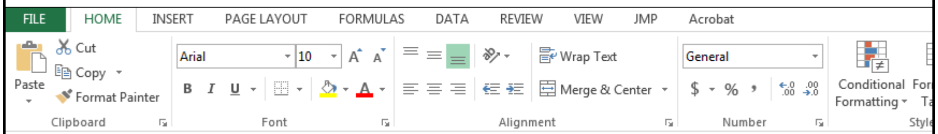
b) Give the P value and its interpretation in terms of standards of evidence.

c) Close and save the data set.

28 Stratification Analysis — Quantitative Y

We want to test for significant differences among the business units (BUs) with respect to turnaround time (TAT)

Open *Data Sets* → *unstacked quotation process current state*



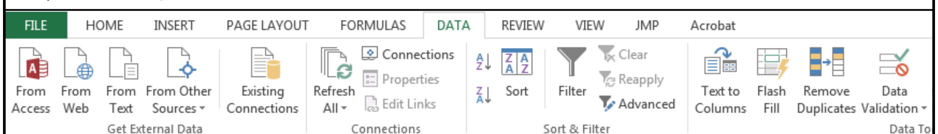
	A	B	C	D	E	F	G	H	I	J
1	Quote Num	AcctMgr	BU	Initial RFQ	Month	RFQ cycles	Finance review	TAT	TAT<=3	PO
2	6250012	19	6	02-Jun-03	2003.06	1	Yes	2	Pass	Yes
3	7250023	5	7	02-Jun-03	2003.06	1	No	2	Pass	Yes
4	7250022	5	7	02-Jun-03	2003.06	1	Yes	1	Pass	Yes
5	5250039	8	5	03-Jun-03	2003.06	2	No	3	Pass	Yes
6	5250040									
7	7250011									
8	6250014									
9	6250015									
10	7250025									
11	5250044									
12	3250033									
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

First, the data needs to be reorganized into the format required for ANOVA.

FYI: this file has been sorted by **Initial RFQ** 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

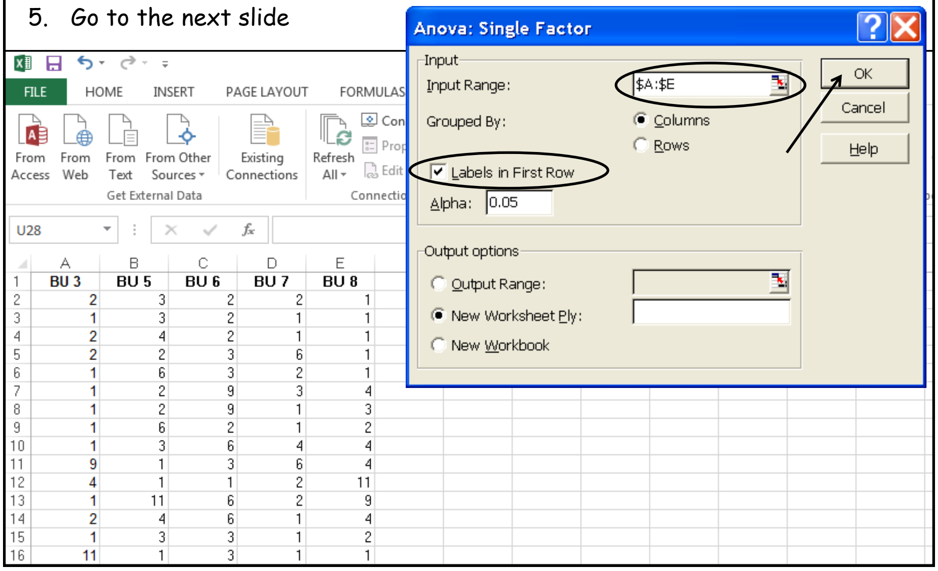


	A	B	C	D	E
1	BU 3	BU 5	BU 6	BU 7	BU 8
2	2	3	2	2	1
3	1	3	2	1	1
4	2	4	2	1	1
5	2	2	3	6	1
6	1	6	3	2	1
7	1	2	9	3	4
8	1	2	9	1	3
9	1	6	2	1	2
10	1	3	6	4	4
11	9	1	3	6	4
12	4	1	1	2	11
13	1	11	6	2	9
14	2	4	6	1	4
15	1	3	3	1	2
16	11	1	3	1	1
17	3	1	1	1	1

Stratification with quantitative Y (cont'd)

557

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



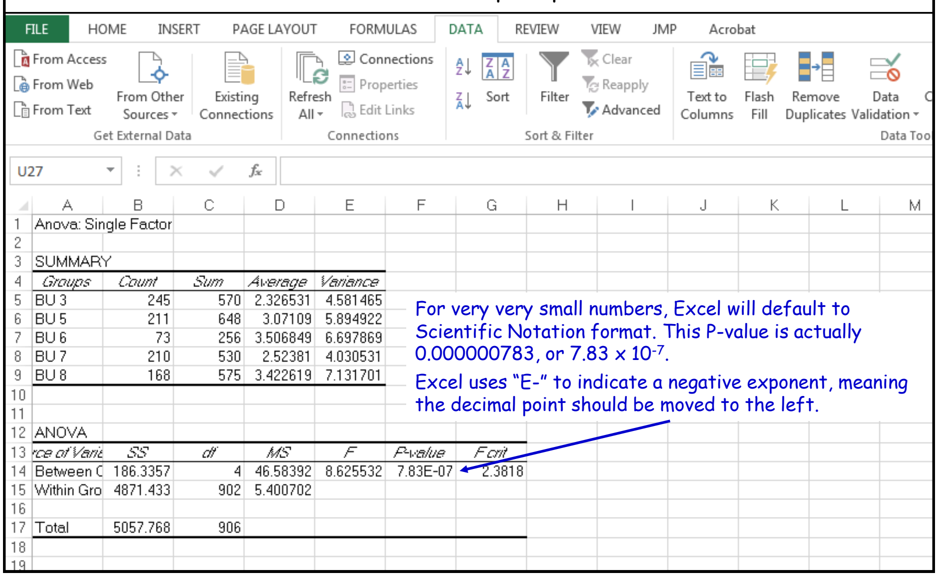
	A	B	C	D	E
1	BU 3	BU 5	BU 6	BU 7	BU 8
2	2	3	2	2	1
3	1	3	2	1	1
4	2	4	2	1	1
5	2	2	3	6	1
6	1	6	3	2	1
7	1	2	9	3	4
8	1	2	9	1	3
9	1	6	2	1	2
10	1	3	6	4	4
11	9	1	3	6	4
12	4	1	1	2	11
13	1	11	6	2	9
14	2	4	6	1	4
15	1	3	3	1	2
16	11	1	3	1	1

557

Stratification with quantitative Y (cont'd)

558

6. Here is the unedited default output
7. Go to the next slide for the cleaned-up output



Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
BU 3	245	570	2.326531	4.581465
BU 5	211	648	3.07109	5.894922
BU 6	73	256	3.506849	6.697869
BU 7	210	530	2.52381	4.030531
BU 8	168	575	3.422619	7.131701

ANOVA

rce of Varia	SS	df	MS	F	P-value	F crit
Between G	186.3357	4	46.58392	8.625532	7.83E-07	2.3818
Within Gro	4871.433	902	5.400702			
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}.

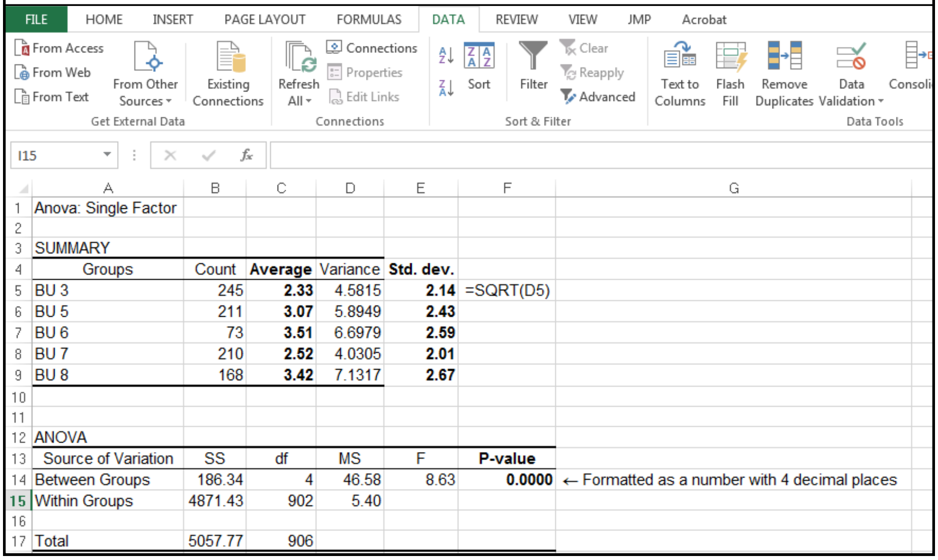
Excel uses "E-" to indicate a negative exponent, meaning the decimal point should be moved to the left.

558

Stratification with quantitative Y (cont'd)

559

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



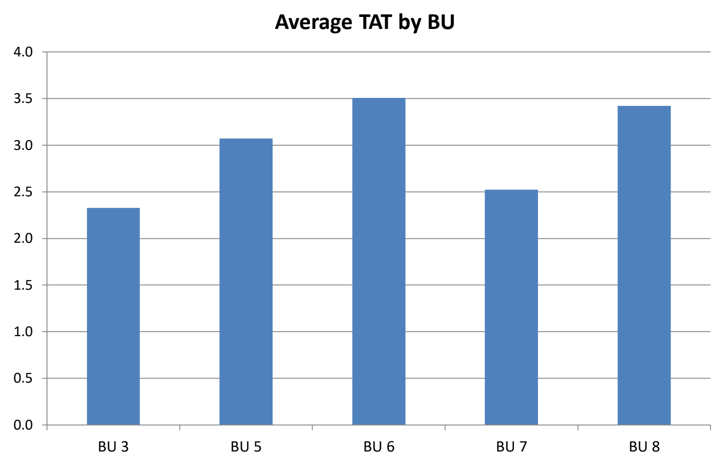
	A	B	C	D	E	F	G
1	Anova: Single Factor						
2							
3	SUMMARY						
4	Groups	Count	**Average**	Variance	**Std. dev.**		
5	BU 3	245	**2.33**	4.5815	**2.14**	=SQRT(D5)	
6	BU 5	211	**3.07**	5.8949	**2.43**		
7	BU 6	73	**3.51**	6.6979	**2.59**		
8	BU 7	210	**2.52**	4.0305	**2.01**		
9	BU 8	168	**3.42**	7.1317	**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				

559

Stratification with quantitative Y (cont'd)

560

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 .



560

Exercise 28.1

561

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) Close and save the data set.

561

Exercise 28.2

562

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?

562

Exercise 28.2 (cont'd)

c) 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.

d) The target value for *diam* is 50. Which machine is closer to target?

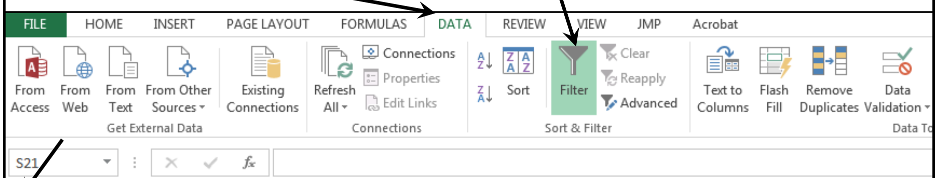
e) Describe an appropriate follow up action.

f) Close and save the data set.

Example: Unstacking Data using Filtering

<u>For reference only:</u>

1. Highlight BU column
2. Select the **Data** ribbon
3. Select **Filter**
4. Go to the next slide



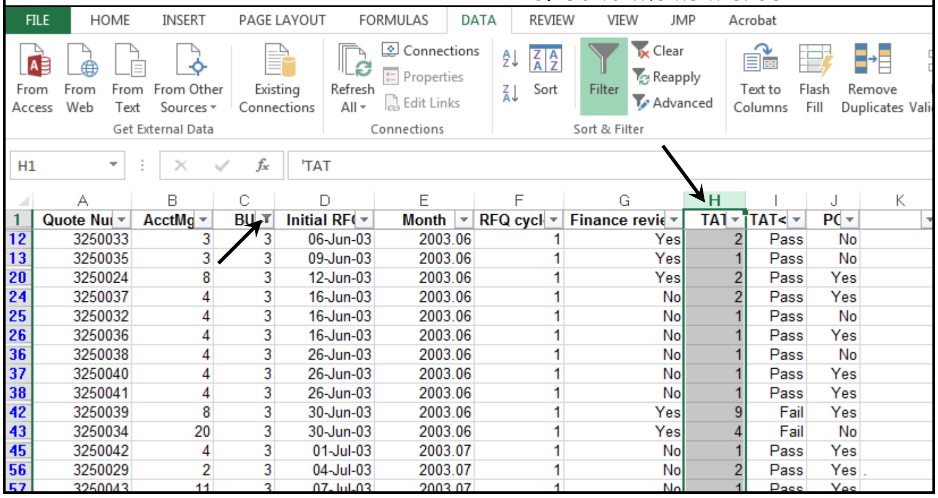
	A	B	C	D	E	F	G	H	I	J	K
1	Quote Nu	AcctMg	BU	Initial RF	Month	RFQ cycl	Finance revie	TAT	TAT<	PC	
2	6250012	19	6	02-Jun-03	2003.06	1	Yes	2	Pass	Yes	
3	7250023	5	7	02-Jun-03	2003.06	1	No	2	Pass	Yes	
4	7250022	5	7	02-Jun-03	2003.06	1	Yes	1	Pass	Yes	
5	5250039	8	5	03-Jun-03	2003.06	2	No	3	Pass	Yes	
6	5250040	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	

Example: Unstacking Data using Filtering (cont'd)

565

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	1	Pass	Yes

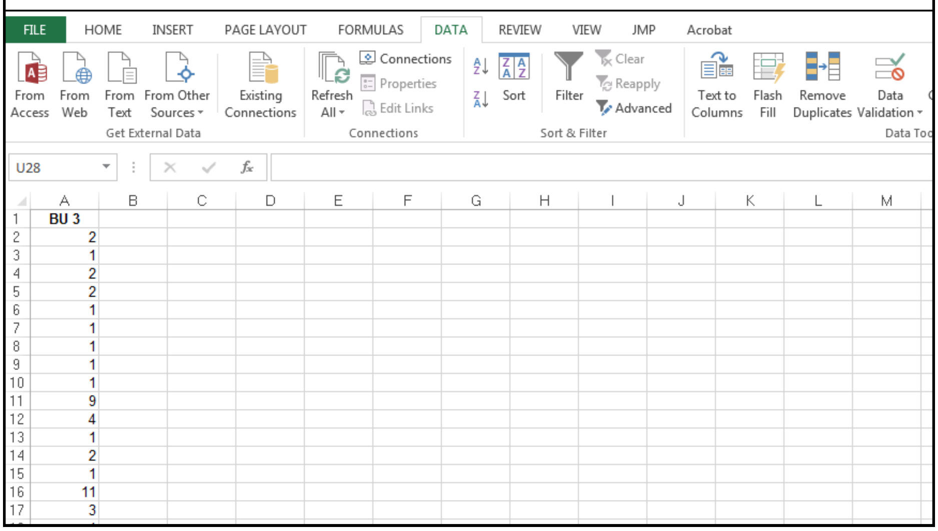
565

Example: Unstacking Data using Filtering (cont'd)

566

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

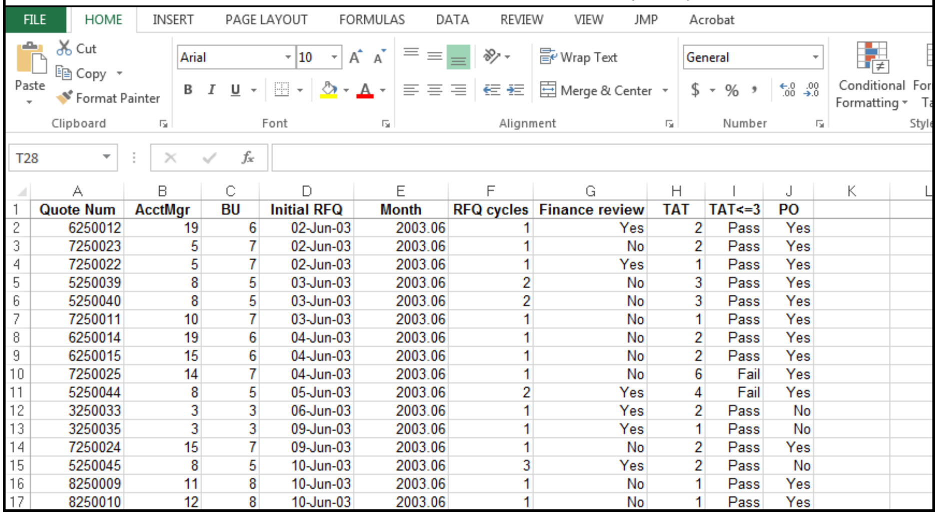
566

29 Stratification Analysis — Pass/Fail Y

567

Open *Data Sets* → *quotation process current state*

We want to test for significant differences among the business units (BUs) with respect to PO hit rate



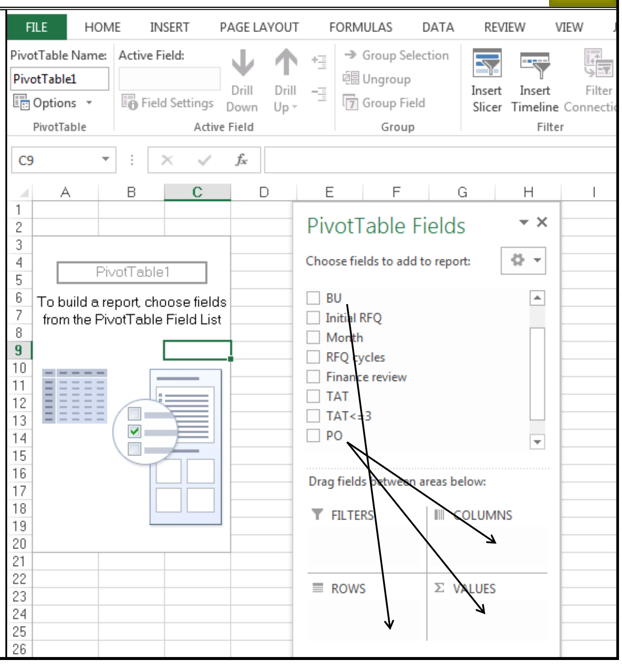
Quote Num	AcctMgr	BU	Initial RFQ	Month	RFQ cycles	Finance review	TAT	TAT<=3	PO
6250012	19	6	02-Jun-03	2003.06	1	Yes	2	Pass	Yes
7250023	5	7	02-Jun-03	2003.06	1	No	2	Pass	Yes
7250022	5	7	02-Jun-03	2003.06	1	Yes	1	Pass	Yes
5250039	8	5	03-Jun-03	2003.06	2	No	3	Pass	Yes
5250040	8	5	03-Jun-03	2003.06	2	No	3	Pass	Yes
7250011	10	7	03-Jun-03	2003.06	1	No	1	Pass	Yes
6250014	19	6	04-Jun-03	2003.06	1	No	2	Pass	Yes
6250015	15	6	04-Jun-03	2003.06	1	No	2	Pass	Yes
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
7250024	15	7	09-Jun-03	2003.06	1	No	2	Pass	Yes
5250045	8	5	10-Jun-03	2003.06	3	Yes	2	Pass	No
8250009	11	8	10-Jun-03	2003.06	1	No	1	Pass	Yes
8250010	12	8	10-Jun-03	2003.06	1	No	1	Pass	Yes

567

Stratification with pass/fail Y (cont'd)

568

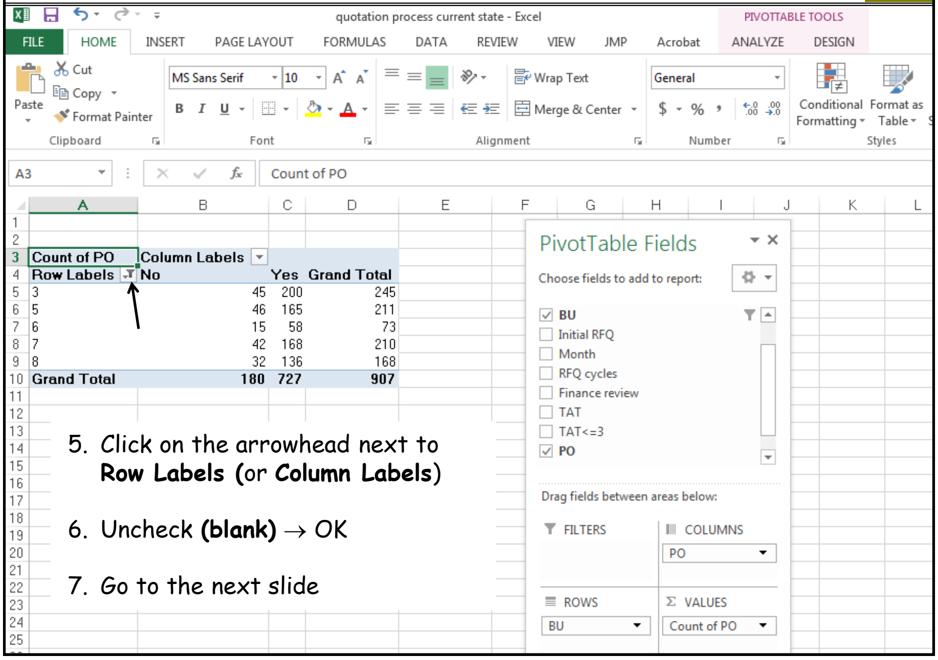
1. Highlight all columns
2. Insert → PivotTable → OK
3. Drag/drop **BU** to the **Rows** area
4. Drag/drop **PO** to the **Columns** area
5. Drag/drop **PO** to the **Values** area
6. Go to the next slide



568

Stratification with pass/fail Y (cont'd)

569

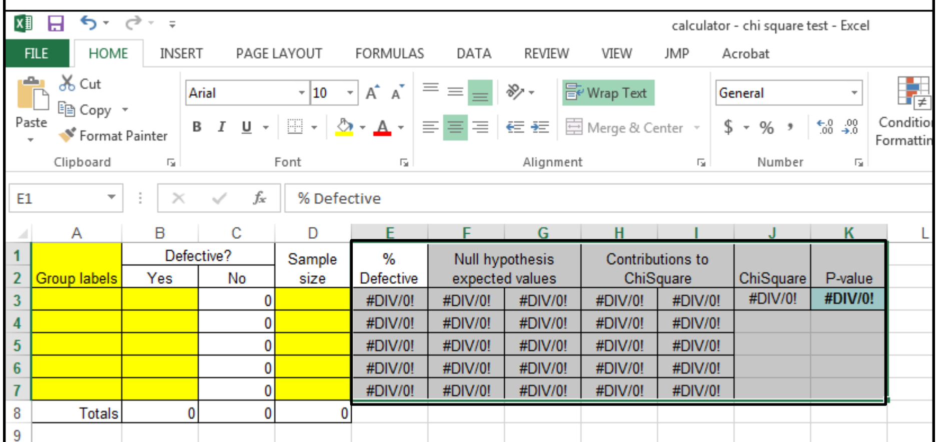


5. Click on the arrowhead next to **Row Labels** (or **Column Labels**)
6. Uncheck **(blank)** → OK
7. Go to the next slide

Stratification with pass/fail Y (cont'd)

570

8. Open ***Student Files*** → ***calculator - chi square test***
9. Select the **5 groups** sheet, select and copy the cell range shown below

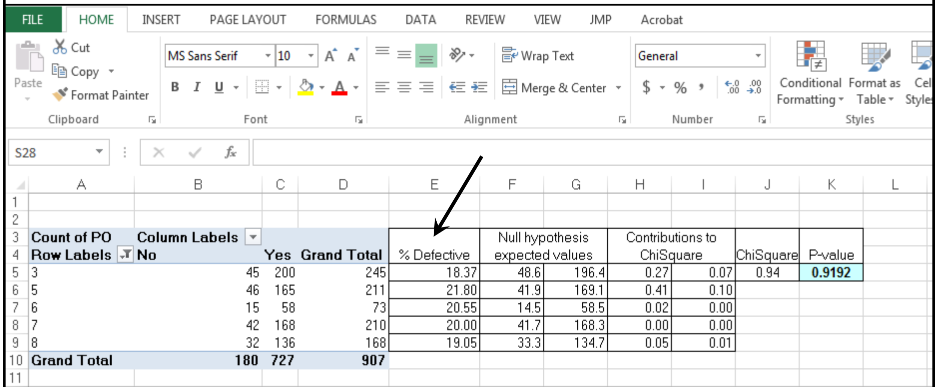


10. Go to the worksheet containing your pivot table
11. Go to the next slide

Stratification with pass/fail Y (cont'd)

571

10. Paste in cell **E3**
11. The P value is 0.9192. There is no evidence of differences among the BUs with respect to PO hit rate.



	A	B	C	D	E	F	G	H	I	J	K
1											
2											
3	Count of PO	Column Labels				Null hypothesis		Contributions to			
4	Row Labels	No	Yes	Grand Total	% Defective	expected values		ChiSquare		ChiSquare	P-value
5	3	45	200	245	18.37	48.6	196.4	0.27	0.07	0.94	0.9192
6	5	46	165	211	21.80	41.9	169.1	0.41	0.10		
7	6	15	58	73	20.55	14.5	58.5	0.02	0.00		
8	7	42	168	210	20.00	41.7	168.3	0.00	0.00		
9	8	32	136	168	19.05	33.3	134.7	0.05	0.01		
10	Grand Total	180	727	907							
11											

12. Note: for this to work, your pivot table has to contain raw counts, **not** percentages of row totals.
13. Close and save your workbook.

571

Exercise 29.1

572

Open *Data Sets* → *ATE Mar & Apr*.

a) Test for significant differences in % failing among the four test stations. Give the P value and its interpretation in terms of standards of evidence.

b) Based on the % failing for each test station, which pairs of stations appear to be statistically equivalent? Which pairs appear to be statistically different?

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.

d) Close and save the data set.

Exercise 29.2

573

Open *Data Sets* → *supplier comparison*. This is pass/fail inspection of raw material lots from suppliers A and B.

a) Test for a difference in % failing between suppliers A and B. Give the P value and its interpretation in terms of standards of evidence.

b) Make a pivot table with *Supplier* as the *Column Label*, *Inspector* as the *Row label*, and either one in the *Values* area. There is something here that casts doubt on your conclusion in (a). What is it?

c) Close and save the data set.

Exercise 29.3 (Read all instructions carefully!)

574

Open *Data Sets* → *out of box failures*. This tabulated pass/fail data. 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.)**

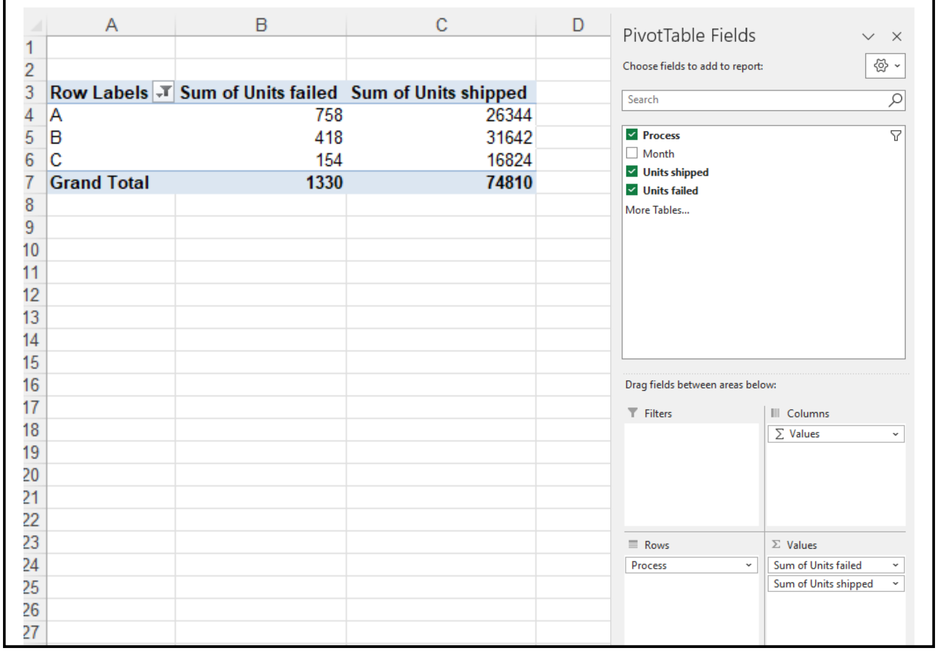
a) Compare processes A, B, and C in terms of % failing. Give the P value and its interpretation in terms of standards of evidence.

b) Is there a significant difference between processes B and C? Give the P value and its interpretation in terms of standards of evidence.

c) Close and save the data set.

Exercise 29.3 (cont'd)

575



Row Labels	Sum of Units failed	Sum of Units shipped
A	758	26344
B	418	31642
C	154	16824
Grand Total	**1330**	**74810**

Notes

576

Exercise 29.4 --Small group exercise

Open *Data Sets → 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 a significant difference ($P \leq 0.15$), identify the process participant with best practice.

g) Share results, so each person has a completed table of results.

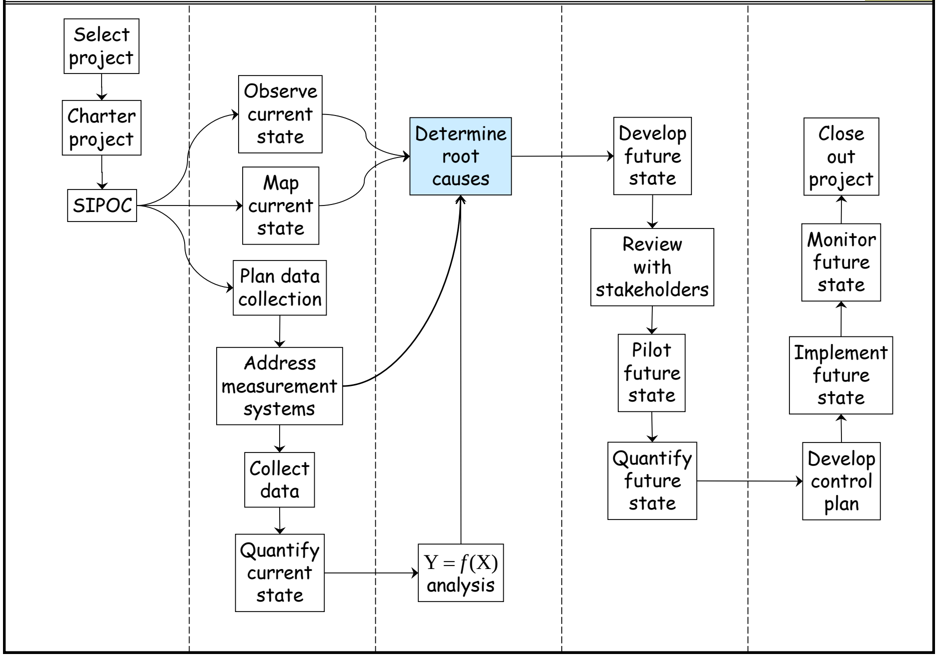
h) Discuss the results. Where would you focus your efforts to make improvements?

Exercise 29.4 --Small group exercise (cont.)

		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%	

30 Root Cause Analysis

579



579

Topics

580

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 $Y = f(X)$

580

Tools used in Root Cause Analysis

581

Usually we identify problems while mapping and observing the current state during the *Measure* phase

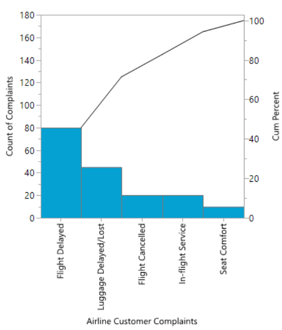
Observed problems

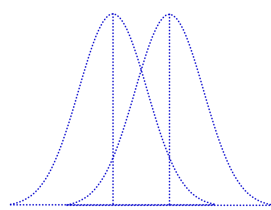
(aka opportunities for improvement)

Tools used in Root Cause Analysis (cont.)

582

Analyses such as Pareto Charts and Testing for Statistical Significance point us in the direction of the root causes or critical x's





$H_0: \mu_1 = \mu_2$
$H_1: \mu_1 \neq \mu_2$

But, we usually need to dig deeper . . .

Failure Modes and Effects Analysis (FMEA)

FMEA can be used in the Analyze Phase to prioritize x's

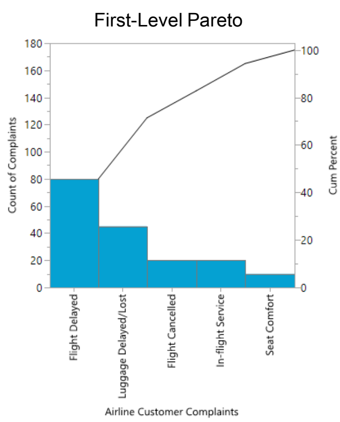
- It is used at the *beginning* of the Analyze Phase:
  - to identify the inputs that are likely to have a significant impact on the primary metric Y, and to remove from consideration those that are deemed trivial
  - data collection and analysis are required for verification of those failure modes with high RPNs, to validate their significant impact on Y, as FMEA is an opinion-based tool
- Actions for remedying failure modes with high RPNs are *not* discussed or taken in Analyze
- We will learn about FMEA in the Improve Phase, when it is used to evaluate risk and prevent problems before they occur in the proposed process, its original application.

Process Functions	Requirements	Failure Modes	Effects	SEV	Causes	OCC	CN	Current Controls	DET	RPN	Actions Planned	Responsible	Due Date	Actions Taken
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**				
Material storage	Stocking of materials and reagents in designated location within the functional laboratory	Insufficient shelf space for materials.	Material stock-out	3	Too many items on shelving	3	**9**	Shelving units with four shelves	5	**45**				
		Staff is unclear where material items should be stored	Materials not stocked in designated location within the functional area	2	Insufficent labeling system to designate material and reagent locations	3	**6**	Labels on shelving only	3	**18**				
Material Distribution	Distribution of materials based on MIN/MAX forecasting	MIN/MAX values not accurate	Material shortage	2	Forecasting not accurate	3	**6**	Master Science Forecasting	5	**30**				

Multi-Level Pareto Analysis

We can drill down to root causes using a series of Pareto Charts

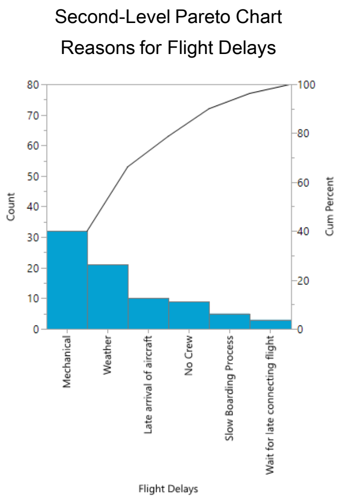
- From a first-level Pareto Chart, we can see which categories are contributing the most to our problem



Second-Level Pareto Chart

585

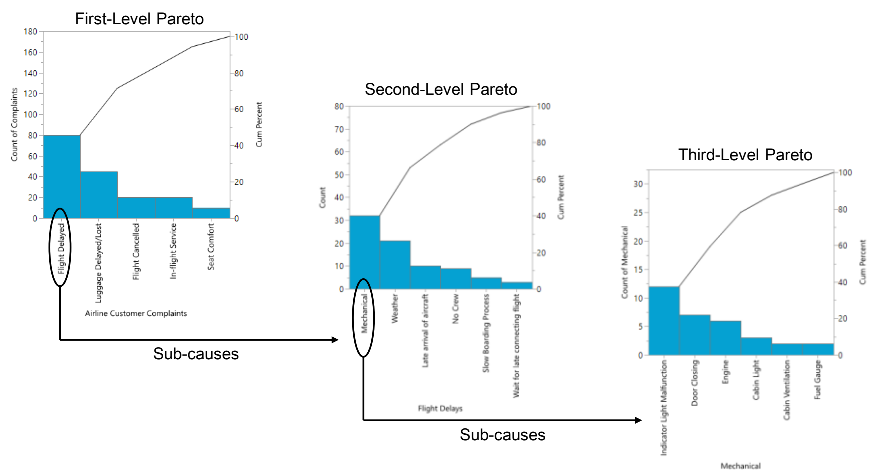
The highest bar(s) from the first-level Pareto can be broken down further into a second-level Pareto Chart:



Multi-Level Pareto Analysis (cont.)

586

By continuing to drill down, we can determine root causes of most frequently occurring defects.

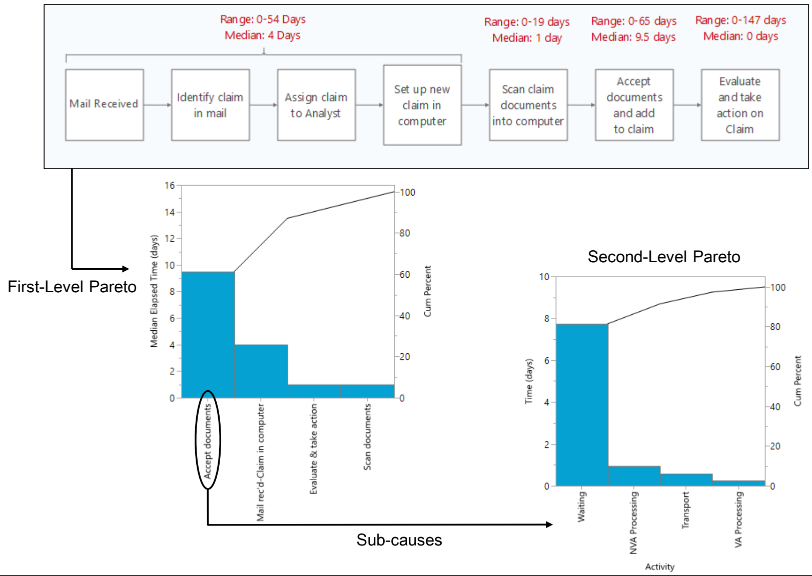


When data is not available for multi-level Pareto analysis, use the first-level Pareto Chart with 5 Whys to determine root causes.

Example 2: Multi-Level Pareto Analysis

587

Lead time by high-level process step is measured:

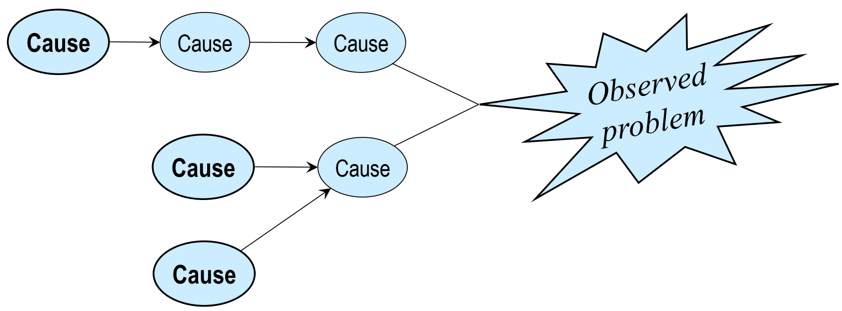


587

5 Whys

588

- 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.

588

Getting to root cause with Five Whys

589

"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.

589

Exercise 30.1: Five Whys

590

- 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!

590

Exercise 30.1: Five Whys (cont'd) "There's too much scrap in the Coiling Department" 591

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.

591

Exercise 30.1: Five Whys (cont'd) "There's too much scrap in the Coiling Department" 592

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.

592

"I was late for work today."

593

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?

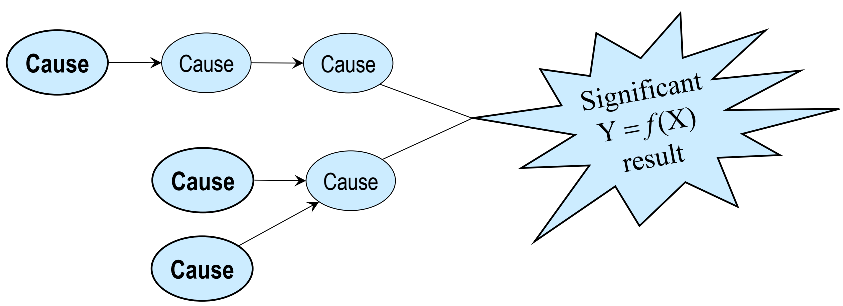
If you get to a non-actionable root cause, back up and try to find a different path to an answer.

593

Five Whys based on $Y = f(X)$ analysis

594

- 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.



594

Want to reduce external failures

595

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.

Want to reduce turnaround time

596

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

Want to reduce turnaround time (cont'd)

597

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.

Want to improve internal customer satisfaction

598

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.

Identifying root causes

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

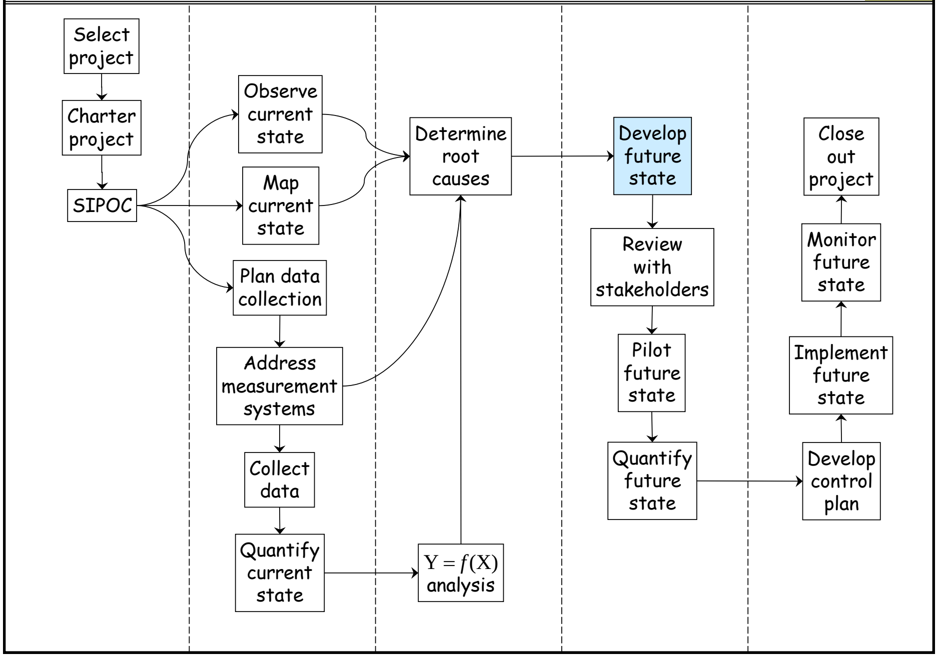
599

Notes

600

31 Developing and Prioritizing Solutions

601

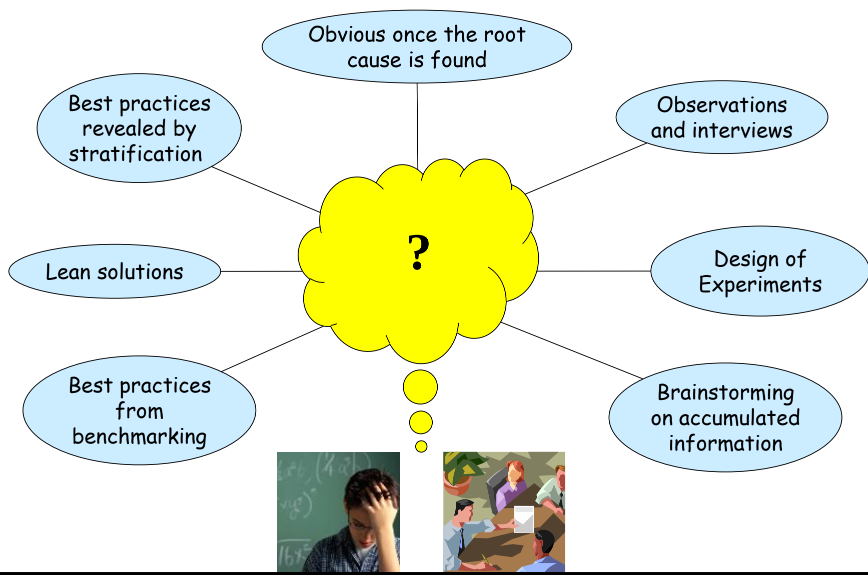


601

Developing solutions

602

Solutions come from many sources



602

Developing solutions (cont'd)

603

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

604

- 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

Solution categories (cont'd)

605

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.

605

Prioritizing solutions

606

- 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

606

Instructions for prioritizing solutions

607

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.

607

Student Files → prioritizing solutions - exercise

608

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 | Impact ratings | Feasibility ratings | Impact-feasibility plot | Impact calculations | Feasibility c

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

608

Prioritizing solutions (cont'd)

609

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
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																0

Metrics | **Impact ratings** | Feasibility ratings | Impact-feasibility plot | Impact calculations | Feasibility calculations

609

Prioritizing solutions (cont'd)

610

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**	
Solution Id																
ATE Design Change																0
PCBA Re-Design																0
Supplier Process Change																0
Improve material transport methods																0
0																0
0																0
0																0
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0																0
0																0
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0																0
0																0

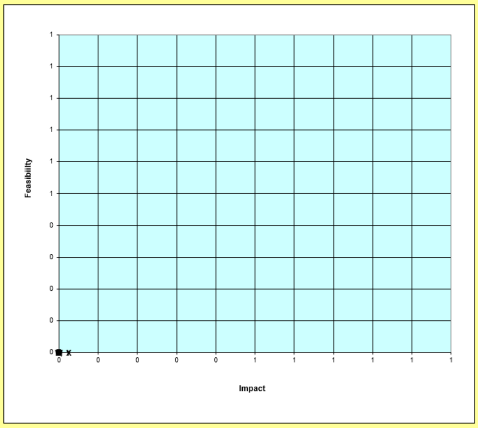
Metrics | Impact ratings | **Feasibility ratings** | Impact-feasibility plot | Impact calculations | Feasibility calculations

610

Prioritizing solutions (cont'd)

611

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

Exercise 31.1

612

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.

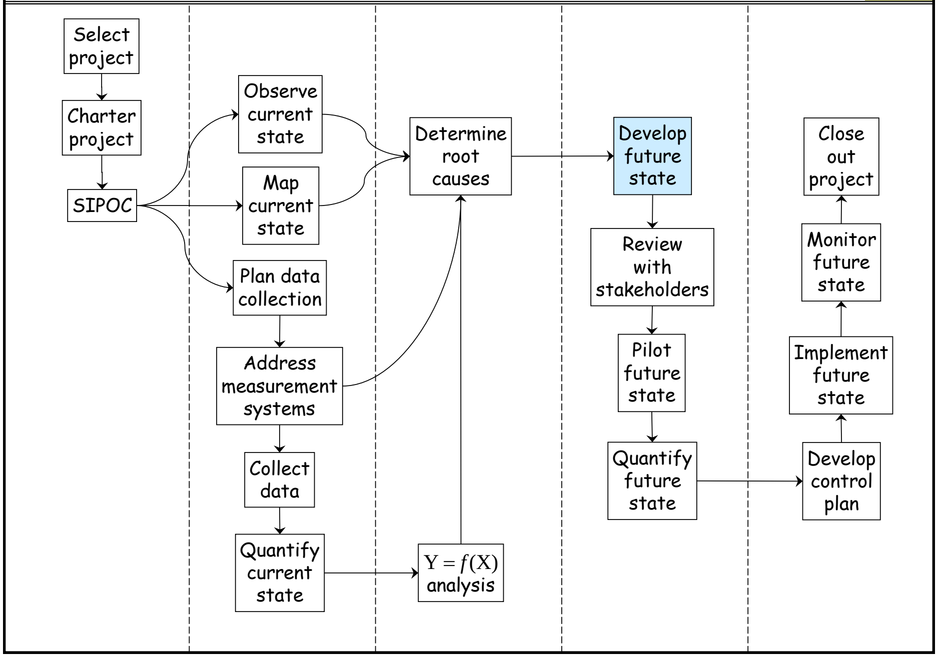
b) Fill out the *Impact ratings* sheet using H, M, L or blank.

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.

32 Lean Solutions

613



613

Commonly used Lean solutions

614

5S

Stop & fix

Pull systems

Standardization

Mistake proofing

Reduce batch sizes

Value stream teams

Visual management

Changeover reduction (SMED)

Work balancing (leveling)

⋮

614

The 5S Vision

615

A Workplace that is:

- Clean, organized, orderly
- Safe
- Efficient and pleasant
- The foundation for all other improvement activities

Resulting In:

- Fewer accidents
- Improved efficiency
- Improved quality
- Workplace control

And therefore:

- Reduced waste
- Reduced cost

615

5S

616

- 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
  - Its easier to identify a maintenance need on clean equipment
- Standardize
  - Build the framework for maintaining Sort, Set in Order, and Shine
  - Clarity about what is and is not normal with simple action plans
- Sustain
  - Incorporate 5S into the daily work cycle

616

Pull systems for supply replenishment

617

- 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

617

Kanban card for supply items

618

- 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?

618

Example: two-bin kanban system

619

- 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

Two-bin system (cont'd)

620

Using data to set max/min values

621

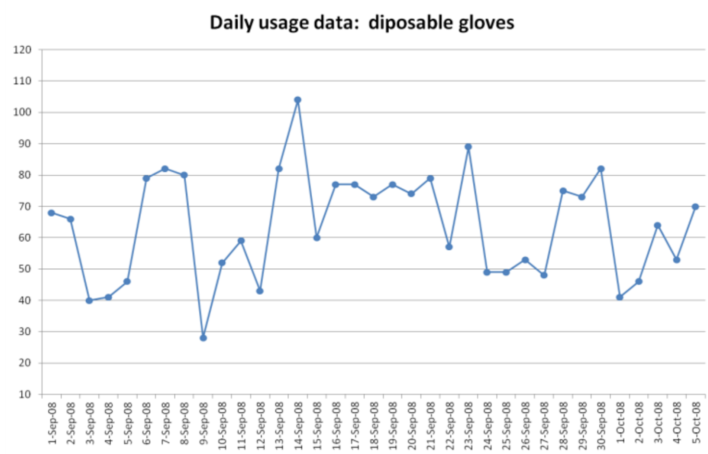
- Required inputs
  - ✓ Time basis for usage data (hourly, each shift, daily, weekly, . . .)
  - ✓ Average usage per time period
  - ✓ Standard deviation of usage per time period
  - ✓ Minimum order quantity
  - ✓ Min. value (number of orders)
  - ✓ Max. value (number of orders)
- Values calculated in 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

621

Setting max/min values (cont'd)

622

Data Sets → usage of disposable gloves



Average = 63.9
Std. dev. = 17.2

622

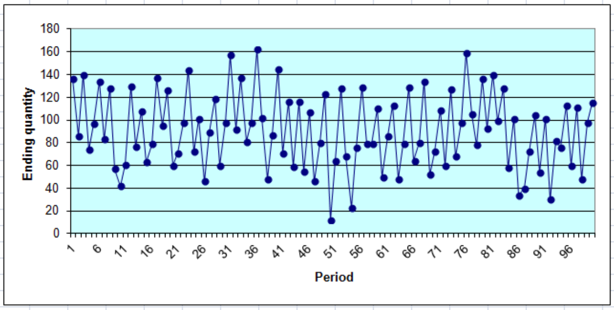
Setting max/min values (cont'd)

623

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	

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	136	86	140	74	97	134	83	128	57	42	61	130	77	108	63	79	137
Quantity received	0	0	100	0	100	100	0	100	0	100	100	100	0	100	0	100	100	0
Quantity used	64	50	46	66	77	63	51	55	71	115	81	31	53	69	45	84	42	42
Ending quantity	136	86	140	74	97	134	83	128	57	42	61	130	77	108	63	79	137	95
Quantity ordered	0	100	0	100	100	0	100	0	100	100	100	0	100	0	100	100	0	100



Average ending qty.	90.7	# Orders	61	# Stock-outs	0

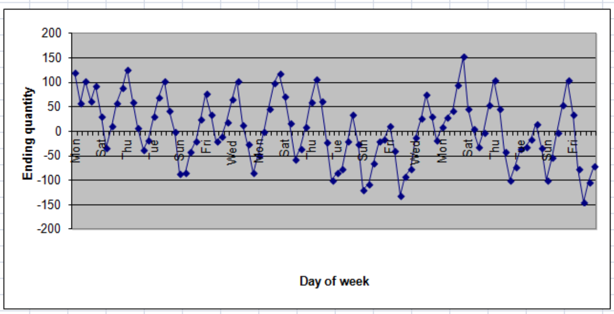
Setting max/min values (cont'd)

624

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

Examples of mistake-proofing (Poke Yoke)

625

- 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

625

Reduce batch sizes (keep the work moving)

626

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

626

Reduce batch sizes (cont'd)

627

Of course, there can be a legitimate problem with reducing batch sizes: it increases the number of changeovers.

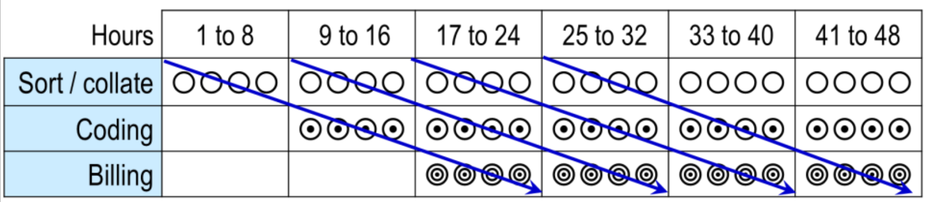
Fortunately, this is a problem for which Lean has excellent solutions. Lean projects have reduced changeover times by 80% or more.

627

Current state: daily batching

628

3 operations
2 hours per transaction per operation



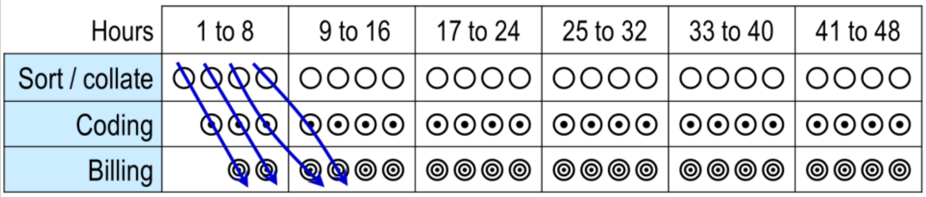
Lead time = 24 hours (3 days)

628

Future state: continuous flow

629

3 operations
2 hours per transaction per operation



Lead time = 6 hours (less than one day)

629

Organizing by departments

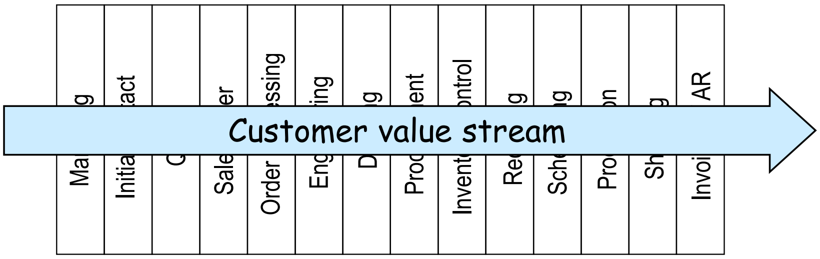
630

- 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

630

Organizing by value stream

631



- 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."

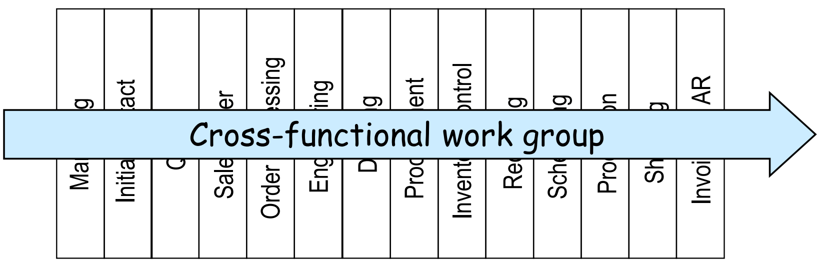
— Fuji Cho, as quoted in John Shook's "Managing to Learn"

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.

631

Organizing by value stream (cont'd)

632

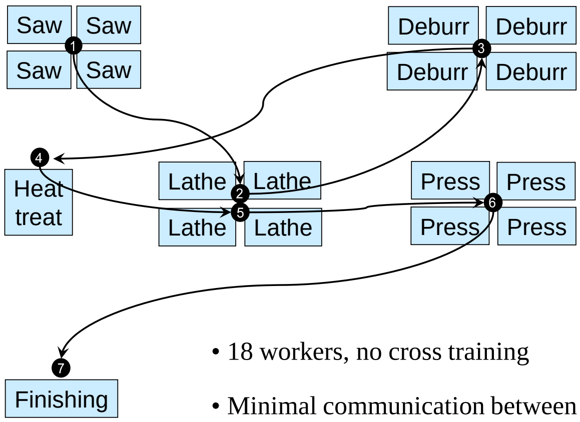


- Responsible for entire value stream for a product/service "family"
- Physical co–location is ideal (work cells)
- Alternative: "value stream team"
- Stand-up meetings: every day, shift, or other frequent interval
- Alternative: virtual meetings

632

Manufacturing operation in silos

633

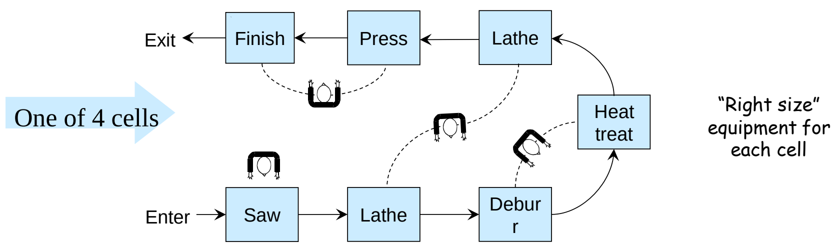


- 18 workers, no cross training
- Minimal communication between silos
- Each silo handles all products
- Silos produce as much as possible, all the time (push system)
- WIP moves between silos in large batches → long lead time

633

Manufacturing operation in U-shaped work cells*

634



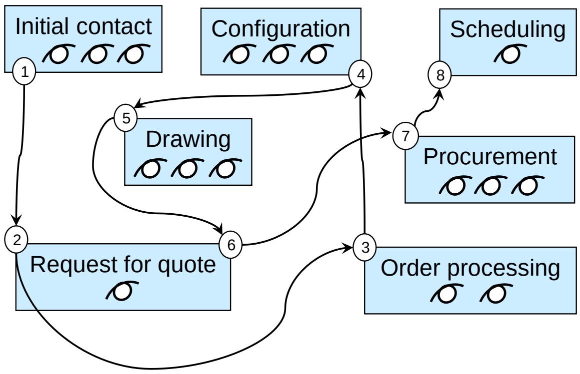
- Each cell handles all operations for one product family, and produces just what is needed to meet current demand (pull system)
- Continuous flow → minimal WIP → short lead time
- Rapid response to workflow or quality problems
- 16 workers instead of 18 — what happened to the other 2?

*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.

634

Transactional process in silos

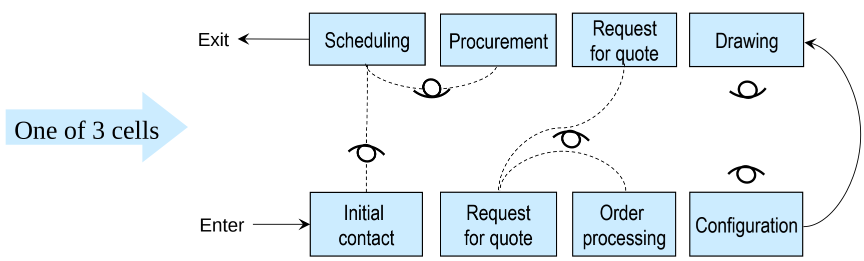
635



- 16 workers (σ), 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

636



- 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?

Definitions

637

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

637

Definitions (cont'd)

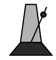
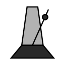
638

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)

638

Definitions (cont'd)

639

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

639

Definitions (cont'd)

640

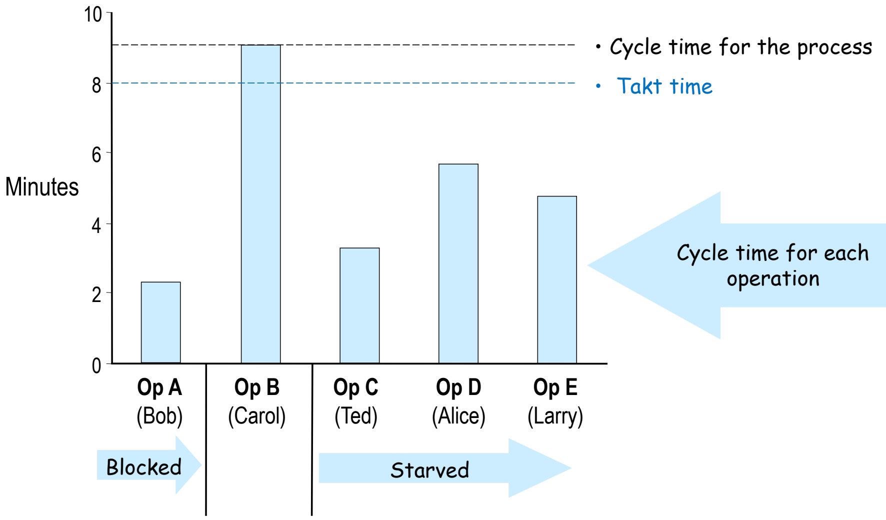
Process Cycle Efficiency (PCE)	• The percentage of time that WIP is being transformed by VA activities. In other words, the percentage of lead time that is value added.
Work In Progress (WIP)	• Includes items waiting to be worked on and items actively being worked on. WIP includes all of the inventory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

640

Work balancing

641

- Cycle time for a process = cycle time for the *slowest* operation
- This process is unable to meet the customer's needs



641

Work balancing (cont'd)

642

- 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

642

Improving work balance by adding resources

643

- 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 ÷ 2 = 4.5 mins (see next slide)
- New cycle time for the process is 5.8 mins (cycle time for operation D)

643

Effect of multiple resources on cycle time

644

- 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 mins) / (4 parts or transactions) = 1.5 mins

- Similarly, if a machine processes a batch of 4 parts every 6 minutes, the cycle time is 1.5 minutes.

644

Effect of multiple resources on cycle time (cont'd)

645

- 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.

645

Multiple resources (cont'd)

646

- In general:

Cycle time = (Cycle time of one resource) / (# Resources)

- Calculating number of resources required to meet customer demand:

Resources needed = (Cycle time) / (Takt time)

646

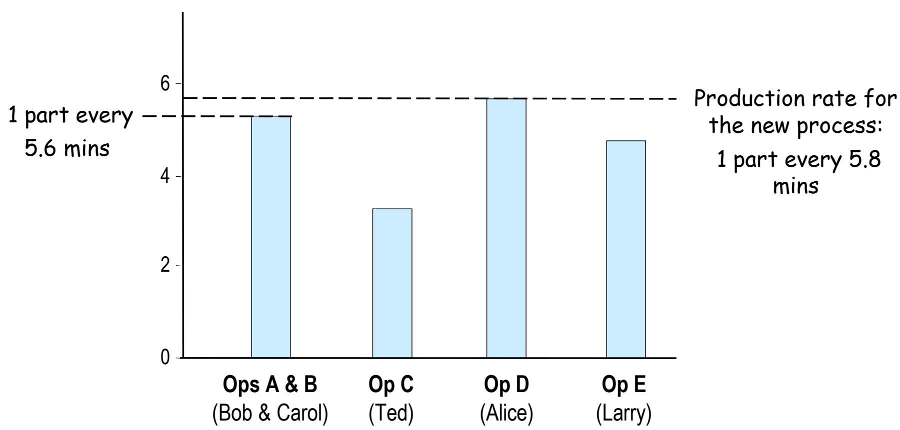
Improving work balance by cross training

647

- 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?

Cross training (cont'd)

648



Exercise 32.1 Lean workshop

649

The Instructor will provide directions for this workshop.

649

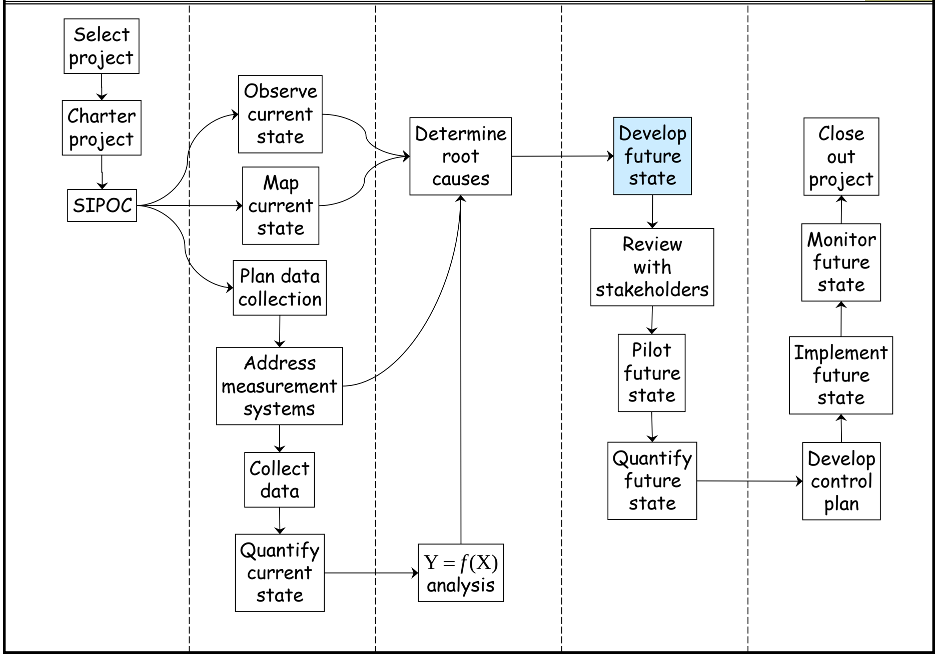
Notes

650

650

33 Theory of Constraints (TOC)

651



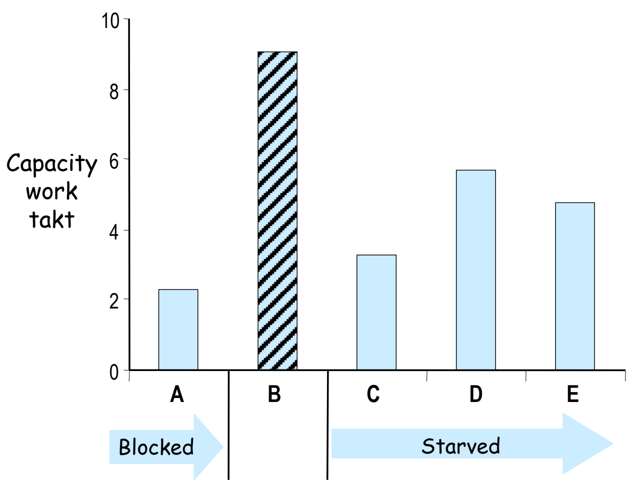
651

TOC (cont'd)

652

What if cross training is not feasible?

What if the bottleneck is machine capacity?



652

TOC (cont'd)

653

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

653

Ways to identify the constraint

654

- Greatest WIP
- Longest cycle time
- Longest process time
- Highest % utilization

654

Example: current state

655

Front end
4 machines
4 operators

Heat treat
1 machine
1 operator
Max qty = 60

Back end
4 machines
4 operators

	Q	Front end	Q	Heat treat	Q	Back end
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		120/60 = 2 mins		4 mins/4 pcs = 1 min
Constrained cycle time		1 min		2 mins		2 mins

Blocked (Front end)

Starved (Back end)

655

Future state #1: reallocate resources

656

Front end
4 machines
(1 idle)
3 operators

Heat treat
1 machine
3 operators
Max qty = 60

Back end
4 machines
(1 idle)
3 operators

	Q	Front end	Q	Heat treat	Q	Back end
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		100/60 = 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		

656

Future state #2: improve load change process

657

	Q	Front end 4 machines (1 idle) 3 operators	Q	Heat treat 1 machine 3 operators Max qty = 60	Q	Back end 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		95/60 = 1.58 mins		4 mins/3 pcs = 1.33 mins
Constrained cycle time		1.33 mins		1.58 mins		1.58 mins

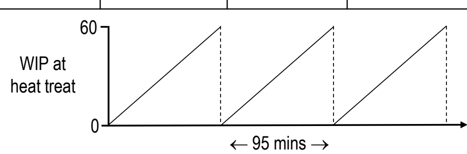
Even faster load change

657

Future state #3: pull system in front end

658

	Q	Front end 4 machines (1 idle) 3 operators	Q	Heat treat 1 machine 3 operators Max qty = 60	Q	Back end 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		95/60 = 1.58 mins		4 mins/3 pcs = 1.33 mins
Constrained cycle time		1.58 mins		1.58 mins		1.58 mins



658

Future state #4: establish and maintain safety WIP

659

Q

Front end
4 machines
(1 idle)
3 operators

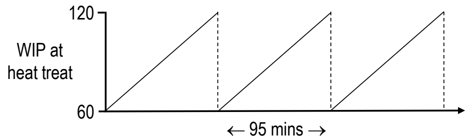
Q

Heat treat
1 machine
3 operators
Max qty = 60

Q

Back end
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		95/60 = 1.58 mins		4 mins/3 pcs = 1.33 mins
Constrained cycle time		1.58 mins		1.58 mins		1.58 mins



659

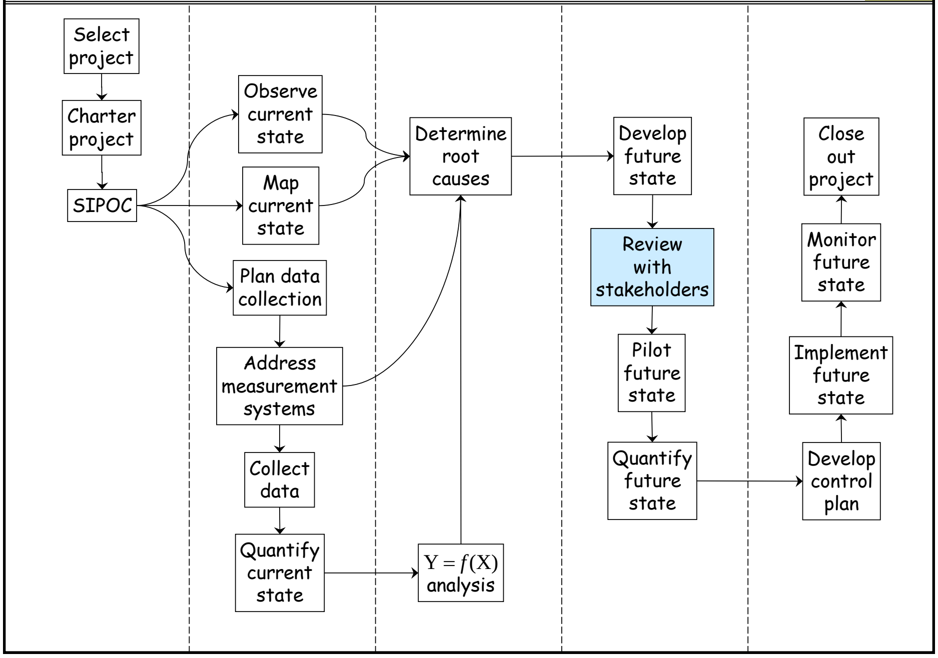
Notes

660

660

34 Reviewing the Proposed Future State

661



Reviewing the future state

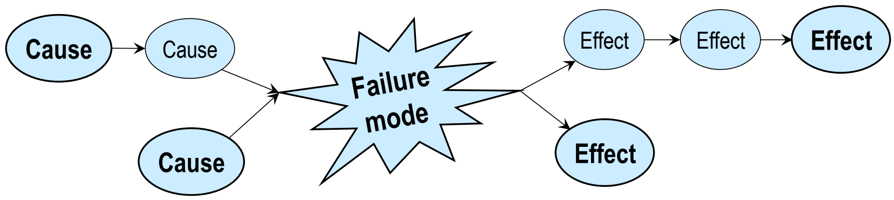
662

- 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

Failure Modes & Effects Analysis (FMEA)

663

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

663

The role of FMEA in a LSS project

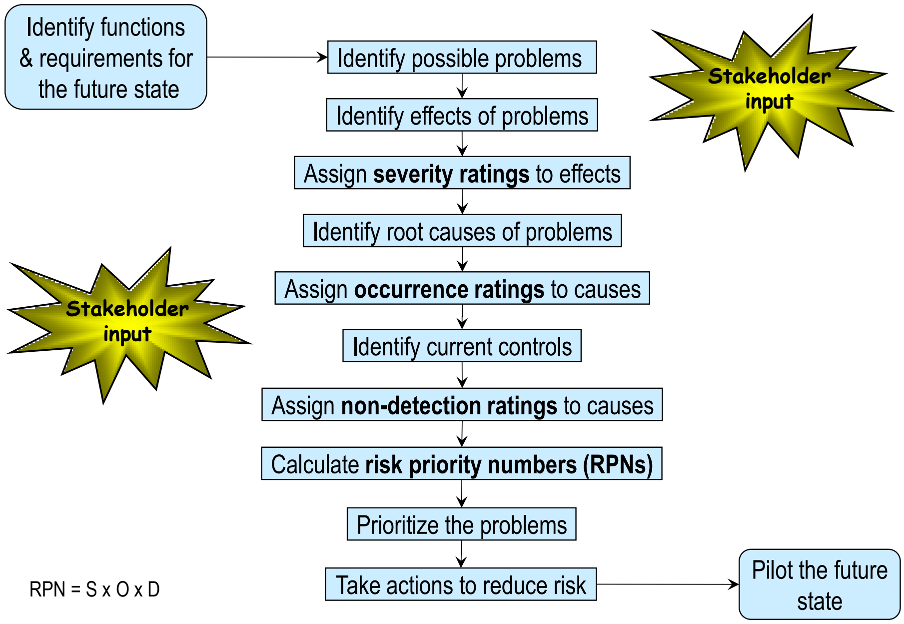
664

- 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

664

Detailed FMEA process

665



665

Example of a Severity rating

666

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.

666

Example of an Occurrence rating

667

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

667

Example of a Detection rating

668

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.

668

FMEA ratings

- 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

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

671

Average daily number of stock outs	2.1
Average time to fill material requests	4 hrs
Annualized direct labor cost	$91,000

671

FMEA step 1 for Proposed Future State Process

672

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			

672

FMEA step 2

673

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		

673

FMEA step 3

674

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

674

FMEA step 4

675

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				

675

FMEA step 5

676

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	

676

FMEA step 6

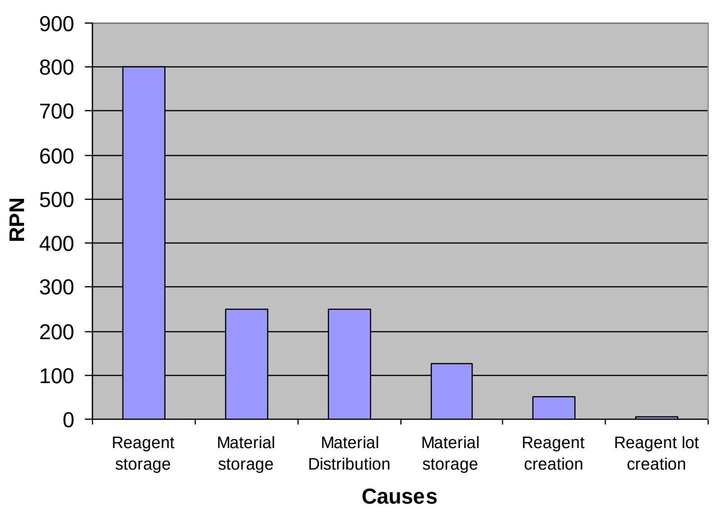
677

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	

677

Pareto of causes by RPN

678



678

FMEA step 7

679

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

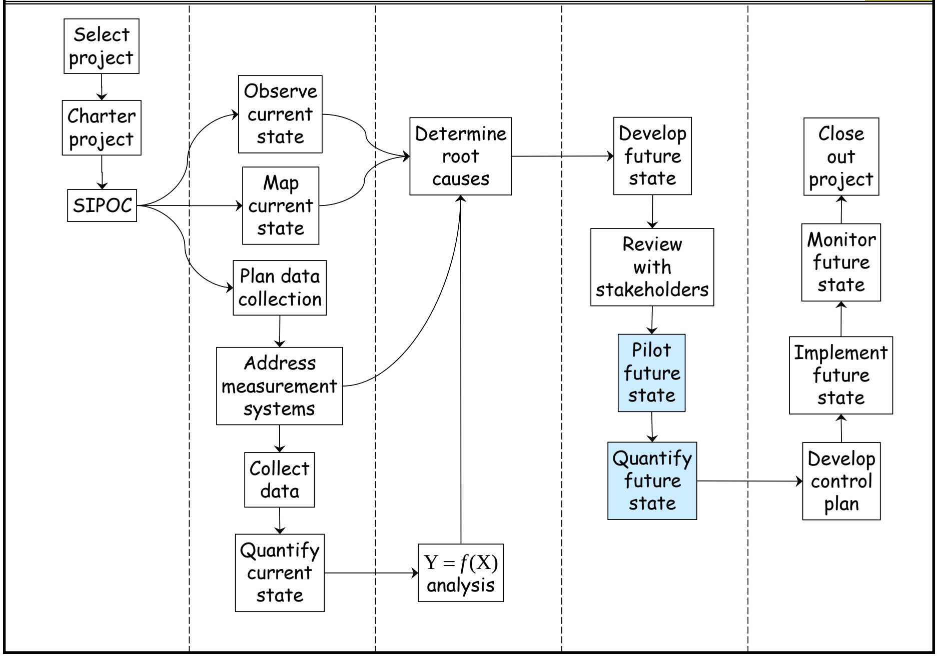
Results from pilot data

680

	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%

35 Piloting the Future State

681



Piloting the future state

682

- 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.

Benefits of piloting

683

- Identify unanticipated failure modes
- Identify unintended consequences
- Indicates whether or not improvement objectives will be met
- Reduces problems in full scale implementation

683

Piloting checklist

684

- ❑ 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?

684

Sample size calculation for a pilot study

685

Student Files → calculator - sample size → Comparisons

Y is a quantitative measurement	
Sample size per population	9
Standard deviation of Y	1
Desired DTD	1
Actual DTD	0.9993
% Confidence level	95

- Sample size per population → Sample size for the pilot
- Standard deviation of Y → Current state standard deviation
- Desired DTD → Baseline average minus goal
- Actual DTD → Set C7 to the value in C6 by changing C4 (use Goal Seek)

Y is pass/fail, yes/no, etc.	
% Defective - population A	10
% Defective - population B	5
DTD	5
Sample size per population	213

- % Defective - population A → Baseline value from charter
- % Defective - population B → Goal from charter
- Sample size per population → Sample size for the pilot

DTD = Difference to Detect

685

Example: quotation process pilot study

686

Scope of the pilot: Business Unit 8

Metric	Baseline (BU 8)	Goal
Average TAT	3.6 days	1.5 days
TAT > 3	37.9%	10%

Std Dev = 3.3 days

DTD = 2.1 days

Y is a quantitative measurement	
Sample size per population	20
Standard deviation of Y	3.3
Desired DTD	2.1
Actual DTD	2.1000
% Confidence level	95

Y is pass/fail, yes/no, etc.	
% Defective - population A	37.9
% Defective - population B	10
DTD	27.9
Sample size per population	18

If you have more than one statistical metric, you must use the largest of the calculated sample sizes

Sample size for the pilot should be at least 20

686

Exercise 35.1

687

Use the information 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		

*Std Dev of PO-PD = 19.5 days

Analyzing pilot results

688

- 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

Interpreting P values - “Statistical Standard of Evidence”

689

P value	Evidence that samples are different or variables are correlated	Confidence level (CL)
1.00 – 0.15	None	None
0.15 – 0.05	Some	85% ≤ CL < 95%
0.05 – 0.01	Strong	95% ≤ CL < 99%
0.01 – 0.0001	Very strong	CL ≥ 99%

689

Notes

690

690

Exercise 35.2

691

Open *Data Sets* → *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 line chart showing the change in PO–PD from the current state to the future state pilot. (Include lines showing the two averages.)

d) Test for a significant improvement in % PO–PD > 30. Give the P value and its interpretation in terms of standards of evidence.

691

Exercise 35.2 (cont'd)

692

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?

692

Exercise 35.3

693

Open *Data Sets* → *quotation process current & future pilot*.

a) Test for a significant improvement in average TAT. 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 line chart showing the change in TAT from the current state to the future state pilot. (Include lines showing the two averages.)

Exercise 35.3 (cont'd)

694

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.

Margin of Error (MOE) calculation for a pilot study

695

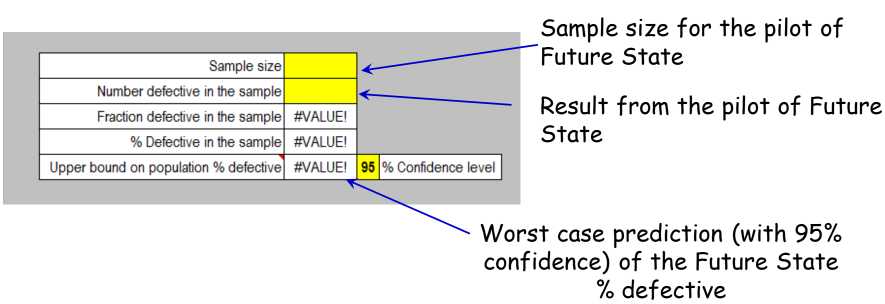
- In Module 16 Data Collection, we explored the concept of the Margin of Error (MOE) and how to use it to calculate a sample size to estimate Current State population baselines for project metrics.
- We learned that the more precisely we wanted to estimate an overall percent defective or average, the 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.

695

MOE calculation for a pilot study — Pass/Fail Y

696

Student Files→ calculator – margin of error → % Defective



696

Example: pilot study MOE calculation — Pass/Fail

697

Reference Exercise 27.6: Is there a significant reduction in % defective?

Open *Student Files→ calculator – margin of error → % Defective*

	Sample size	No. defective	% Defective
Current state	500	147	29.4%
Future state pilot	10	1	10.0%

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 Exercise 27.7, 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.

Example: pilot MOE calculation — Pass/Fail (cont'd)

698

Reference Exercise 27.6: Is there a significant reduction in % defective?

Student Files→ calculator – margin of error → % Defective

- 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 average of 29.4%.
- It may be worth collecting more samples for the Future State process before giving up on the proposed improvements.

MOE calculation for a pilot study — Quantitative Y

699

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.

699

Example: pilot study MOE calculation — Quantitative Y

700

Reference Exercise 27.8: *Data Sets → lead time*. Is there a significant reduction in lead time?

Student Files→ calculator – margin of error → Pop. mean of quant.Y

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance	Std. Dev.
Current	7	563	80.43	95.62	
Future	7	380	54.29	47.24	6.87

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

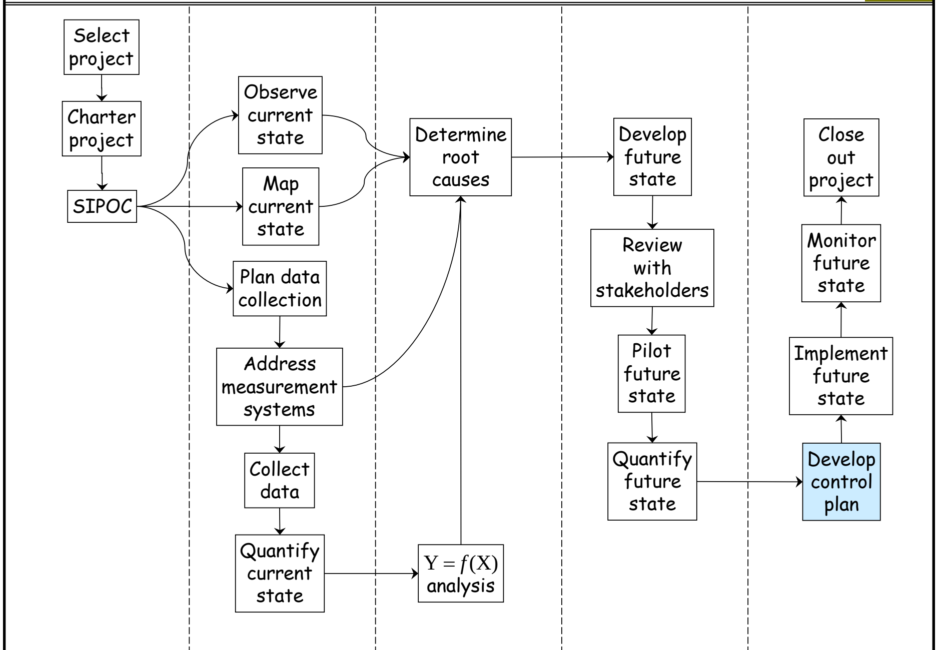
Confidence interval
(46.57 , 62.00)

In Exercise 27.9, 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!

700

36 Control Plan

701



What is a control plan?

702

- 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: training, auditing, control chart
- Most common control chart quantities: *individual measurements*, *averages*, and *percentages*

Student Files → blank control plan 703

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**		

703

Student Files → tool development control plan 704

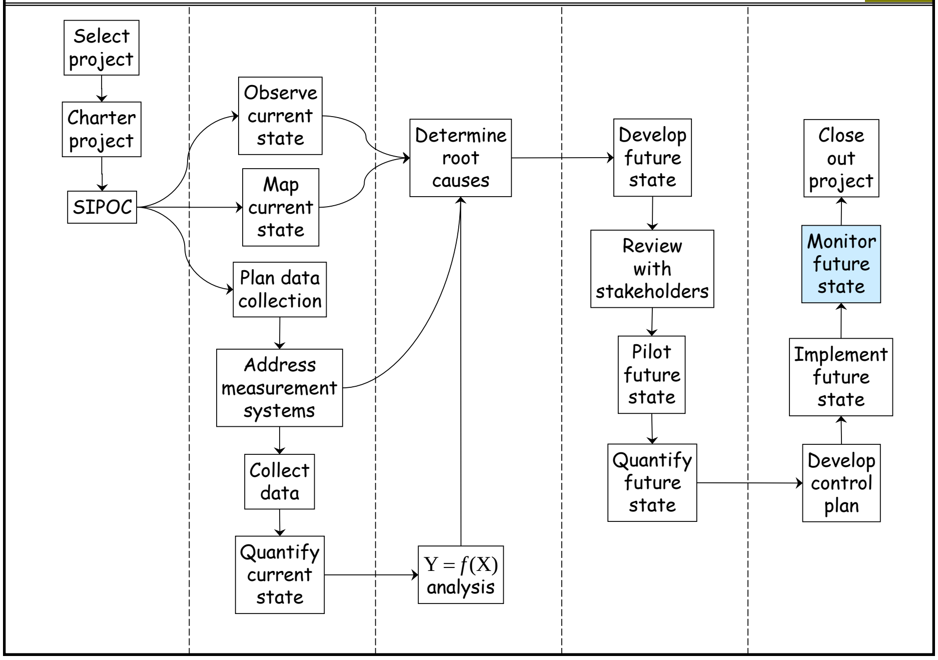
Process name:	Tool Testing Process
Process owner:	Testing Area Manager
Revision date:	

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

704

37 Statistical Monitoring

705



705

Statistical monitoring*

706

- 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.

Exercise 37.1

707

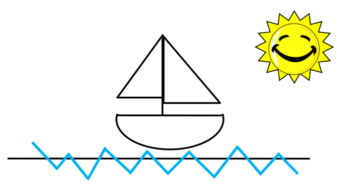
a) Sign your name five times in the space provided below.

b) Put your pencil or pen into the other hand. Sign your name once in the space provided below.

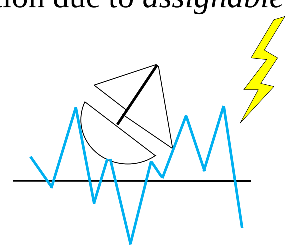
Two kinds of variation

708

Variation due to *common causes*



Variation due to *assignable causes*



Two kinds of variation (cont'd)

709

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

709

Quantifying common cause variation

710

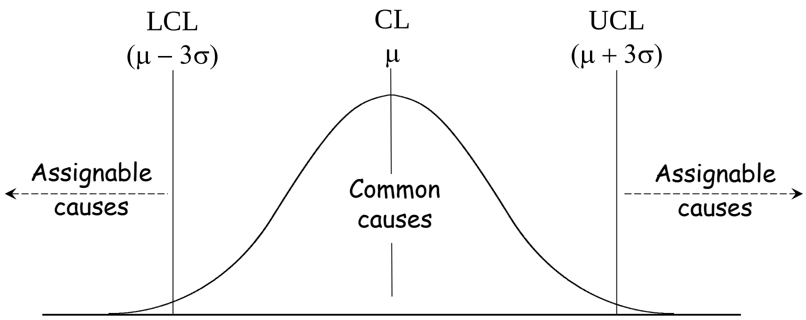
- Common cause variation is usually represented by upper and lower *control limits*
- Upper control limit (UCL) = $\mu + 3\sigma$
- Lower control limit (LCL) = $\mu - 3\sigma$
- These are also called *three-sigma limits*
- Center Line (CL) = μ

710

Common cause variation (cont'd)

711

Control limits provide an *operational definition* of common cause variation



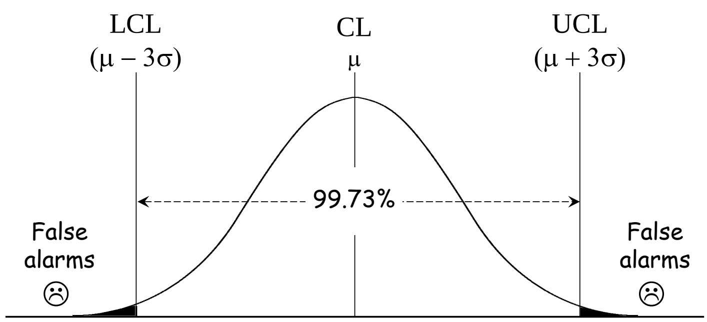
Baseline distribution of variable to be monitored

μ = average
σ = standard deviation

Common cause variation (cont'd)

712

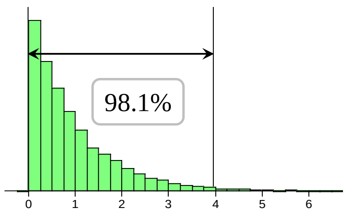
If the quantity to be monitored follows a Normal distribution, the chance of a *false alarm* is 0.27%



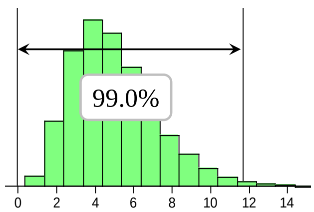
Baseline distribution of variable to be monitored

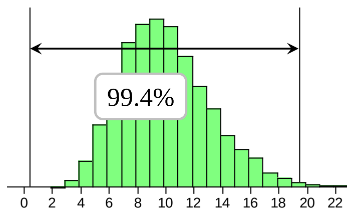
Common cause variation (cont'd)

713



- 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*

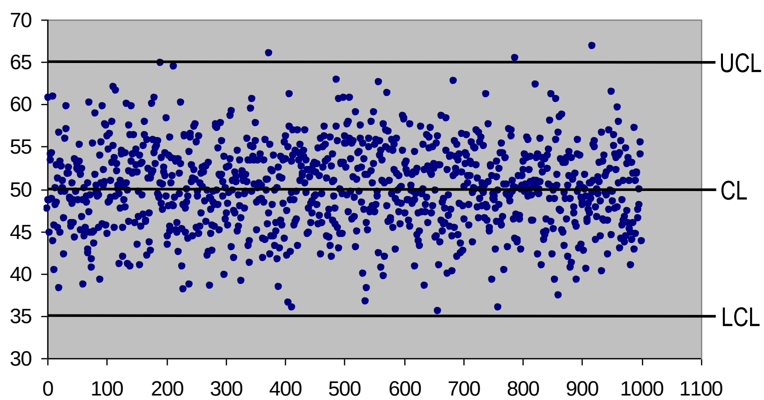




Behavior of Averages: the "Central Limit" effect

714

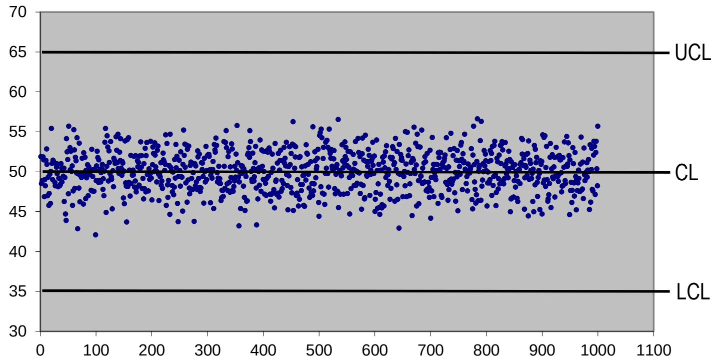
Individual data values sampled from a population with $\mu = 50$ and $\sigma = 5$



Behavior of Averages: the “Central Limit” effect (cont’d)

715

Averages of 4 data values sampled from the same population
with $\mu = 50$ and $\sigma = 5$

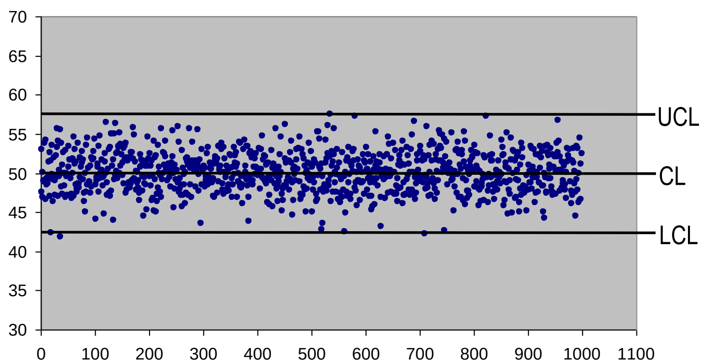


- Why would the limits shown above be ineffective for statistical monitoring of the averages?
- Control limits for a distribution of averages must be calculated a different way.

Behavior of Averages: the “Central Limit” effect (cont’d)

716

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.

The Standard Deviation of Averages

717

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:

$$\frac{\sigma}{\sqrt{N}}$$

717

Control Limits for Averages

718

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:

$$\text{UCL} = \mu + 3\frac{\sigma}{\sqrt{N}}$$

$$\text{LCL} = \mu - 3\frac{\sigma}{\sqrt{N}}$$

718

Establishing Control Limits

719

- 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!

719

Sampling for control charts

720

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.

720

Common Shewhart control charts

721

Quantitative measurement:

- $\bar{X}$ & s (sample average and standard deviation)
- $\bar{X}$ & R (sample average and range)
- IX and MR (individual values and moving range

Categorical classification:

- p (fraction defective)

721

Quantitative control charts

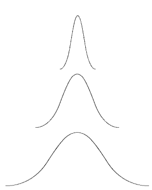
722

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?

SCENARIO A



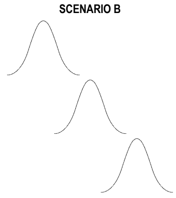
The centering is ______________

____

The consistency is ____________

____

SCENARIO B



The centering is ______________

____

The consistency is ____________

____

722

Quantitative control charts (cont'd)

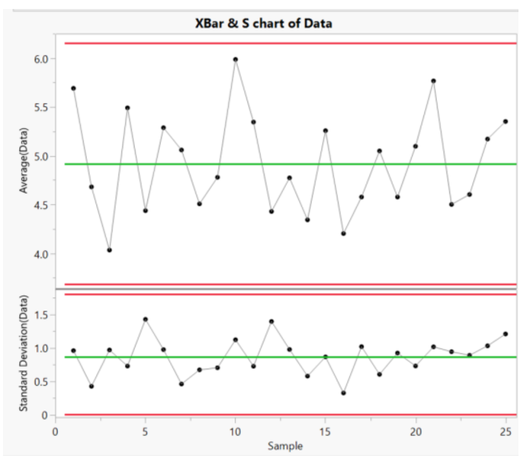
723

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*.

Example: $\overline{X}$ and s chart

724

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*

Control limit calculations for X–bar and s charts

725

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)

726

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

727

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 ($\overline{x}$) 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.

Exercise 37.2 (cont'd)

728

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.

$UCL_{\bar{x}} =$ $UCL_s =$

$CL_{\bar{x}} =$ $CL_s =$

$LCL_{\bar{x}} =$ $LCL_s =$

Control limits for X–bar and R charts

729

$\overline{X}$ 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

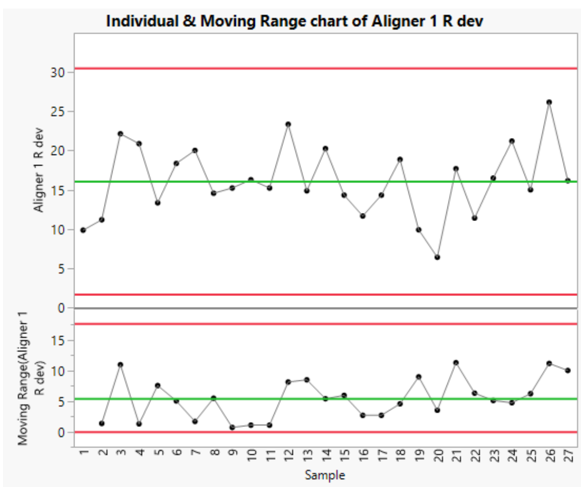
From Introduction to Statistical Quality Control by Douglas C. Montgomery

729

Example: Individual and Moving Range chart

730

For each unit, the measurement is plotted on the Individual chart and the Moving Range is plotted below.



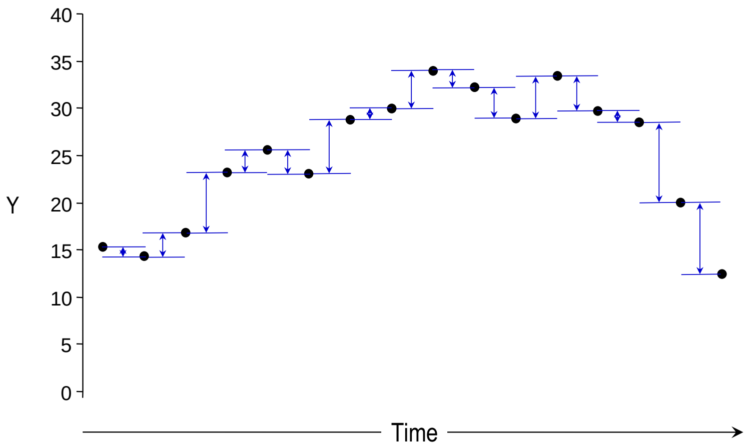
Why is the first point missing on the MR chart?

730

Estimating standard deviation using the moving range method

731

Each moving range is the absolute value of the difference between consecutive data points.



731

Control limit calculations for Individual and Moving Range chart

732

Individual Chart Control Limits:

$$UCL = \bar{x} + 3\frac{\overline{MR}}{d_2}$$

$$CL = \bar{x} \qquad MR = |x_i - x_{i-1}|$$

$$LCL = \bar{x} - 3\frac{\overline{MR}}{d_2}$$

The value of d_2 is 1.128 since the range is between two consecutive points.

Moving Range Chart Control Limits:

$$UCL = D_4\overline{MR} = 3.267\overline{MR}$$

$$CL = \overline{MR}$$

$$LCL = D_3\overline{MR} = 0$$

732

Individual and Moving Range chart calculator

733

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

733

Example: Individual and Moving Range chart calculator

734

Excerpted data from *Data Sets→ solution properties*

A	B	C	D	E	F	G	H	I
	Formulas for n=2		Individual Measurements Chart			Moving Range Chart		
Data	Moving Ranges	Average Moving Range	LCL	CL	UCL	LCL	CL	UCL
0.9239		0.0006	0.9214	0.9230	0.9246	0.0000	0.0006	0.0019
0.9233	0.0006							
0.9236	0.0003							
0.9224	0.0012							
0.9231	0.0007							
0.9224	0.0007							
0.9231	0.0007							
0.9236	0.0005							
0.9230	0.0006							
0.9233	0.0003							
0.9229	0.0004							
0.9232	0.0003							
0.9225	0.0007							
0.9218	0.0007							

- If $Y \geq 0$ and $LCL < 0$, ignore LCL
- With MR calculations, the number of decimal places shown may need to be increased

734

Exercise 37.3

735

We want to use $\overline{\text{IX}}$ 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?

$\overline{\text{MR}}$ =

Exercise 37.3 (cont'd)

736

c) What are the control limits for the Individual Chart?

UCL =

CL =

LCL =

d) What are the control limits for the Moving Range Chart?

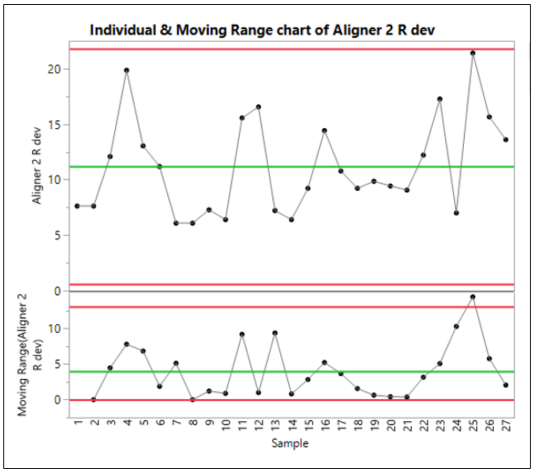
UCL =

CL =

LCL =

Individual & Moving Range chart plotted

737



JMP Output of Individuals & MR Chart of Aligner 2 R dev
Data Sets → control chart aligner

p Chart

738

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.

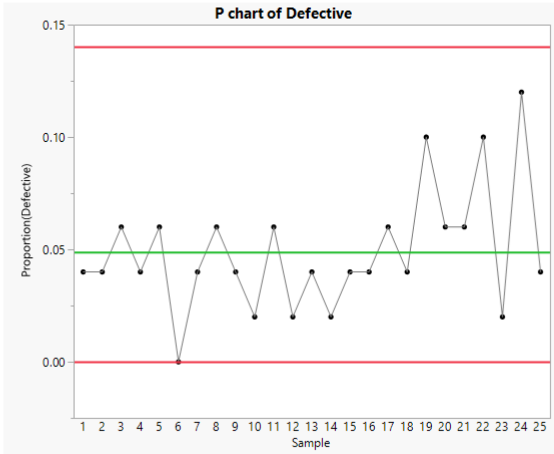
- The standard deviation of the Binomial distribution is:

$$\sqrt{\frac{p(1-p)}{n}}$$

p Chart (cont'd)

739

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.

p Chart (cont'd)

740

Control Limits for the p Chart

$$UCL = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

$$CL = \bar{p}$$

$$LCL = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

$$\bar{p} = \frac{\text{Total number of defective units in the samples}}{\text{Total number of units in the samples}}$$

$$n = \text{number of items in each sample}$$

These control limits are the mean +/- 3 sigma for this distribution.

Exercise 37.4

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)

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

743

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.

743

Interpreting control charts

744

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?

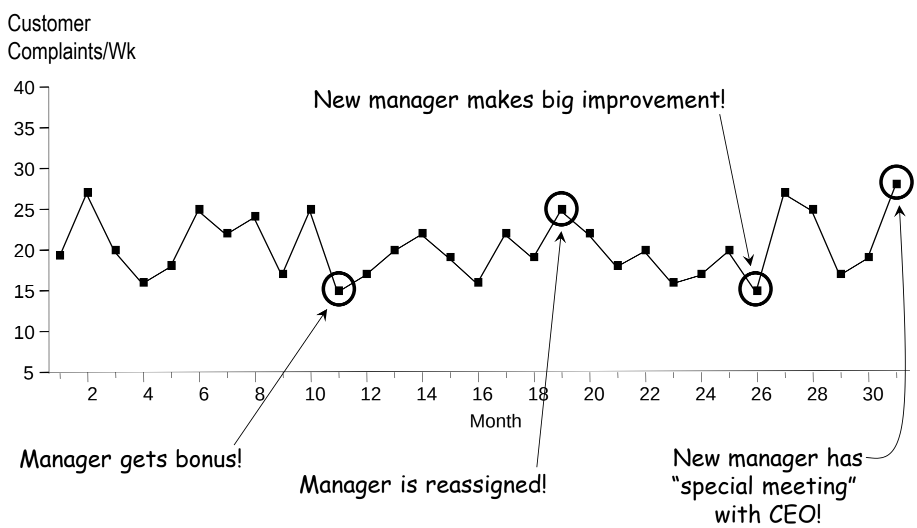
The rules we'll discuss for deciding whether a process is in or out of control work only for control limits — *not* for specification limits.

- 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.

744

A hypothetical KPI scenario

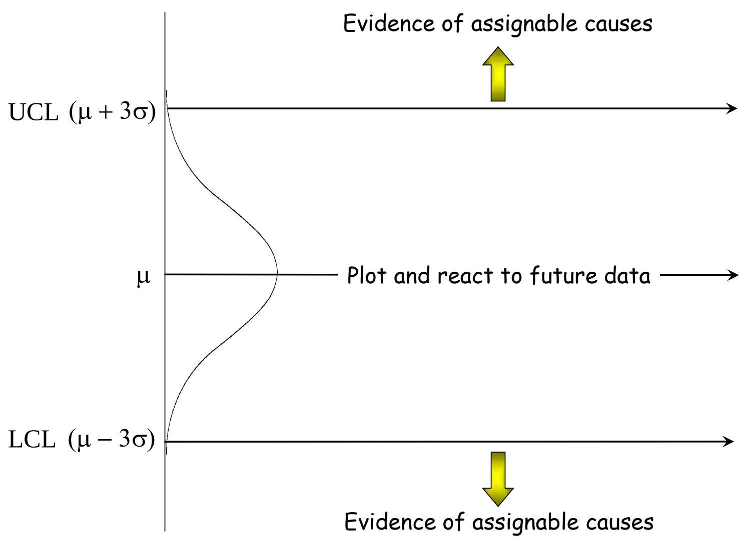
745



745

Using control limits

746



746

Back to our hypothetical scenario

747

Control Limits show there are no assignable causes!

Run charts can cause us to overreact.

747

Using control limits (cont'd)

748

- 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

748

Using control limits (cont'd)

749

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.

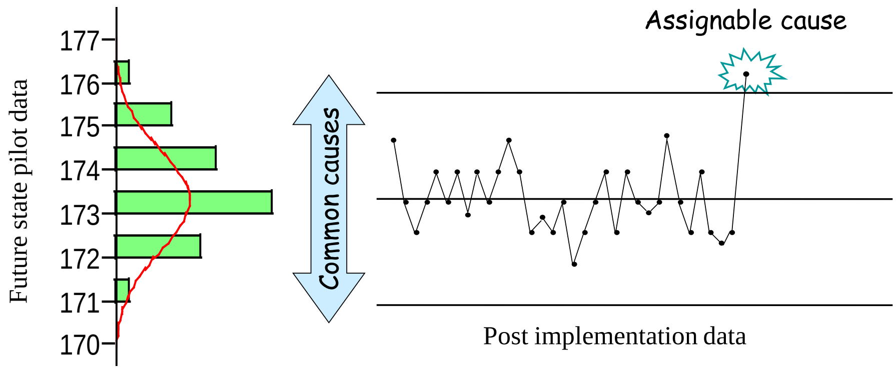
- In this case, it may be sufficient to use an X-bar or IX chart without the associated standard deviation or range chart.
- Adding control limits to the resulting X-bar or IX chart will provide a statistical basis for action.
- It may also be helpful to add a target or goal line to the chart (aligned 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?

Notes

750

Using control limits (cont'd)

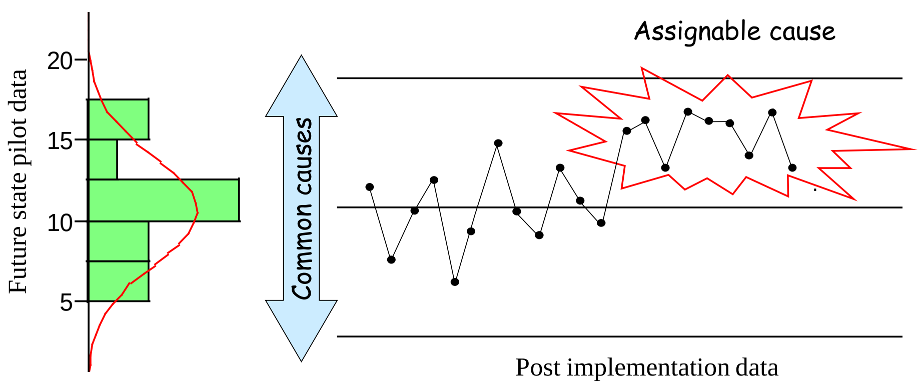
751



1. This event has probability 0.00135 (0.0027 ÷ 2)
2. Investigate to determine the cause
3. Take corrective action to eliminate the cause

Using control limits (cont'd)

752



1. This event has probability 0.00195 [$(0.5)^9$]
2. Investigate to determine the cause
3. Take corrective action to eliminate the cause

Additional tests for assignable causes

753

Control chart zones: A, B, and C

Additional tests for assignable causes (cont'd)

754

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)

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.

755

Tests most commonly used (and most useful)

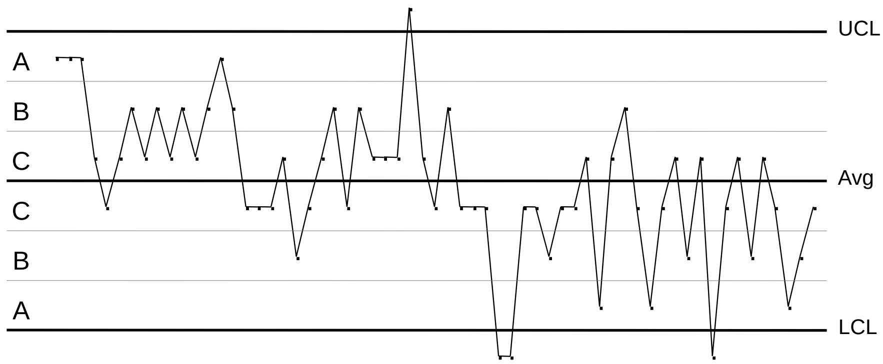
Test #1	One or more points outside the control limits.
Test #2	Nine or more points in a row on one side of the average.

756

Exercise 37.5

757

Circle occurrences of Tests 1 and 2 on the control chart shown below. Indicate which is which.

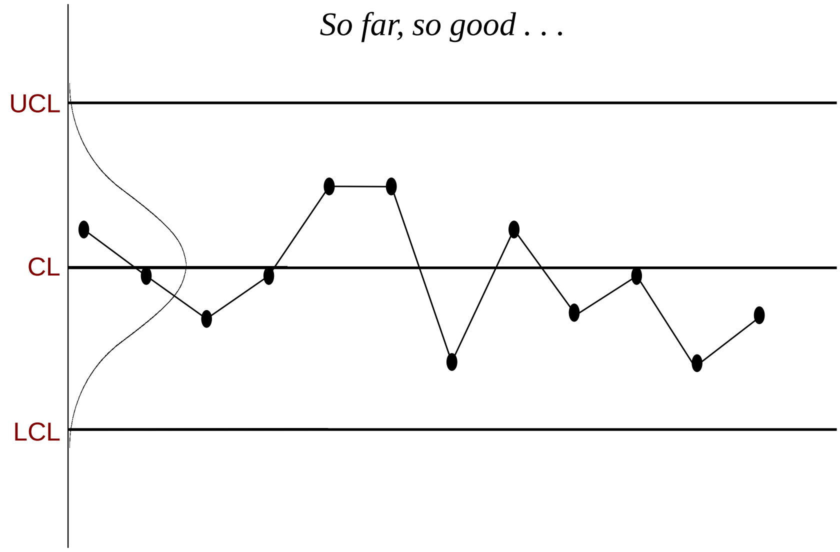


Notes

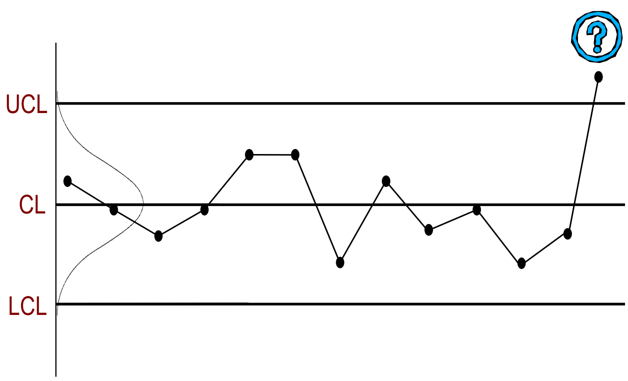
758

Response plans

So far, so good . . .



Out-of-control event (OOC)

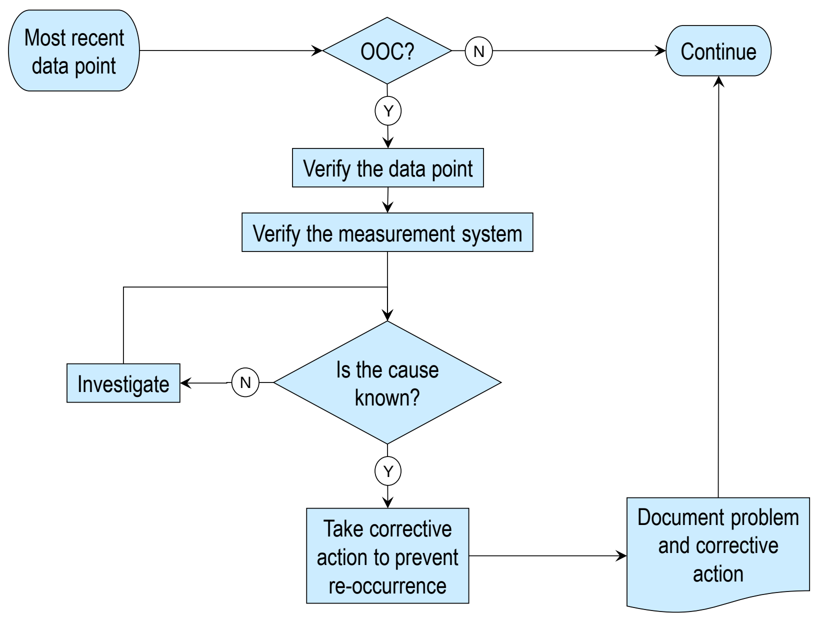


1. Investigate to determine the cause
2. Take corrective action to eliminate the cause

Step 1 requires a *response plan*

Response plan “skeleton”

761



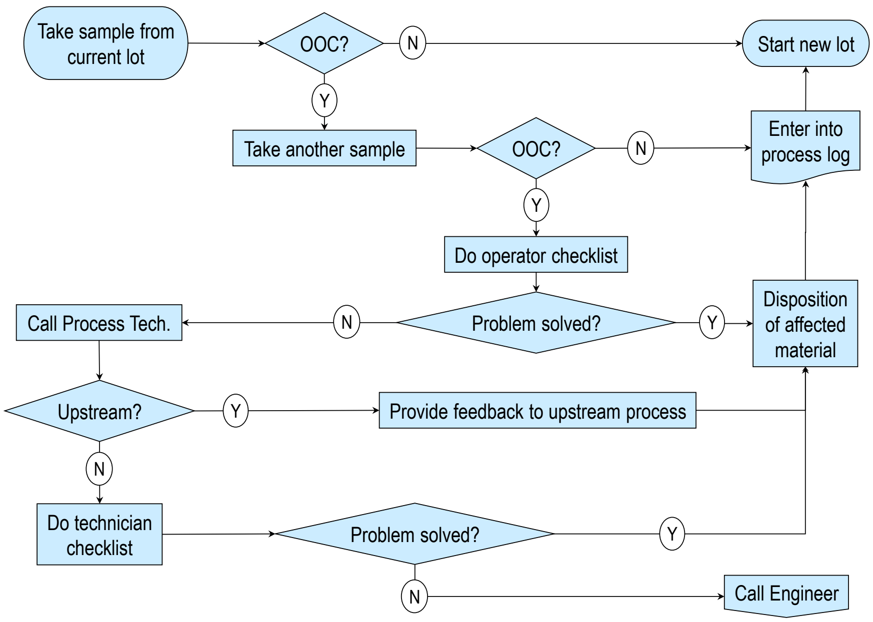
Response plan (cont’d)

762

- OOC stands for *out of control*
- This means the control chart indicates an assignable cause according to one or more selected tests
- 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 one shown above
- It should posted in a place clearly visible to process participants

Response plan example

763



763

Response plan (cont'd)

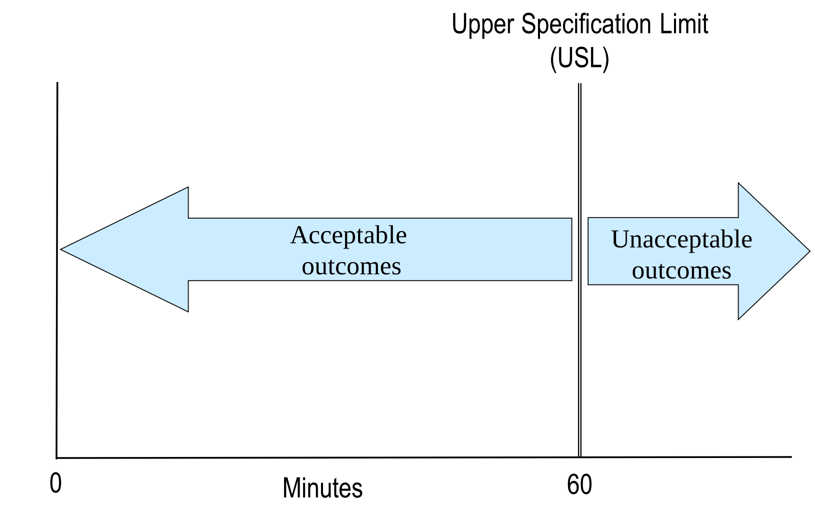
764

- 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*

764

What about performance requirements?

765

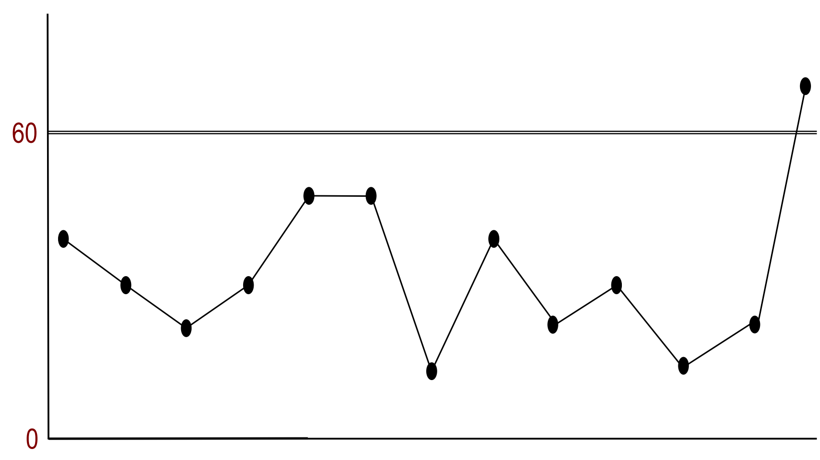


765

Out-of-specification event (OOS)

766

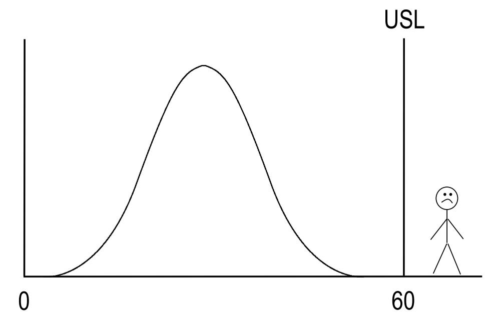
What do we do now?



766

Scenario 1: process capability is good

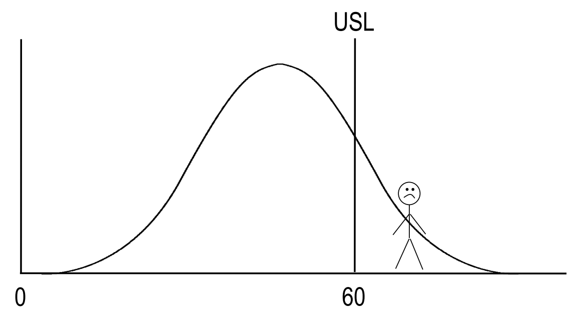
767



- 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

Scenario 2: process capability is poor

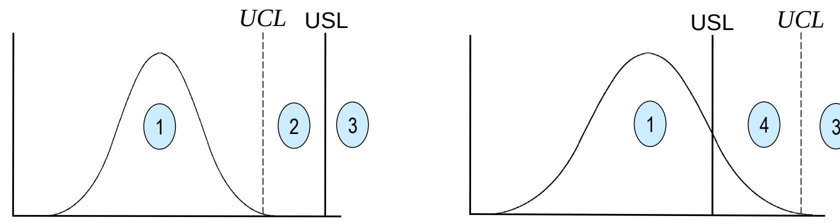
768



- 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 response plan

Exercise 37.6

769



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			

Summary

770

Thank you for participating

in ETI Group's

Lean Six Sigma Green Belt Workshop!

Your Instructor will give 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.