Lean Six Sigma Yellow Belt

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Lean Six Sigma Yellow Belt

Course outline with slide numbers

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Learning Objectives

On completion of this training course, you will be able to:

- Describe how the concepts and tools of Lean and Six Sigma can be integrated to provide a focus on customer value streams and the reduction of non-value- added activities, defects and waste.
- Identify what constitutes a Lean Six Sigma (LSS) project and the factors that lead to effective improvements.
- Explain each phase of the LSS roadmap using the Define, Measure, Analyze, Improve and Control (DMAIC) methodology.
- Use LSS terms and concepts to communicate with others and provide support to Green Belts and Black Belts who are leading LSS improvement projects.
- Apply the most widely used tools for LSS projects, to include:

Define –	project charter for problem statement, value stream and workflow scopes, SIPOC, project metrics, team and resource definition
Measure –	process observation, process mapping, value stream mapping, data collection planning, and use of statistical metrics
Analyze –	run charts, Pareto charts, stratification analysis, root cause analysis (5 whys, affinity analysis, cause and effect diagrams)
Improve –	structured brainstorming, benchmarking, multi-voting, cause and effect matrix for solution impact, Lean solutions, stakeholder engagement and solution piloting
Control –	control plan, statistical monitoring via control charts, response plans, process capability

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1 Basic Concepts of Lean

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 can always defeat methodology
The path forward*	• Management must foster a culture of *continuous improvement* • Improve all processes, every day • Improvement cycles must be an integral part of the daily work of all employees

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

Basic concepts of Lean (cont'd)

1) Define *value* from the customer's point of view

2) Continually reduce or eliminate activities that do not add customer value

3) Focus on the *value stream*:

The set and sequence of all activities required to provide a specified family of products or services to the customer

Customer defines value

Customer value adding (CVA)

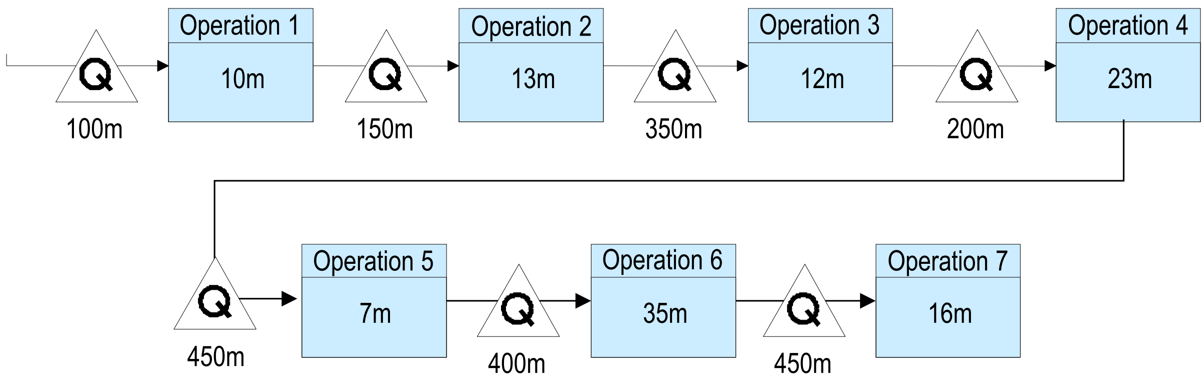
- Activities that are required, from the customer's point of view, to produce/deliver the desired product/service
- What the customer is willing to pay for

Non value adding (NVA)

- There exists a feasible future state in which the desired product/service can be produced/delivered without these activities

Common example of CVA and NVA

Only 5.3% of this value stream is CVA

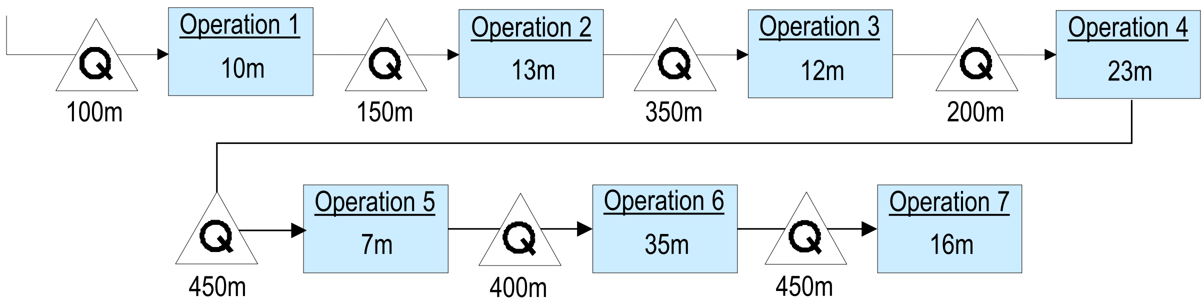


Cycle time = 2216m

Touch time = 116m (5.3%) → mostly NVA

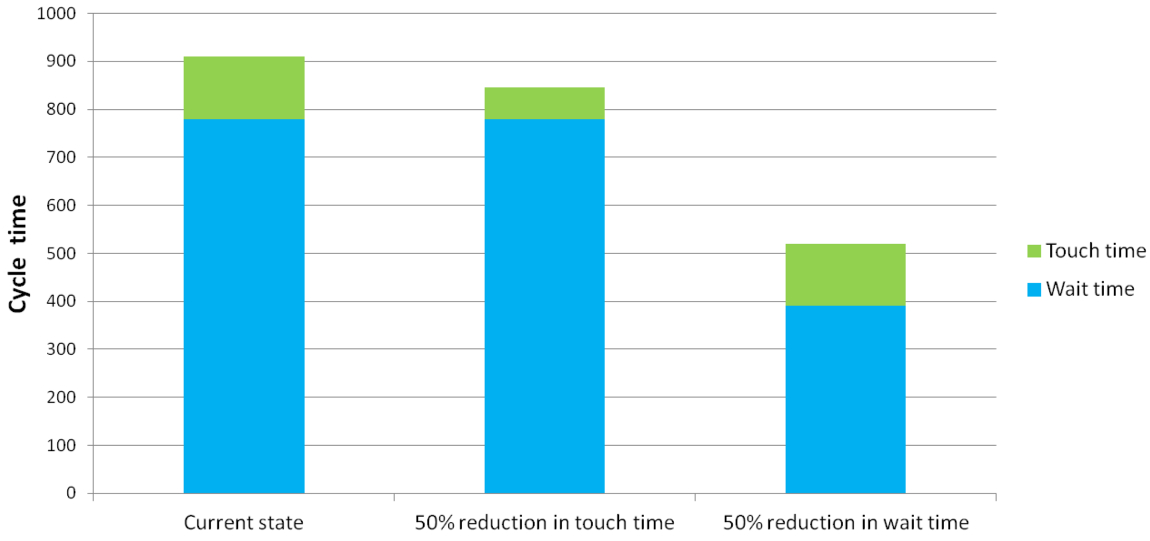
Q Queue (material or transactions waiting to be worked on) → 100% NVA

Which should we reduce: CVA or NVA?



	Current state	50% reduction in touch time	50% reduction in wait time
Touch time	116 m	58 m	116 m
Wait time	2100 m	2100 m	1050 m
Cycle time	2216 m	2158 m	1166 m
Reduction in cycle time →		**3%**	**47%**

Reduce NVA, not CVA!



Other types of NVA associated with Lean

- Making or doing more than is needed at the time
- Supplies, work in process, or finished goods beyond what is needed
- Producing or delivering to a higher standard than is required
- Excessive movement of people or material from one place to another
- Excessive motion in the completion of work activities
- Failure to integrate improvement cycles into the daily work of all employees

Notes

Types of NVA associated with Six Sigma

Defects

Errors

Scrap

Rework

Late delivery

Returned goods

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Notes

Example of defects: not meeting product specifications

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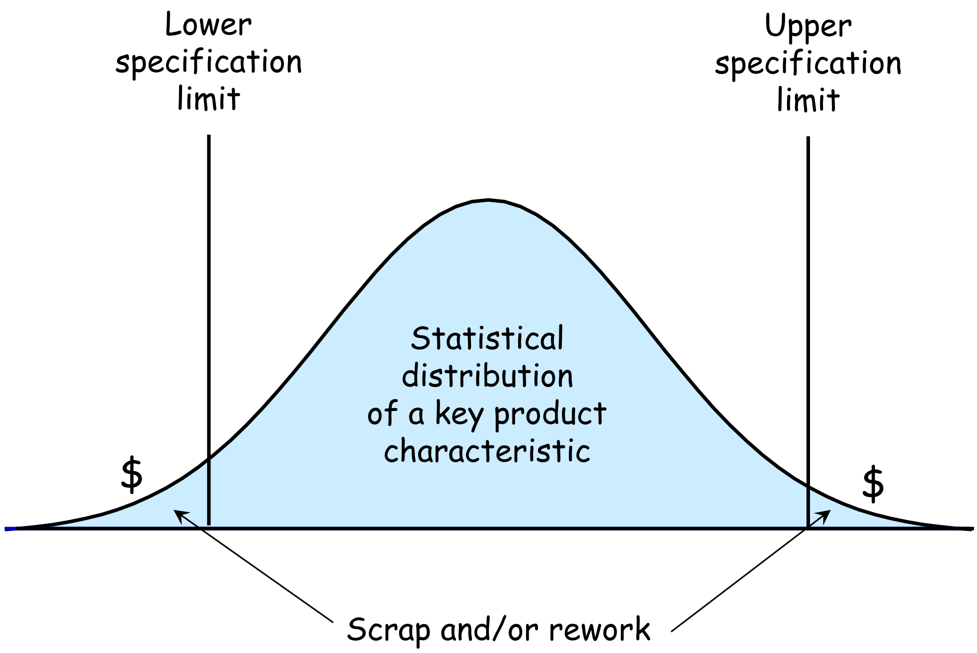

Result of improvement project

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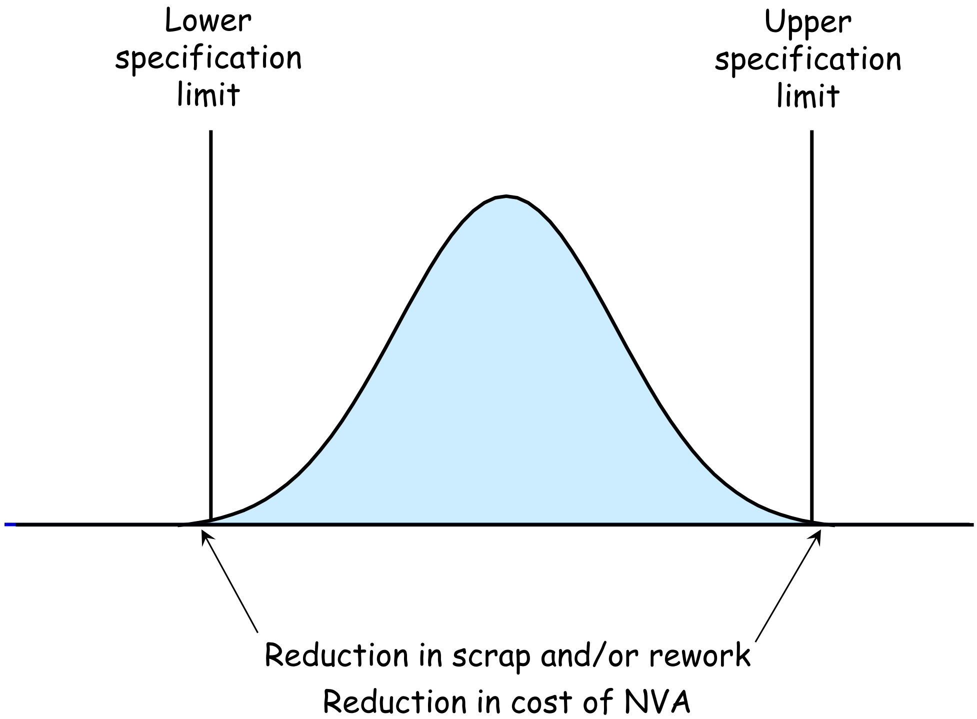


Reasons to combine Lean and Six Sigma

- They employ common strategies
- They focus on complementary problem areas
- They employ complementary methods

Common strategies

- Focus on customer satisfaction
- Focus on reducing waste and its cost
- Focus on processes and process improvement
- Improving processes via team projects
- Keep the improvement cycles going

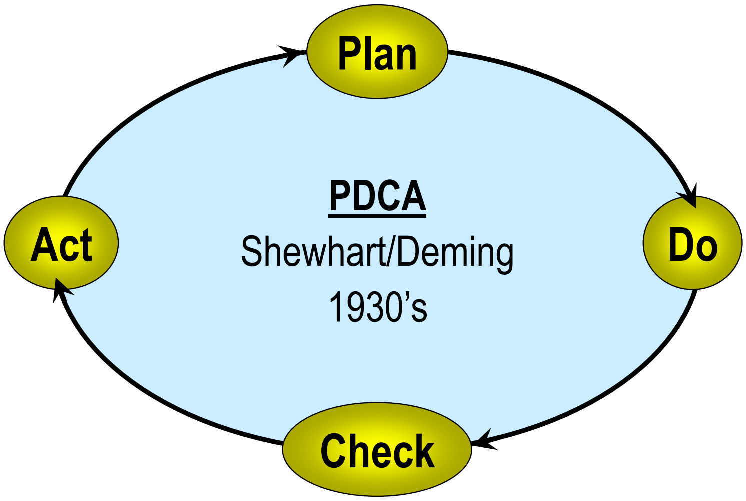
Complementary problem focus and methods

Lean	Six Sigma
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	Root causes harder to determine
Value stream mapping Geographic mapping	Basic process mapping Cross functional process mapping
"Tribal knowledge" "Wisdom of the organization"	Data analysis
Best practices from TPS provide a set of known solutions	Project roadmap provides a method for finding new solutions

Notes

3 The Lean Six Sigma Project Roadmap

In the beginning there was...



One of the first applications of the scientific method to manufacturing and business processes

PDCA (cont'd)

Plan

- ✓ Define the problem to be solved
- ✓ Collect and analyze data on the current process
- ✓ Brainstorm possible causes of the problem

Do

- ✓ Develop possible solutions
- ✓ Select the most likely solution
- ✓ Pilot the solution

Check

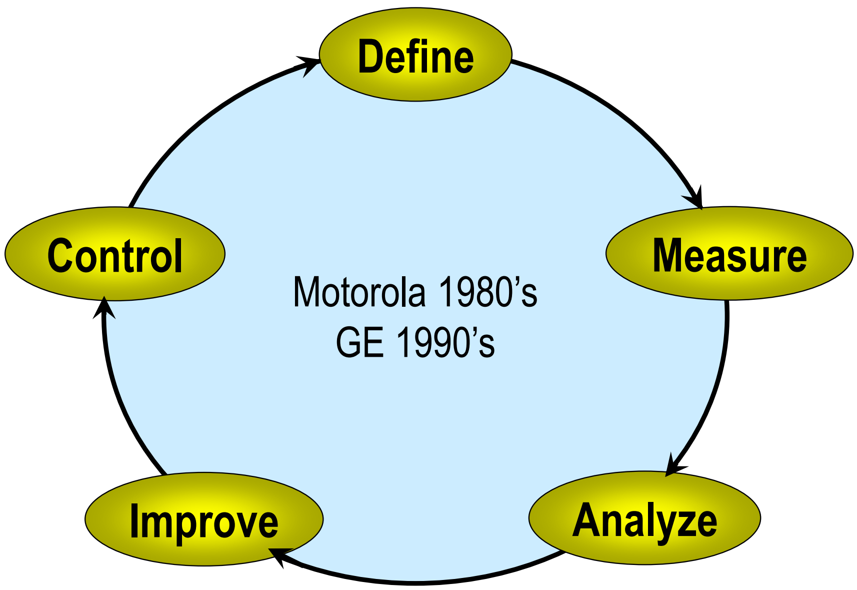
- ✓ Analyze the results to see if the problem has been solved

Act

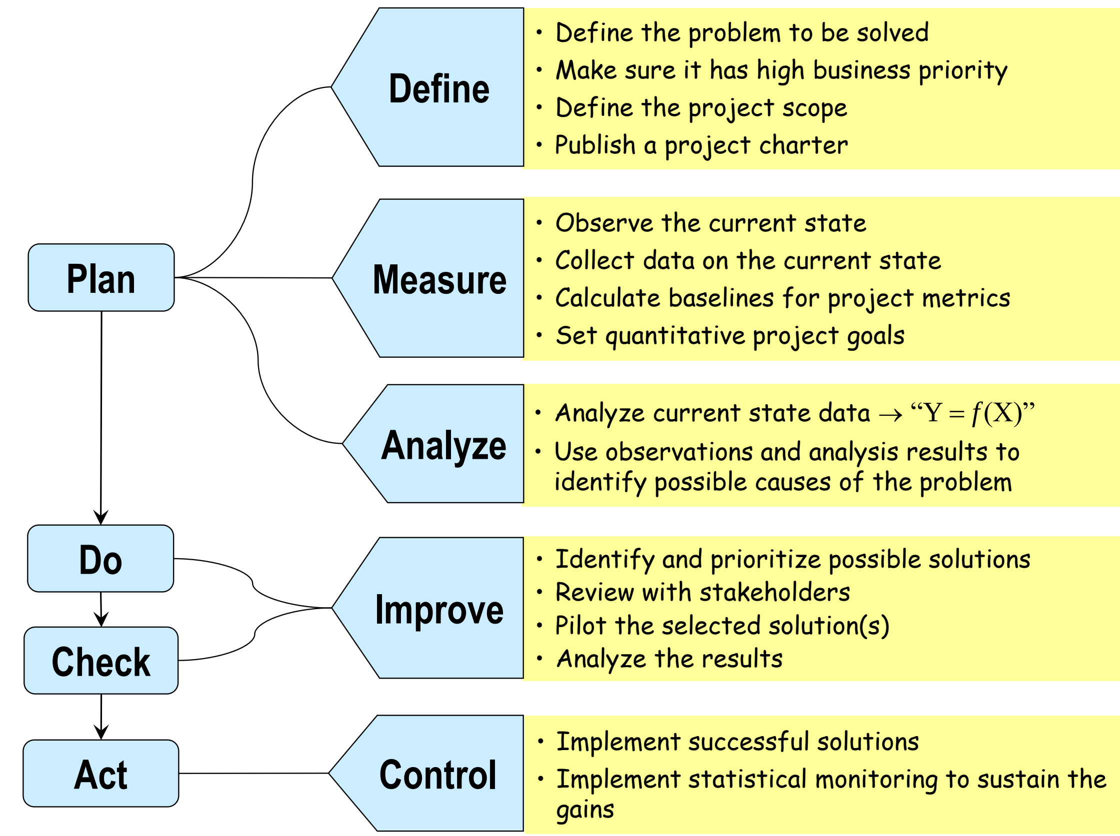
- ✓ Implement the successfully piloted solution, or
- ✓ Start the cycle over again

Nowadays it's spelled D-M-A-I-C

Most widely used process improvement methodology



DMAIC has more "teeth" than PDCA



Strengths of LSS projects

- ✓ 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

Characteristics of DMAIC projects

- We want to improve a process (the way we do something), or
- We want to improve a 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

DMAIC is *not* a set of solutions – it is a process for *finding* solutions

Exercise

Draw lines in pencil connecting the items on the right to the appropriate DMAIC phases on the left.

Define	Establish the current state
Measure	Develop the future state
Analyze	Sustain the gains
Improve	Develop the project charter
Control	Determine the root causes

Notes

Examples of DMAIC projects

Reduce oxidation on titanium castings

Reduce injection molding setup time

Reduce repair shop turnaround time

Reduce injection molding defects

Reduce the cost of belt grinding

Reduce RFQ turnaround time

Reduce unplanned downtime

Other types of project

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

Examples of non-LSS projects

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

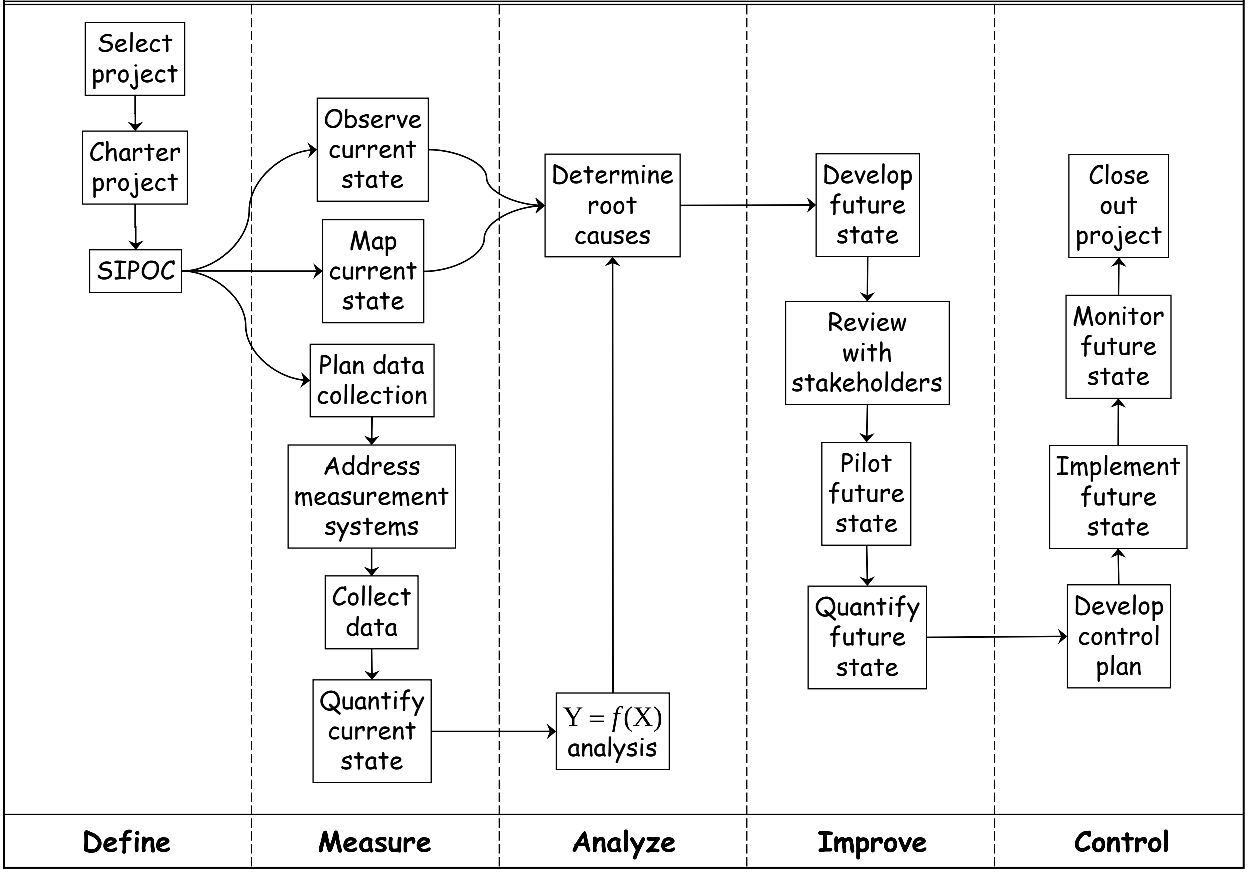
Install a bar coding system

Build a plant in China

Exercise

Classify these projects	DMAIC	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 cycle 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		

DMAIC project roadmap (detailed version)



Notes

Arrows indicate precursor/successor relationships. Dashed lines indicate project reviews with champion

4 DMAIC Case Study

Background

- An extrusion supplier receives a blueprint for a new profile about once a day on average
- The supplier designs and machines the tools that will be used to extrude the profiles
- The supplier bears the development cost, then becomes the sole supplier for the life of the contract
- Once machined, a new tool is tested
- If necessary, it goes back to the machine shop for rework

Define: problem statement

Our tool testing process has always been a problem. The number of rework per new tool ranges from 0 to 20. Each rework takes about 3 days, so the order to sell time can be as long as 2 months. The cost per rework is about $1800, so the cost per tool can be as high as $36,000. We cannot compete on price with our Chinese competition, so our only hope is to compete on quality and lead time.

Another problem is that the current testing process results in manufacturing processes with relatively slow line speeds and excessive material usage.

Define: project metrics and current values

- Average cost per rework: $1800
- Average time per rework: 3 days
- Number of reworks per tool: 0 to 20
- Total rework cost per tool: up to $36,000
- Time from order to sell per tool: up to 2 months
- Annual cost of tool rework: $2.4 million

Define: improvement goals

- 50% reduction in average number of reworks per tool
- 50% reduction in average time from order to sell
- 50% reduction in annual cost of tool rework

Define: project scope

Value stream scope

- Location A only
- PVC products only
- Out of scope: locations B & C, composite products
- These are **replication opportunities**

Workflow scope

- Starts with blueprint from external customer, ends with tool released to manufacturing
- Customers: manufacturing, external customers
- Suppliers: external customers, raw material suppliers

Define: project team

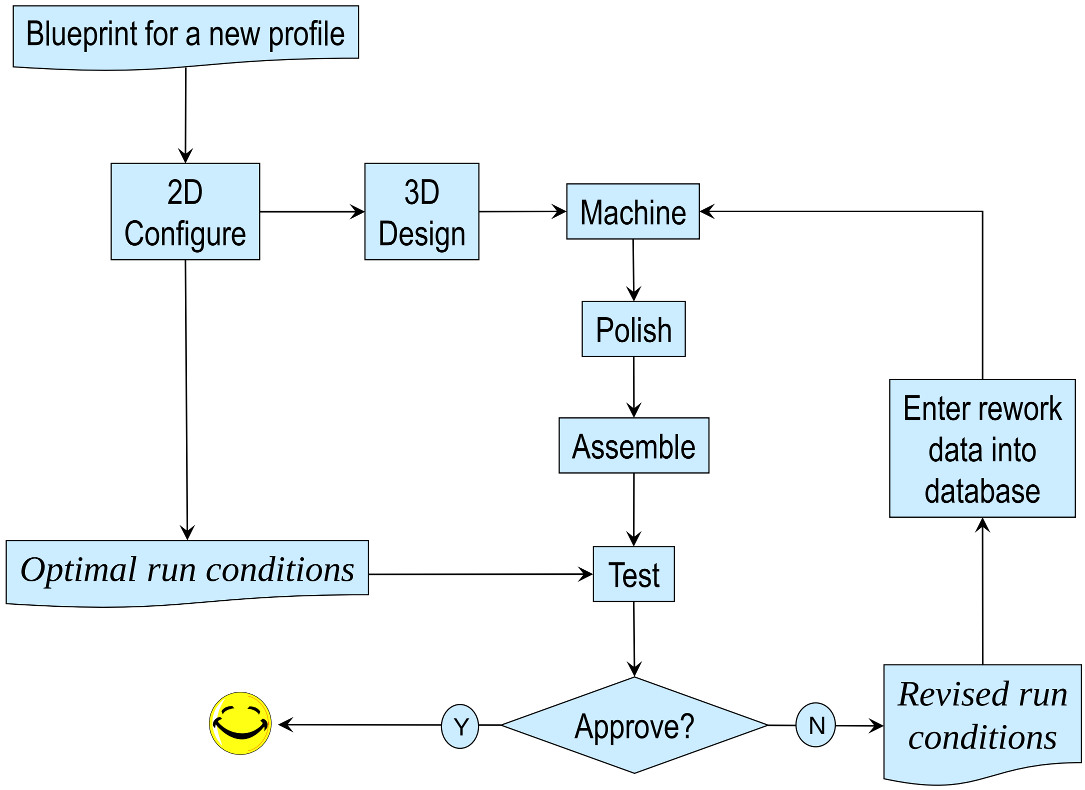
- Tool testing manager (also Champion)
- Quality manager
- Two engineers
- Two operators in the testing department

Measure: observe the current state

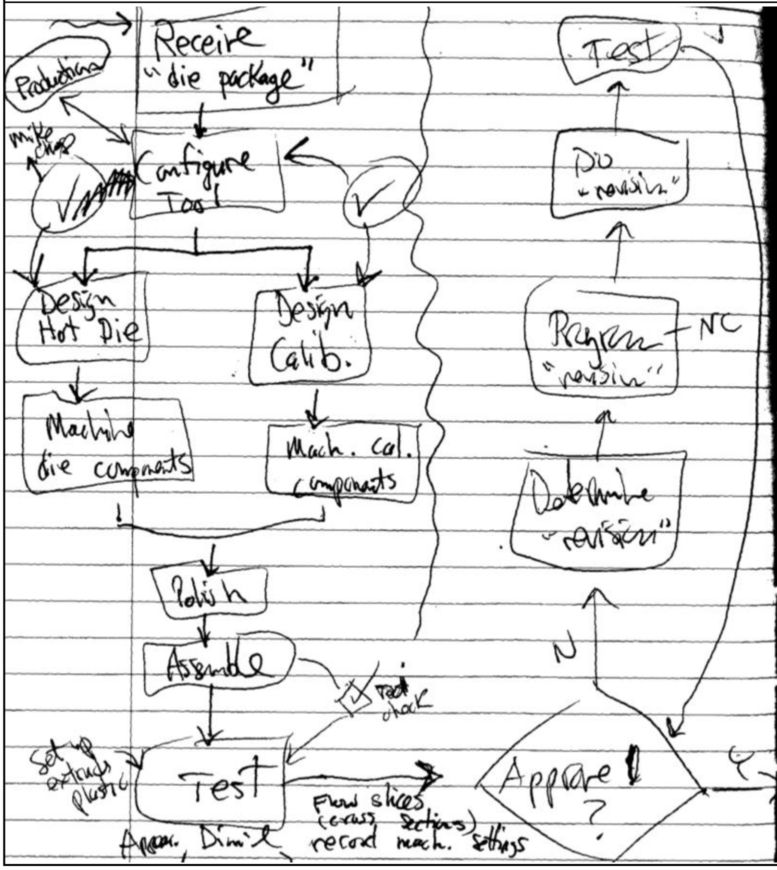
- Testers are under pressure to work quickly (new profile comes in just about every day)
- Run conditions are modified by trial and error to solve dimensional or cosmetic problems
- Dimensional measurements to determine tool rework are taken with hand held calipers on plastic parts
- Testers ignore many of the run conditions specified in the 2D Configure process
- Testers often solve dimensional problems by decreasing the line speed and increasing the weight

Notes

Measure: map the current state



Measure: map the current state



This is what the first draft looked like!

Measure: collect data

Y variables (outputs of the process)

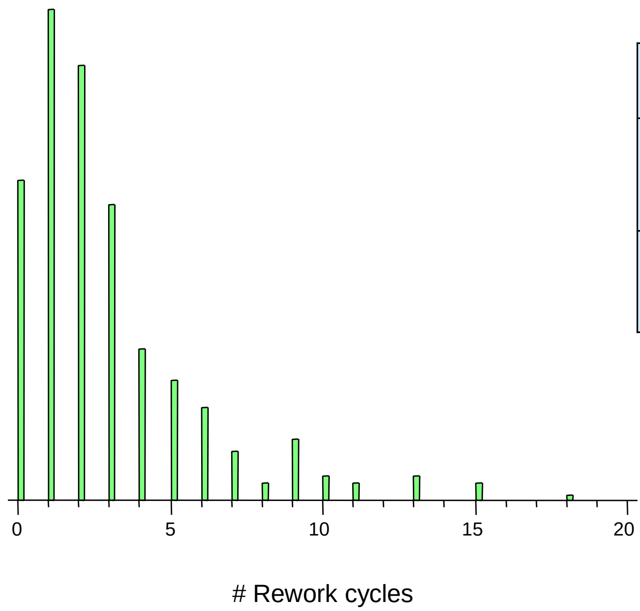
- Dimensions
- Cosmetic quality
- Number of reworks per tool
- Order-to-sell time per tool
- Line speed
- Weight

X variables (inputs to the process)

- Complexity of configuration
- Single or dual orifice die
- Dimensional tolerances
- Run conditions
- Tool testers

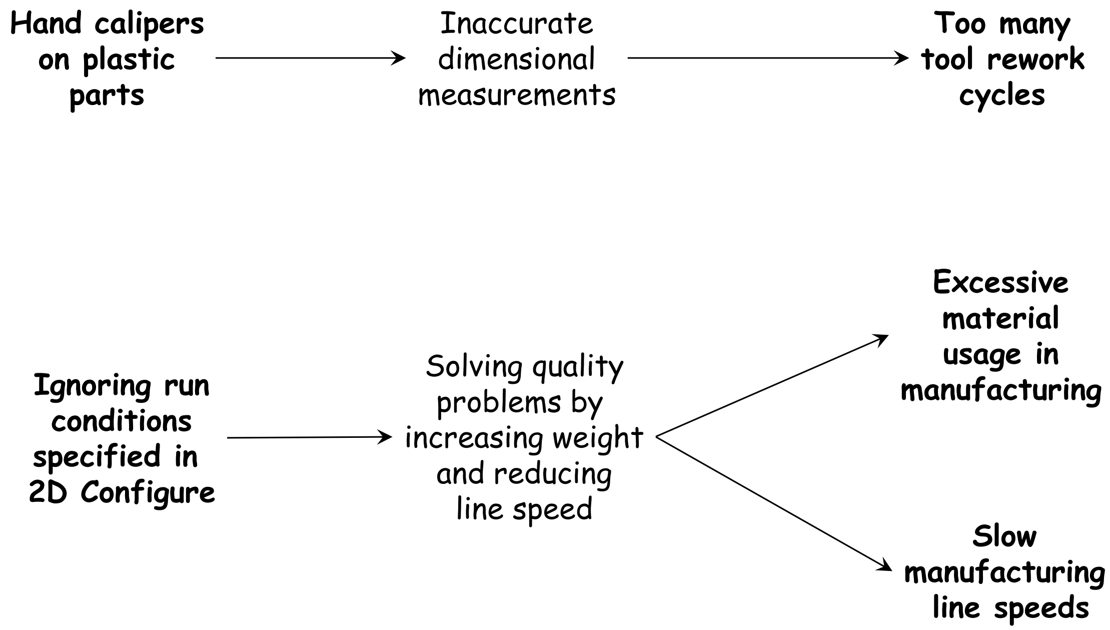
Measure: calculate current-state metrics

A year's worth of new tools



Sample size	339
Average number of rework cycles	3
Tools with 5 or more rework cycles	25%

Analyze: determining root causes



Analyze: correlating X variables to Y variables

X variables				*Y variables*													
	Line		**Die-cal.**	**Control dimensions**													**Distortion**
Weight	**speed**	**Vac.**	**dist.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**rating**
51	1	53	1	4	1	-13	0	1	-5	-5	9	-1	-11	-7	3	0	3
48	1	53	1	-1	4	-12	2	3	-2	-4	5	-1	-11	-11	0	-3	3
49	1	70	2	-4	4	-14	-4	1	-3	1	4	-5	-11	-9	3	0	4
48	1	70	2	1	1	-17	6	7	-5	0	5	-4	-11	-9	1	-4	3
81	1	67	1	0	-1	-12	6	1	-4	-3	5	2	-5	-1	11	3	1
76	1	67	1	0	4	-13	2	2	-7	-5	5	1	-6	-2	7	4	2
77	1	50	3	2	2	-12	1	-1	-5	-4	6	1	-7	-3	17	2	1
74	1	50	3	1	1	-16	3	1	-6	-5	13	1	-5	-4	8	1	2
48	2	77	1	-2	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	-2	5
46	2	77	1	-2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-2	4
47	2	50	3	-4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	3
45	2	50	3	-3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-4	4
67	2	67	2	-1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	4
64	2	67	2	-4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	4
67	2	80	3	-2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6	3
65	2	80	3	-2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3	4
77	2	50	1	-2	-2	-16	-4	0	-1	-4	6	-1	-8	-2	10	1	2
76	2	50	1	-4	-2	-14	-5	0	-2	-3	4	-1	-8	-1	7	3	3
78	2	80	2	-2	1	-14	-6	2	5	-3	3	-1	-8	-6	10	6	1
78	2	80	2	-3	-2	-15	-8	0	3	-1	4	-2	-9	1	9	4	3
49	3	67	1	0	3	-22	-2	5	-3	0	-1	-9	-14	-8	9	0	4
48	3	67	1	-5	-3	-22	-5	-1	-9	-4	1	-8	-15	-9	0	0	3
51	3	80	2	-2	-4	-22	-2	6	-7	0	1	-5	-13	-8	10	2	3
50	3	80	2	-1	-3	-20	-4	6	-4	1	1	-9	-14	-9	1	0	3
66	3	80	1	-5	3	-24	-4	4	-5	-3	-1	-6	-10	-4	7	4	4
66	3	80	1	2	-5	-19	1	7	-3	-1	1	-3	-11	-3	5	6	3

This analysis showed that testers could use variables other than weight and line speed to solve dimensional problems

Improve: develop the future state

- Teach testers to use variables other than weight and line speed to solve dimensional problems
- Require special approval to change weight and line speed from the values determined in 2D Configure
- Allow testers more time to evaluate tools in each rework cycle (→ fewer rework cycles)
- Provide testers with DVT gages to measure dimensions with greater accuracy

Improve: pilot the future state (one of several tools)

	Current state	*Future state*
Weight	381	366 (4% decrease)
Line speed	129	200 (55% increase)
Problems	6 dimensions needed rework Serious distortion	5 dimensions needed rework No distortion

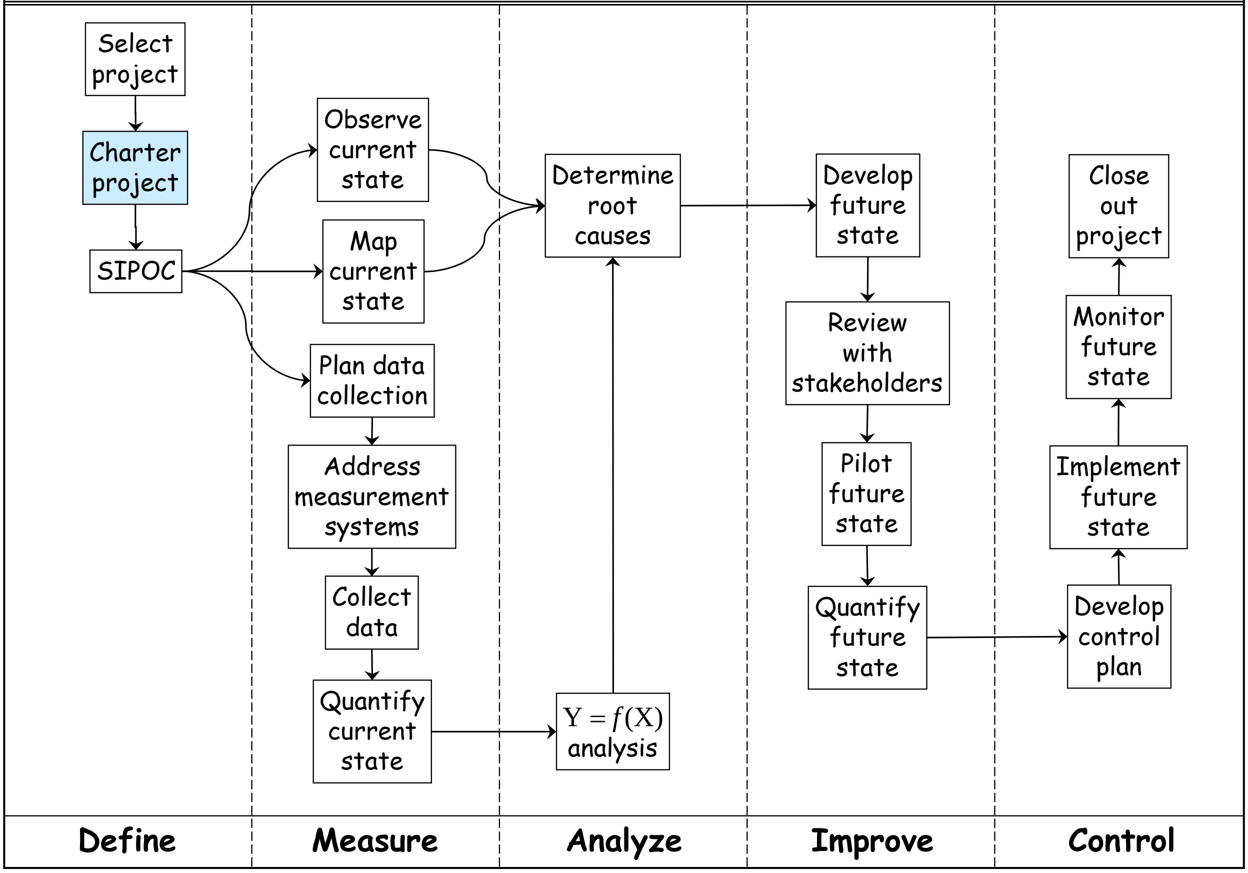
Control: implement and monitor the future state

- Conduct training as needed
- Conduct periodic audits
- Determine control limits for:
  - ✓ Number of days to release
  - ✓ Number of rework cycles
- When either variable exceeds its control limit:
  - ✓ Find the cause
  - ✓ Take corrective action

Control: calculate benefits

- More than 50% reduction in average number of reworks
- More than 50% reduction in average order to sell time
- Replication opportunities
  - ✓ Composite products (vs. PVC)
  - ✓ The other two locations
- Total annual savings (eventually): $2 million

5 Define Phase of DMAIC



Project charter topics

- Problem statement
- Value stream scope
- Workflow scope
- Inputs, outputs, customers, suppliers
- Project metrics
- Project teams
- Resources

Problem statement

The problem statement should . . .

. . . Describe the current situation in objective terms

What is

. . . Not suggest or imply solutions

. . . Locate the problem in time

. . . Include baseline values of project metrics, if possible

. . . Give enough information for “outsiders” to understand what the project is about

. . . Evolve and strengthen during the Define and Measure phases

Notes

Evolution of problem statements

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☹	😐	☺
We are upset with our customers for not paying us on time.	15% of invoices submitted to customers are paid more than 60 days late.	20% of invoices submitted to Stahl & Hyde last year were paid more than 60 days late. This compares to 5% for our other customers.
Due to lack of training in work cell Z, cycle times have trended up.	The average cycle time in work cell Z has increased from 30 minutes to 60 minutes.	In the last 6 months, the average cycle time in work cell Z during second shift has increased from 30 minutes to 90 minutes.

Evolution of problem statements (cont'd)

☹	😐	☺
We are spending too much time searching for parts, paperwork, and supplies.	Over the last 3 months, searching for parts, paperwork, and supplies has consumed 220 FTEs. This 7.1% of total FTEs.	Over the last 3 months, searching for parts, paperwork, and supplies has consumed 220 FTEs. This 7.1% of total FTEs, a cost of $45K per week. These delays have added 3.8 hours to our average lead time.

Problem statement guidelines

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 benefit metrics.

Focus on the "gaps"

Compare the current levels of the project benefit metrics to previous levels, expected levels, or desired levels. Often this is covered in the goal statement.

Problem statement checklist

- ❑ Who is affected by the problem?
- ❑ What is happening?
- ❑ 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?

Example

In 2008 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.

Example (cont'd)

- ❑ Who is affected by the problem?
  Employees directly, the company indirectly
- ❑ What is happening?
  Industrial accidents
- ❑ What are the "gaps"?
  2008 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, loss of productivity
- ❑ Where does the problem occur?
  Site wide
- ❑ When does the problem occur?
- ❑ When did the problem start?
  In 2008

Exercise

Critique this problem statement using the checklist below. The important thing is to identify things that are missing.

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.

Exercise (cont'd)

60

- ❑ Who is affected by the problem?
- ❑ What is happening?
- ❑ 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?

Value stream scope

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Defines the project scope in terms of . . .

- ✓ Products
- ✓ Customers
- ✓ Suppliers
- ✓ Locations
- ✓ Materials

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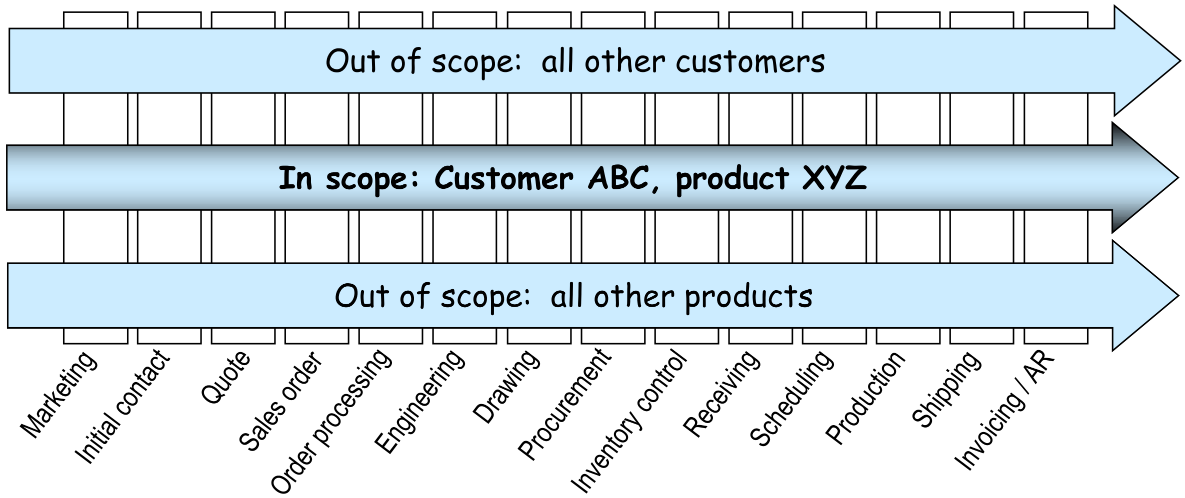
Example


Out of scope: all other customers
In scope: Customer ABC, product XYZ
Out of scope: all other products
Marketing
Initial contact
Quote
Sales order
Order processing
Engineering
Drawing
Procurement
Inventory control
Receiving
Scheduling
Production
Shipping
Invoicing / AR

Example: project to improve tool testing process

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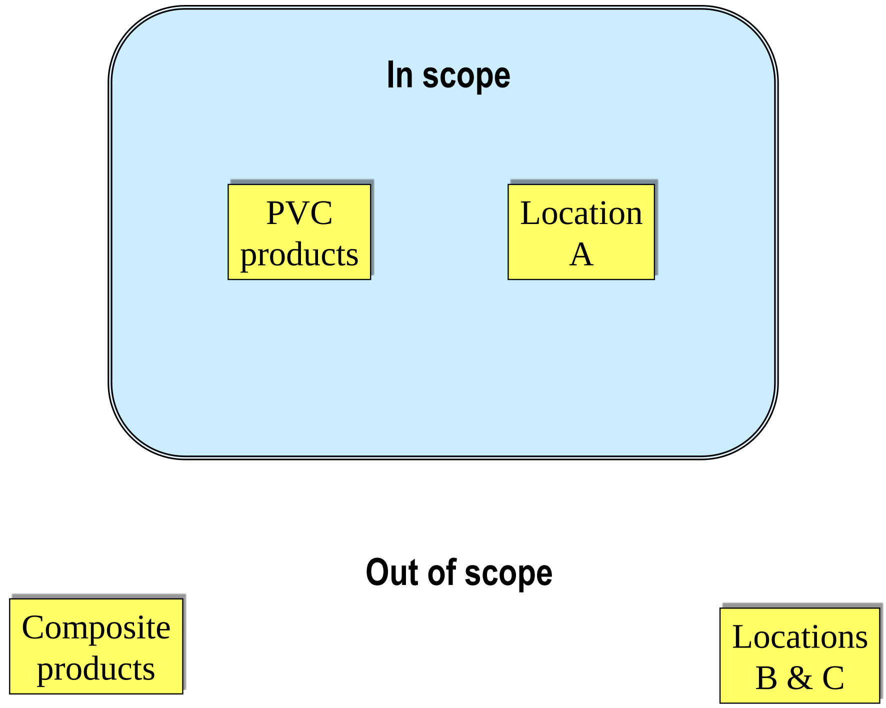

Notes

Exercise

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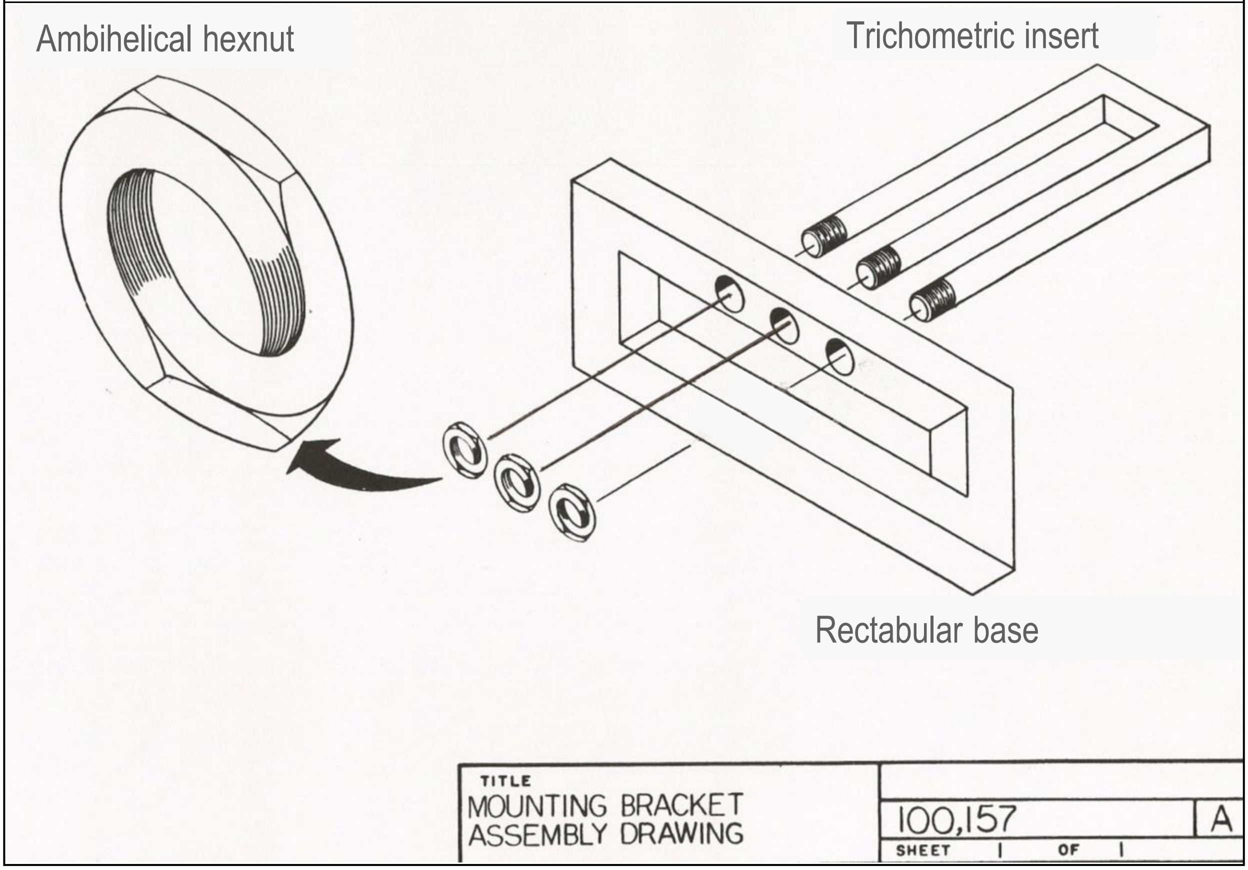
Our company makes prototypes for various types of mounting brackets. A project has been launched to reduce the cycle time for designing and building prototypes for non-standard brackets (see slide below for a typical example). What is the value stream scope for this project?

A non-standard mounting bracket



Workflow scope

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Defines the project scope in terms of . . .

- ✓ Activities
- ✓ Operations
- ✓ Processes
- ✓ Areas
- ✓ Departments

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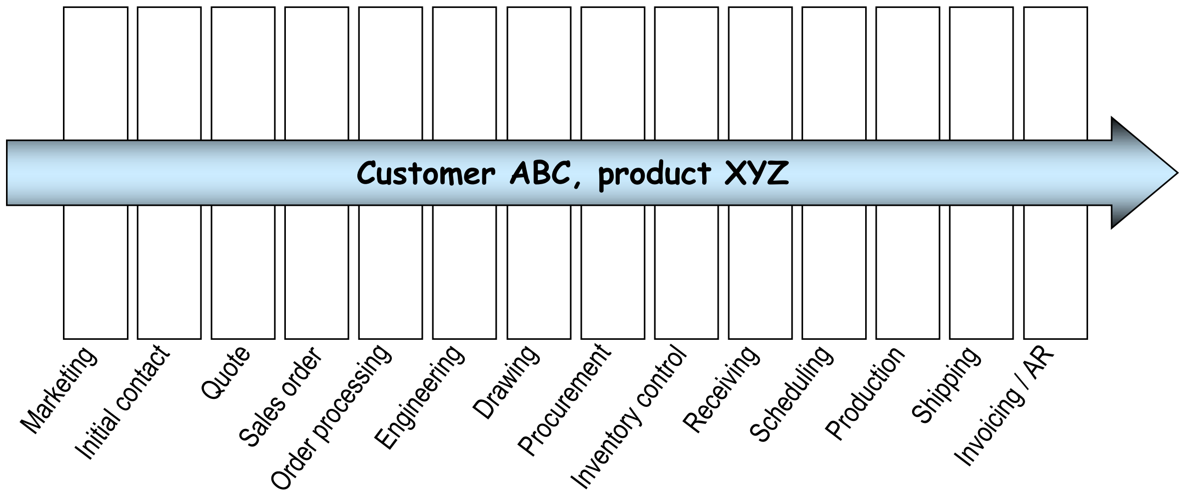
Workflow scope (cont'd)

Suppose we have defined the value stream scope for the project



Workflow scope (cont'd)

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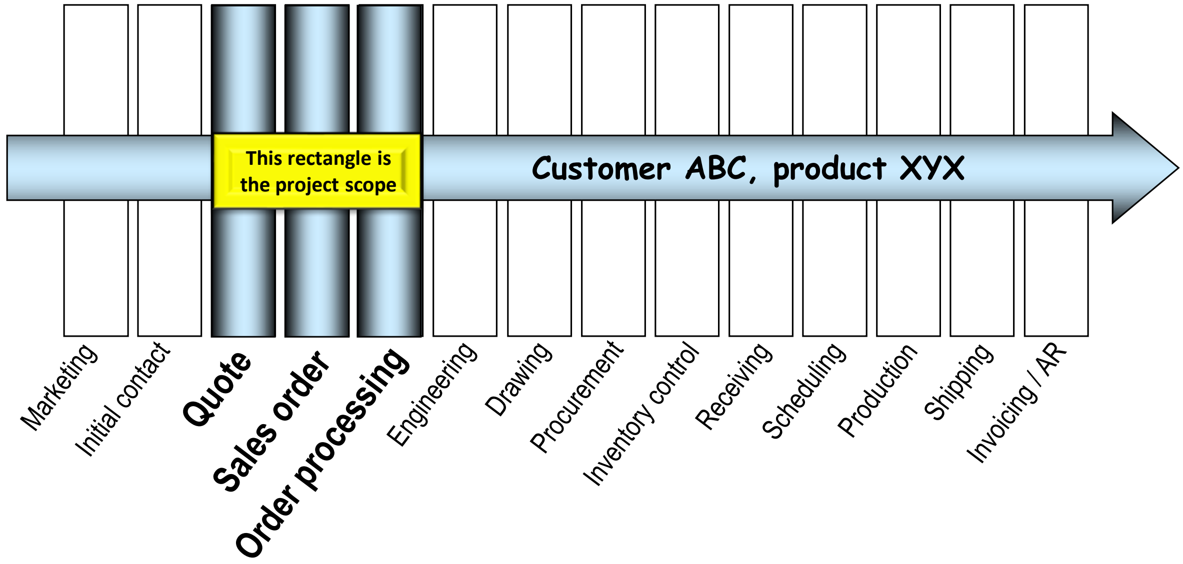
We also have to define the workflow scope



Exercise

Our company makes prototypes for various types of mounting brackets. A project has been launched to reduce the cycle time for designing and building prototypes for non-standard brackets. What is the workflow scope for this project?

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

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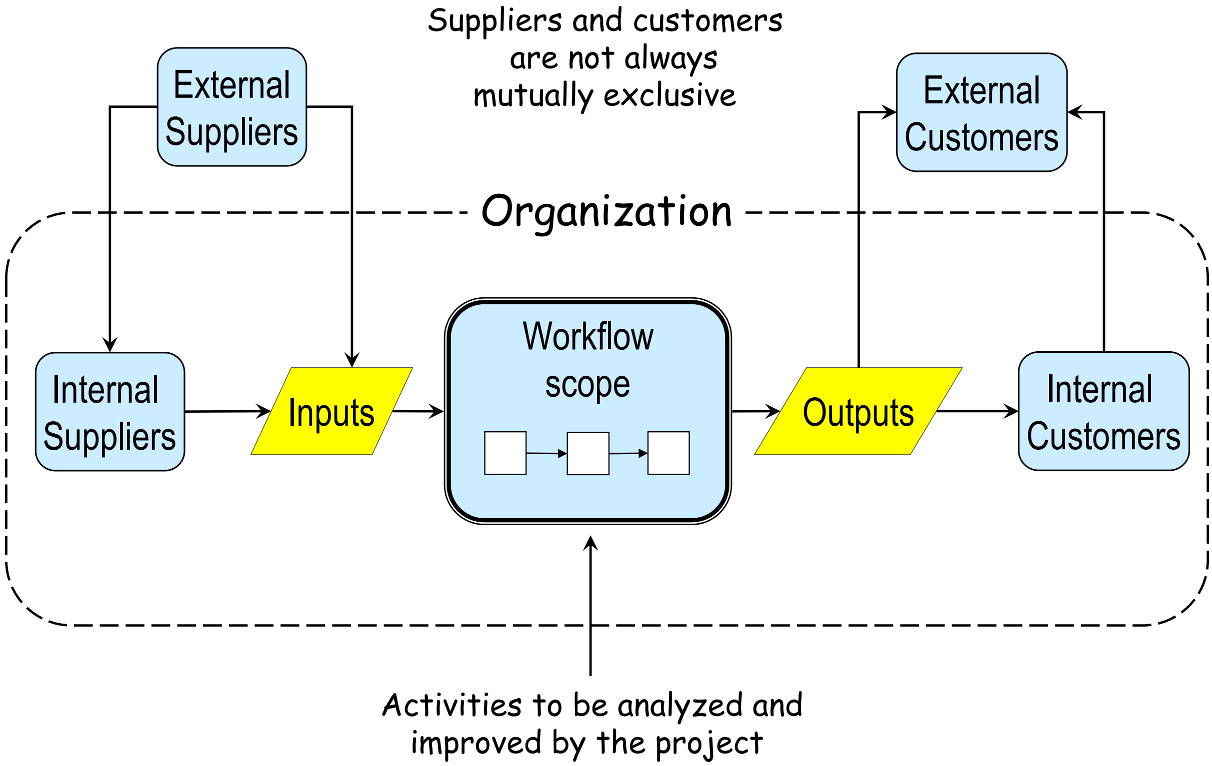
- **Customers** are entities outside the workflow boundaries who receive **outputs** from the workflow
- **Suppliers** are entities outside the workflow boundaries who provide **inputs** to the workflow
- Customers and suppliers are determined by the workflow boundaries
- If we change the boundaries, the customers and suppliers will change

Discussion questions

a) Why is it important to think about the customers of a workflow we want to improve?

b) Why is it important to think about the suppliers to a workflow we want to improve?

Suppliers → Inputs → Process → Outputs → Customers



Exercise

A project has been launched to reduce the cycle ~~lead~~ time for designing and building prototypes for non-standard mounting brackets. Use the information given in the slide below to answer the following questions:

(a) What are the outputs from this workflow?

(b) Who are the customers that receive these outputs?

(c) What are the inputs to this workflow?

(d) Who are the suppliers that provide these inputs?

Exercise (cont’d)

When a customer sends us a purchase order (PO) to design and build a prototype for a non-standard bracket, they provide us with the functional requirements, specifications, a sketch, and desired delivery date. We begin by developing a design specification for the desired bracket. The customer must approve the design specification. If they do, we develop an assembly drawing, which the customer does not have to approve. We build the prototype from the assembly drawing, test it for conformance to the functional requirements and specifications, then ship it to customer.

Sometimes a customer will order a quantity of production parts based on an approved prototype. When this happens, the drawing is released to Manufacturing (MFG).

Project metrics

- Calculated from *statistical data* relevant to project objectives
  - ✓ Averages
  - ✓ Percentages
- Validated *financial calculations* relevant to the project objectives
  - ✓ Annual cost of _____
- Should be linked to *key performance indicators*
  - ✓ Customer satisfaction – quality
  - ✓ Customer satisfaction – delivery
  - ✓ Cost reduction
  - ✓ Revenue increase
  - ✓ Safety . . .

Examples

Project metrics	Baseline	Goal
Annual cost of tool testing	$2.4M	$1.2M
Avg. number of reworks	3	1.5
Avg. order-to-sell time	9 days	4.5 days
Avg. line speed	TBD	TBD
Avg. weight	TBD	95% of customer target

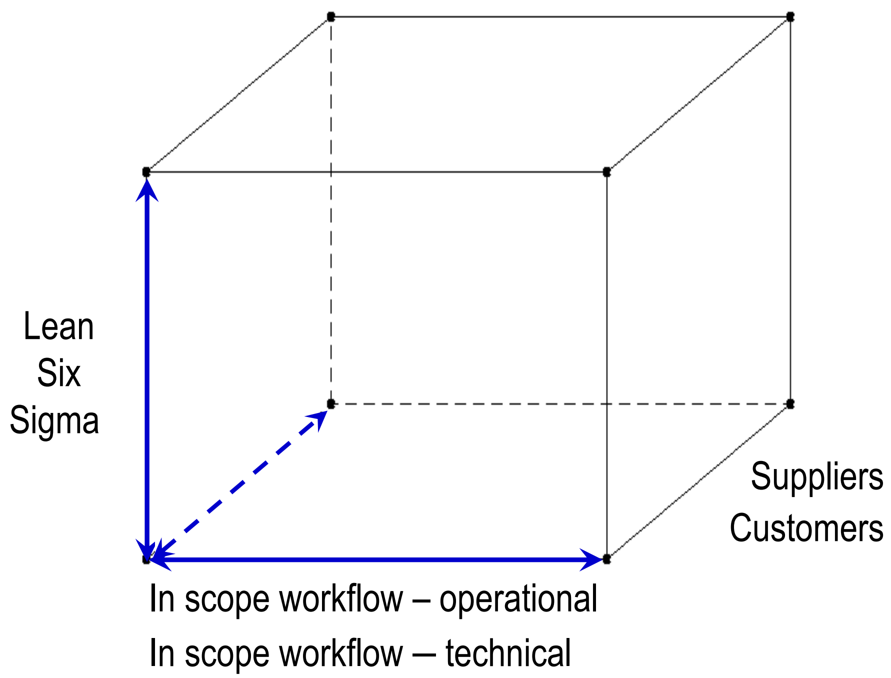
Project metrics	Baseline	Goal
Avg. prototype design time	TBD	50% reduction
% Late prototype deliveries	TBD	50% reduction
Avg. production transition time	TBD	50% reduction
% Late production part deliveries	TBD	50% reduction

Definition of "team"

- A small number of people with complementary skills committed to a common purpose or objective.
- They hold themselves mutually accountable for achieving the objective.
- Coordination of activity among team members is required to achieve the objective.

Team composition

Multiple dimensions of knowledge are needed



Resources

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A project team needs certain things in order to succeed

- Members from the in scope workflow
- Members from internal customers and/or suppliers
- Validated financial calculations
- Data downloads
- A place to have regular meetings
- Coaching on application of LSS methods

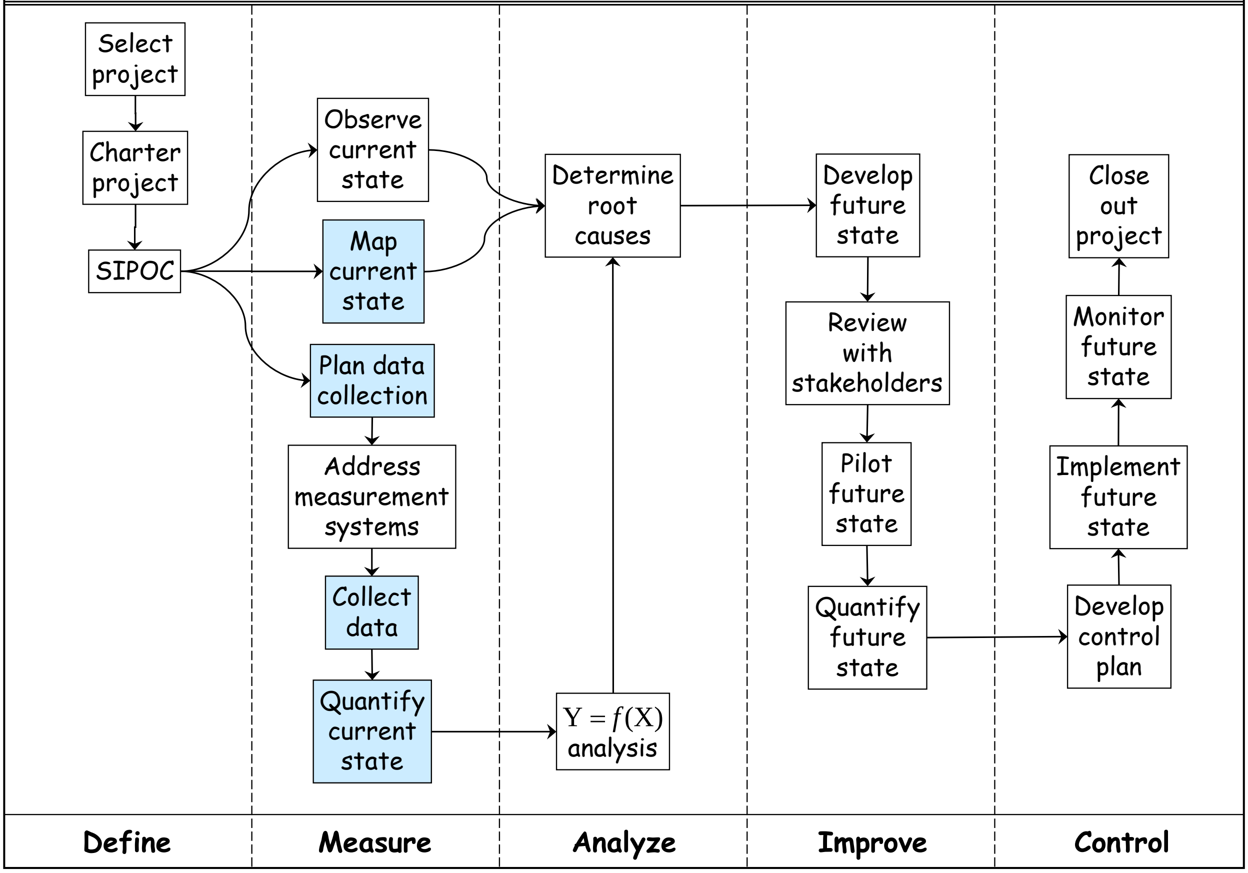
⋮

Resources (cont'd)

A resource is someone who can provide things the team needs

- Project champion
- Area manager or supervisor
- Financial analyst
- IT person
- Facilities
- Master Black Belt

6 Measure Phase of DMAIC



Topics

- Observing the workflow
- Process mapping
- Common mapping formats
- Identifying potential causes
- Planning data collection
- Calculating statistical metrics

Observing the workflow

- Take a guided tour
- Interview workflow participants
- Uncover the “hidden factory”
- Identify opportunities for improvement
- Confirm/revise first-draft process map(s)

Guidelines

- Scope and boundaries should match the project charter
- Workflow participants must have advance notice
- The project and its objectives must be explained (preferably ahead of time)
- The purpose is to gain information related to the project
- Auditing work performance is *not* the purpose — it's a *treasure hunt*, not a witch hunt!
- Try to minimize the "thundering herd" syndrome

Process mapping

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- Appealing, energizing team activity
- Easy to learn, results in useful products
- Graphically documents the in scope workflow – inputs, outputs, sequence and relationship of activities and decisions
- Shows what actually happens, not what should happen
- Identifies opportunities for improvement

Notes

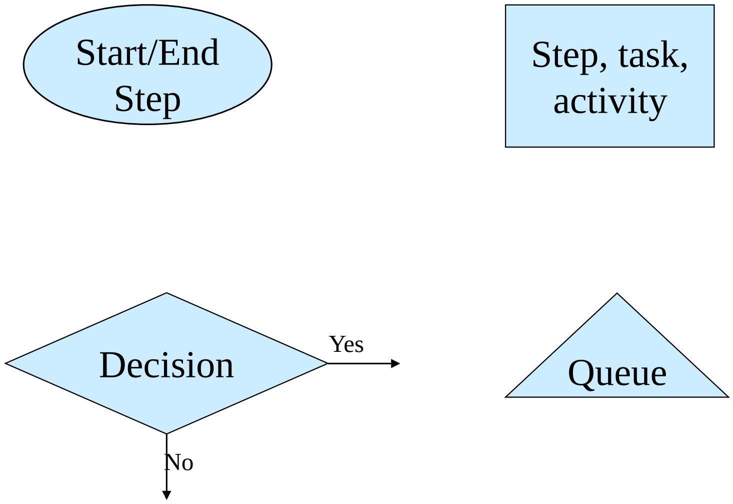
Your project charter should identify the boundaries of your target process. The first, last, and main intermediate steps of the target process give you a *high-level process map*. This is the starting point for *detailed process maps* showing the component tasks and decisions for some or all of the main steps.

We will also look at geographic maps, often called “spaghetti diagrams”, and related “topological” maps.

Mapping as a team activity

Suspend your disbelief	Map the workflow 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 in scope workflow participants, and their internal customers, to review the map for accuracy and clarity.

Standard (basic) process mapping symbols



Writing good narrative

✓ 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

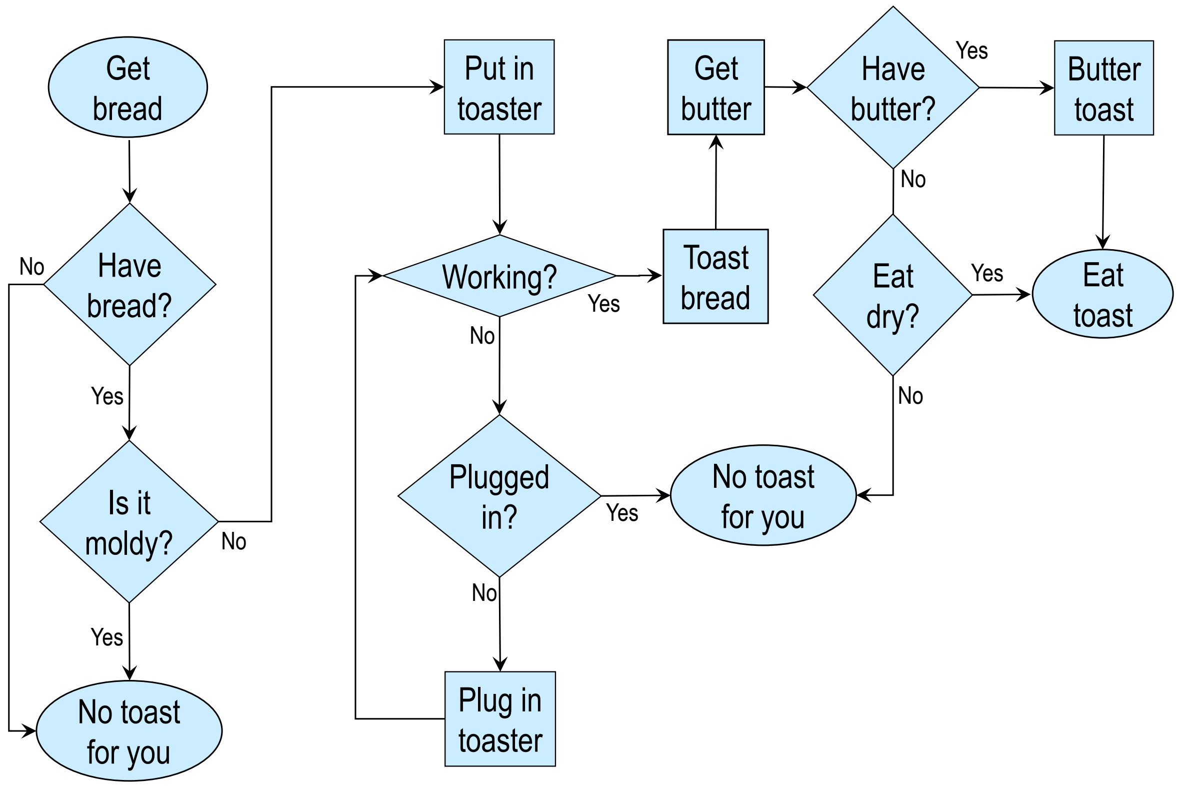
☹ Twilight's last gleaming

☺ Dusk

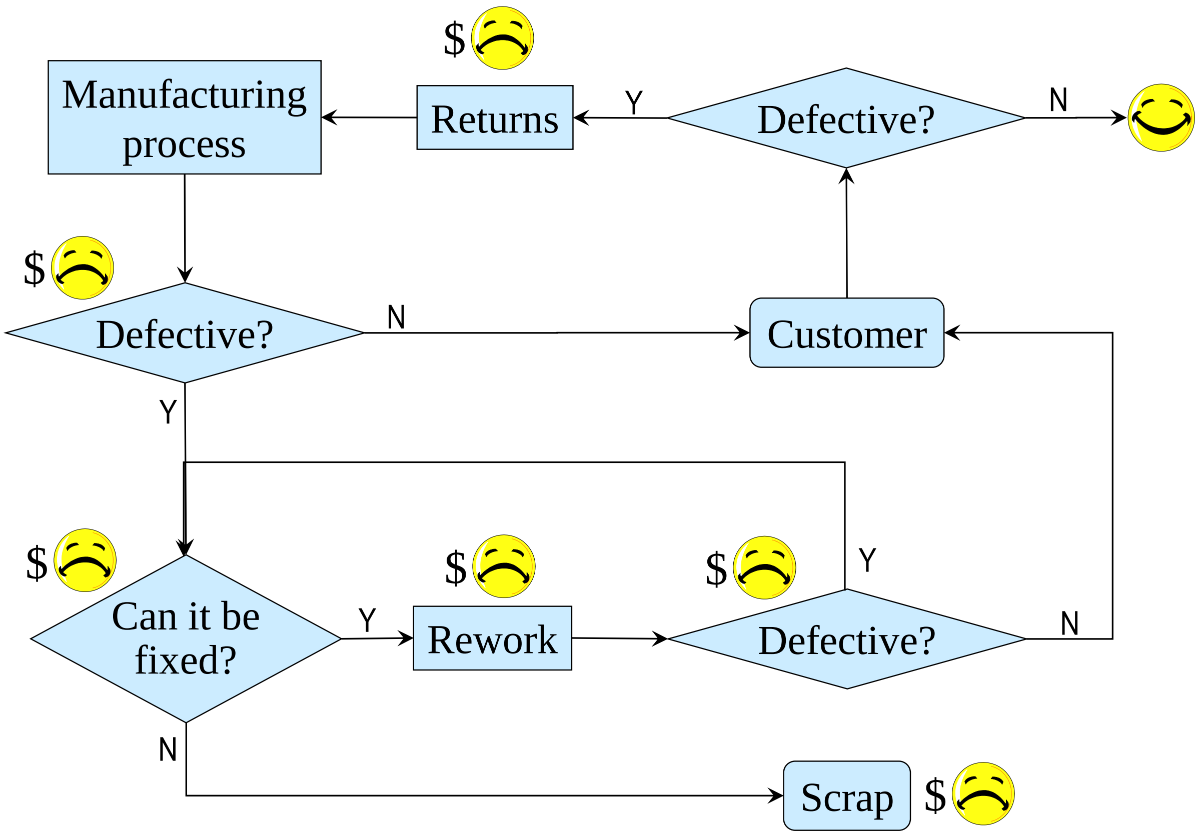
✓ Use present tense

✓ Use logical, consistent layout

Decision steps show what really happens



The “hidden factory”



What about the “hidden office”?

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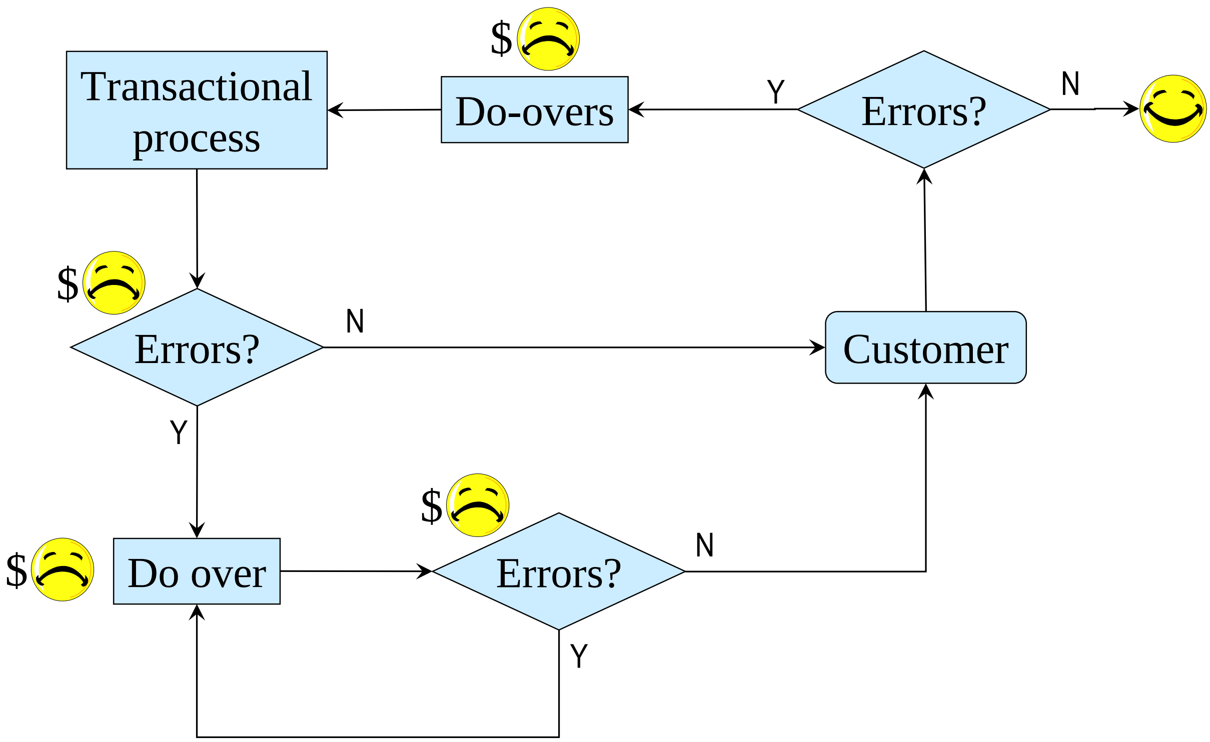
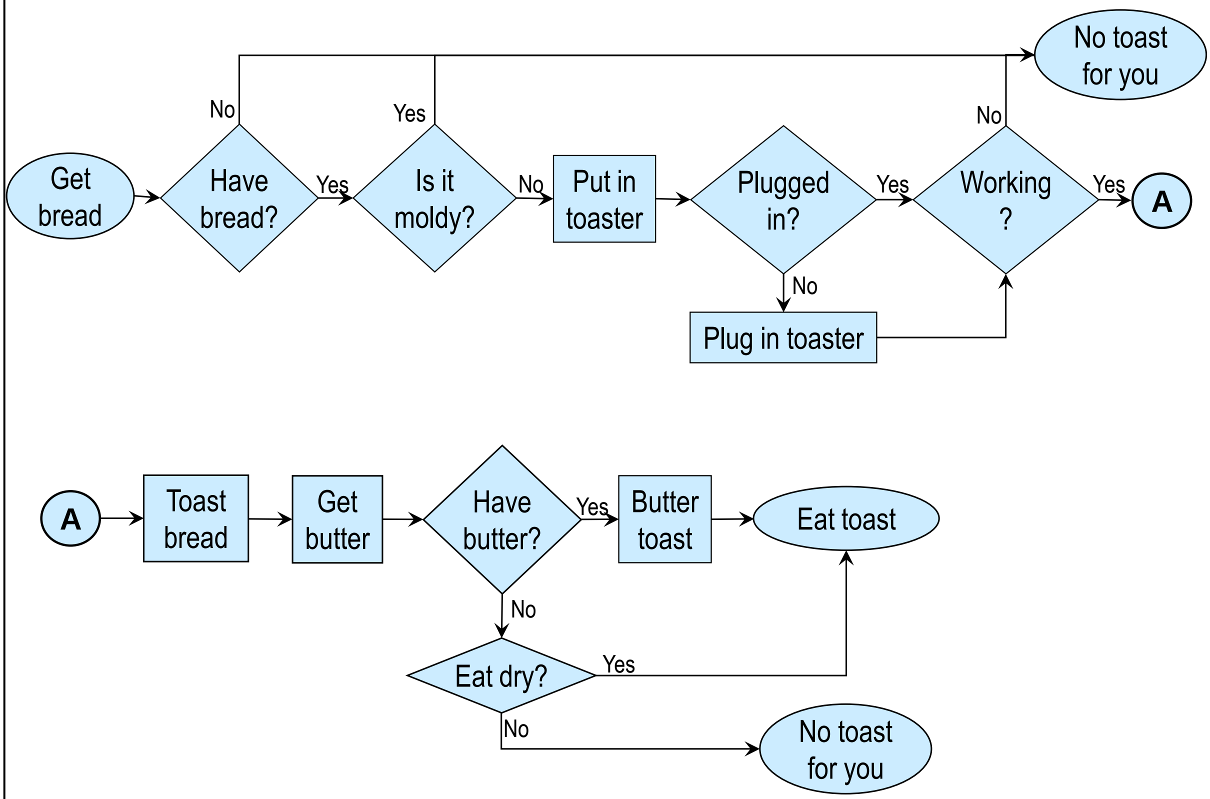
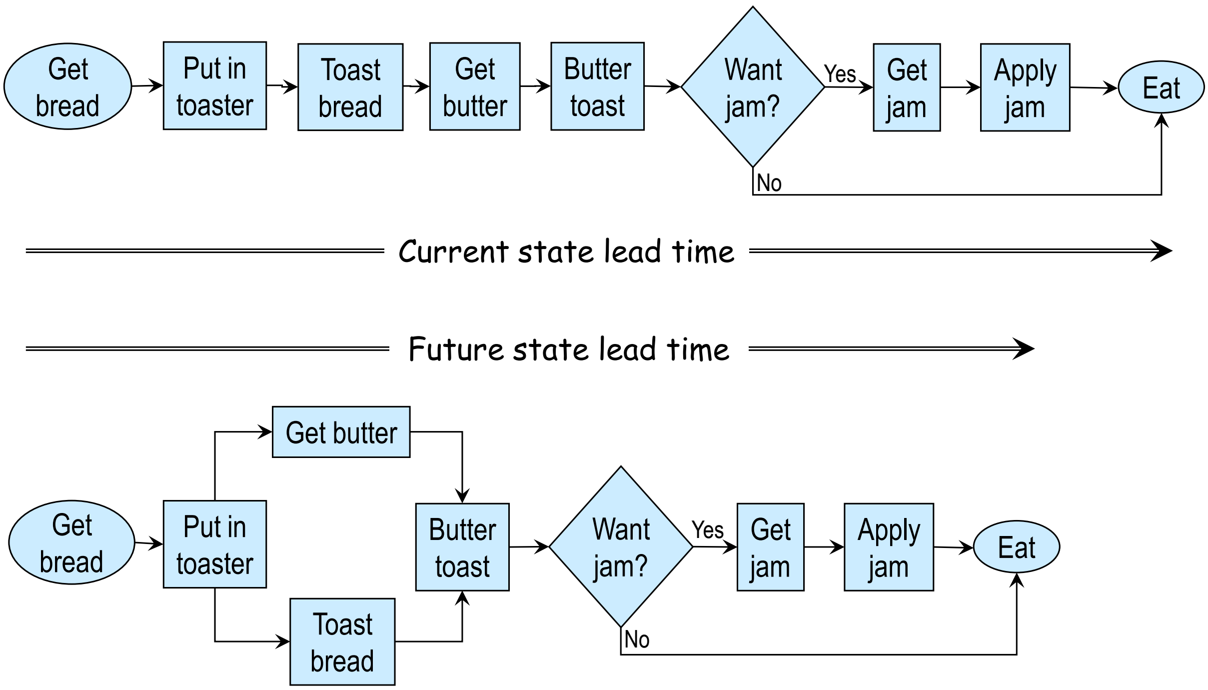


Best practice: follow a qualitative timeline



Parallel activities

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



How could we further reduce lead time for making toast?

Exercise 1

Create a process map based on the information given here. Do not make unwarranted assumptions! Use the blank slide below or a separate sheet of paper.

You have two types of material, A and B. When the need arises, take the material to a processing center. There are two steps in the process. For Process 1, the A and B materials must be processed in separate Type 1 machines. If there are two Type 1 machines available, load the A material into one machine, the B material into another, and run the two machines at the same time. If there is only one machine available, you have to run the two loads sequentially.

When Process 1 is completed, move on to Process 2. Process 2 requires Type 2 machines. If there are two Type 2 machines available, load the A material into one machine, the B material into another, and run the two machines at the same time. If there is only one machine available, you can process the A and B material together in the same machine. 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, organize the material in an orderly configuration, take it back to your original location, and store it for subsequent use.

Exercise 1 (cont'd)

Common mapping formats

- Simple process map
- Swimlane Diagram
- Spaghetti Diagram
- Topological map

A simple process map

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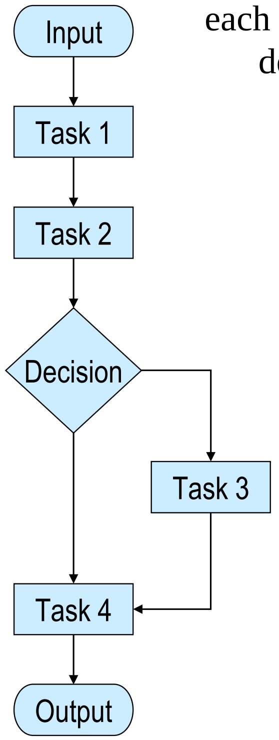


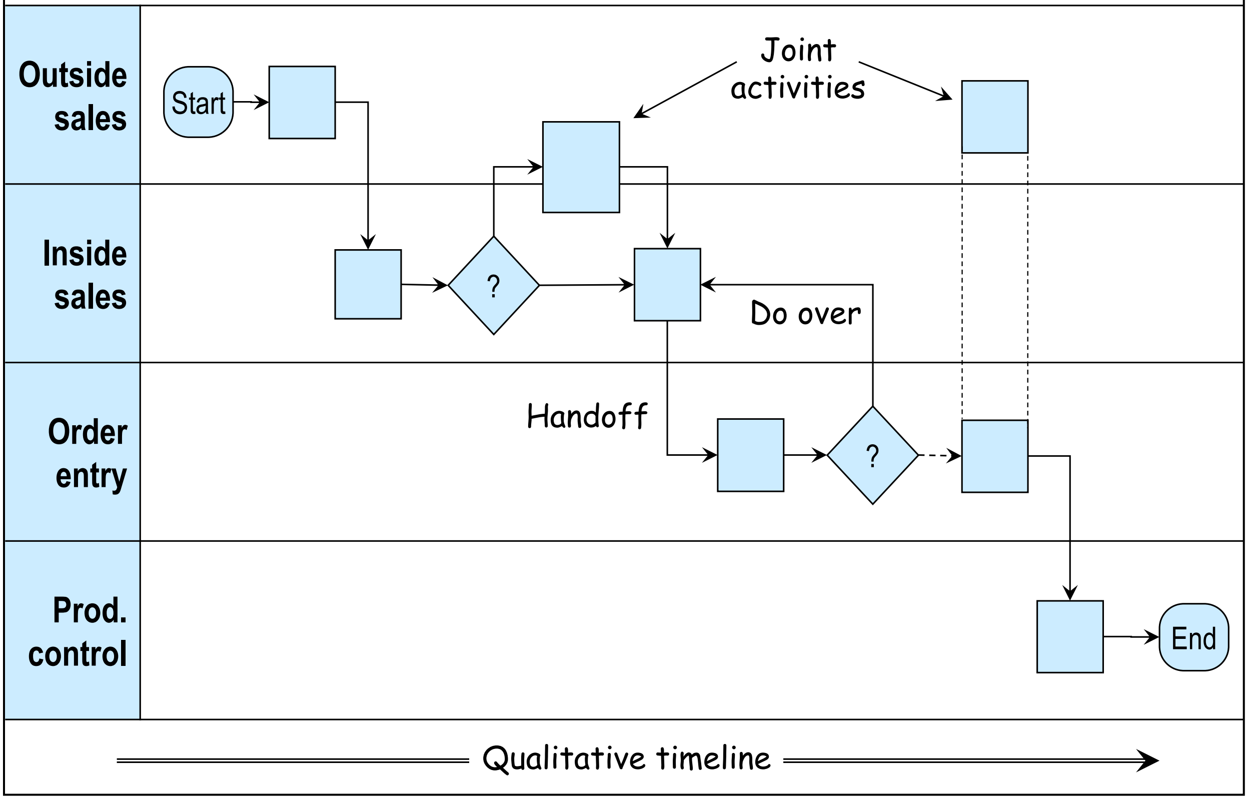
Who is responsible for each activity and decision?

Could make a table:

	Responsible party
Input	
Task 1	
Task 2	
Decision	
Task 3	
Task 4	
Output	

Swimlane Diagram

Also known as *cross-functional map*



Swimlane Diagram (cont'd)

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 draw 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.

Spaghetti Diagram

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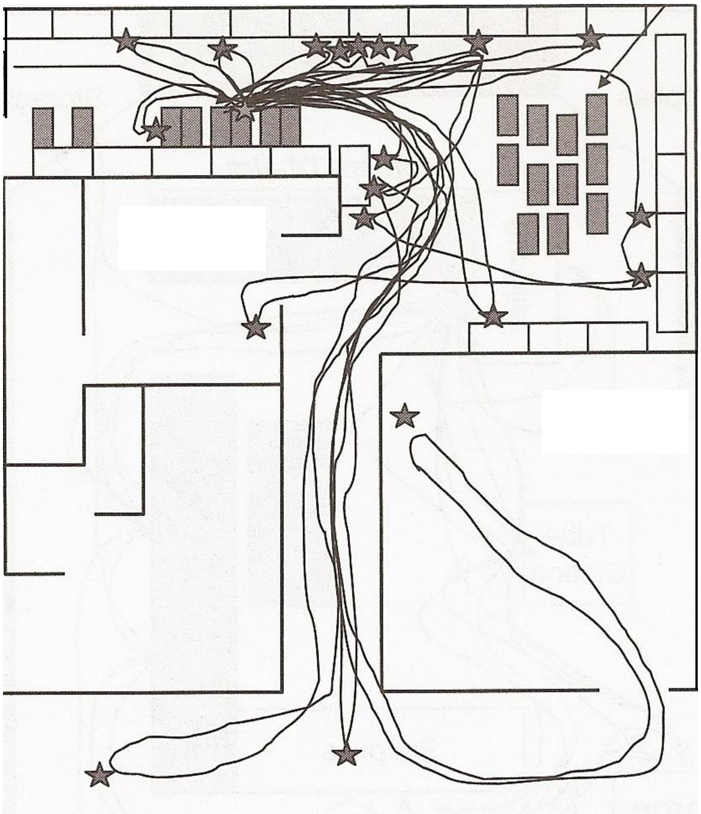
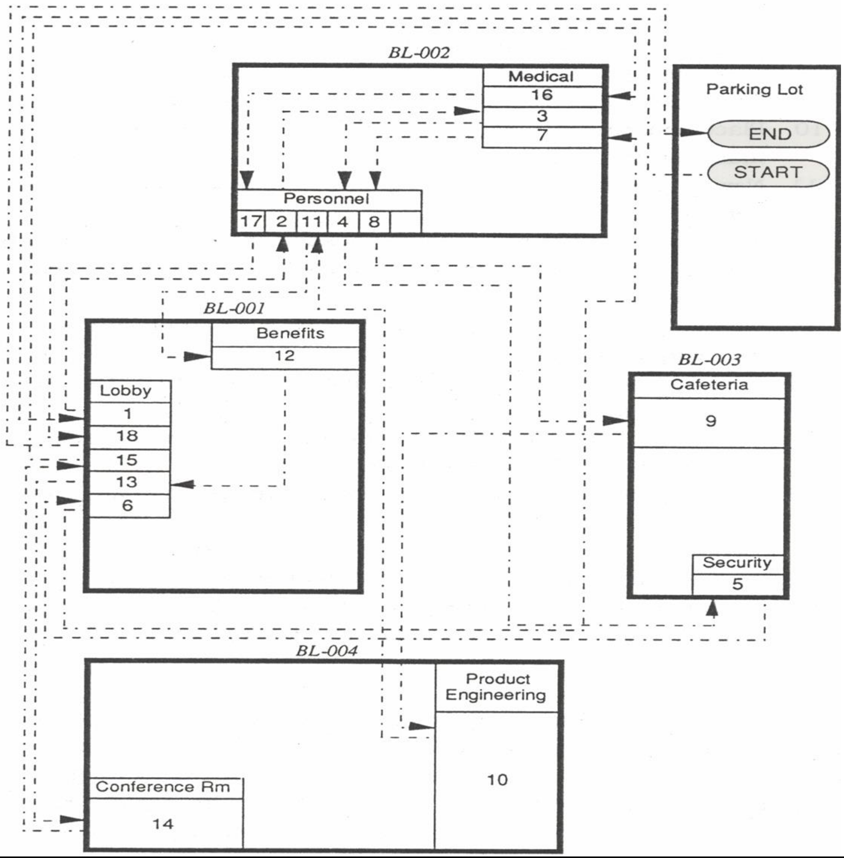
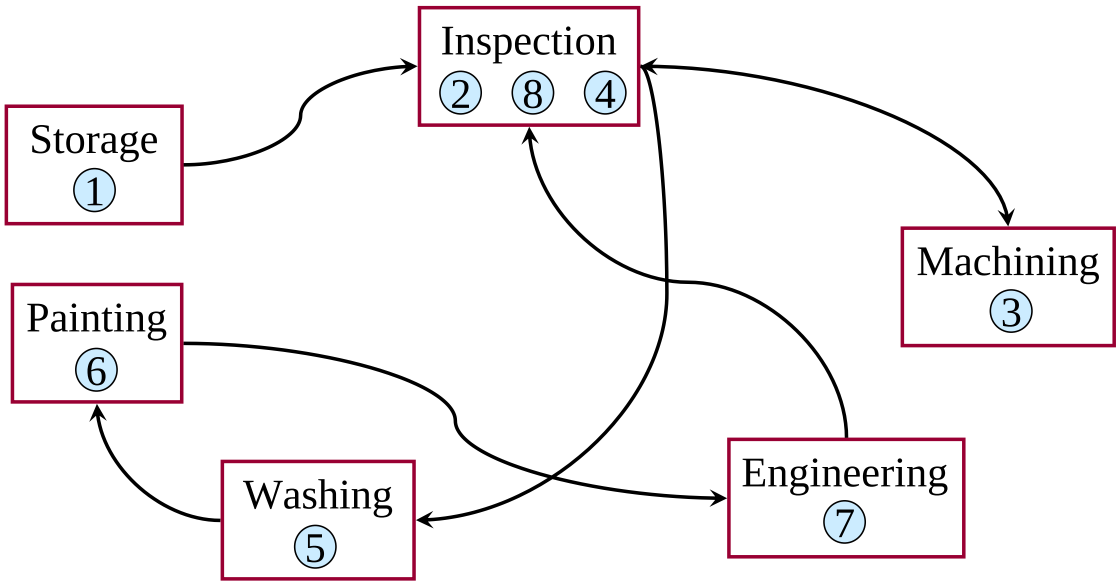


- Most useful in the Analyze Phase
- Requires a floor plan or scale drawing
- Shows typical travel patterns
- Quantify distance travelled
- Also known as a *geographic map*

Large scale spaghetti diagram

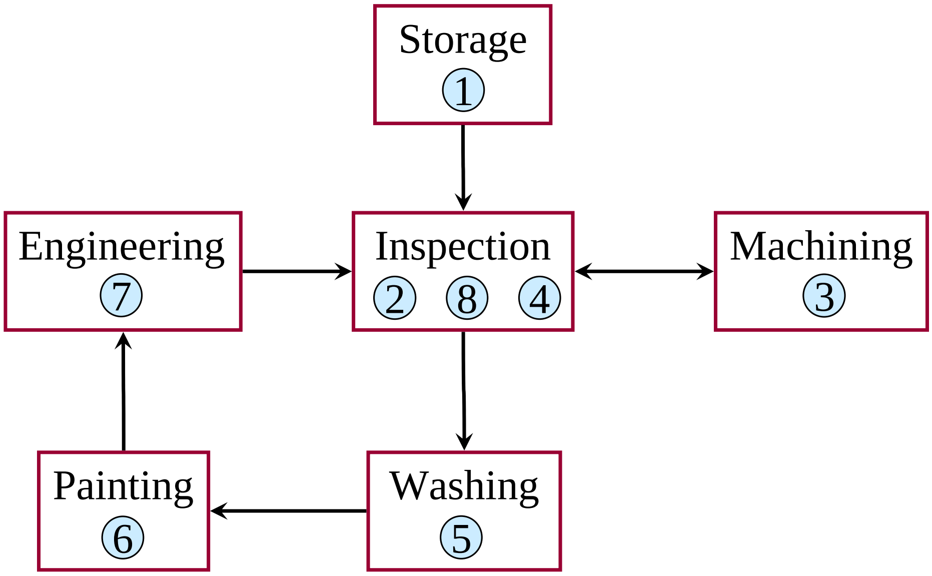


Spaghetti Diagram: current state

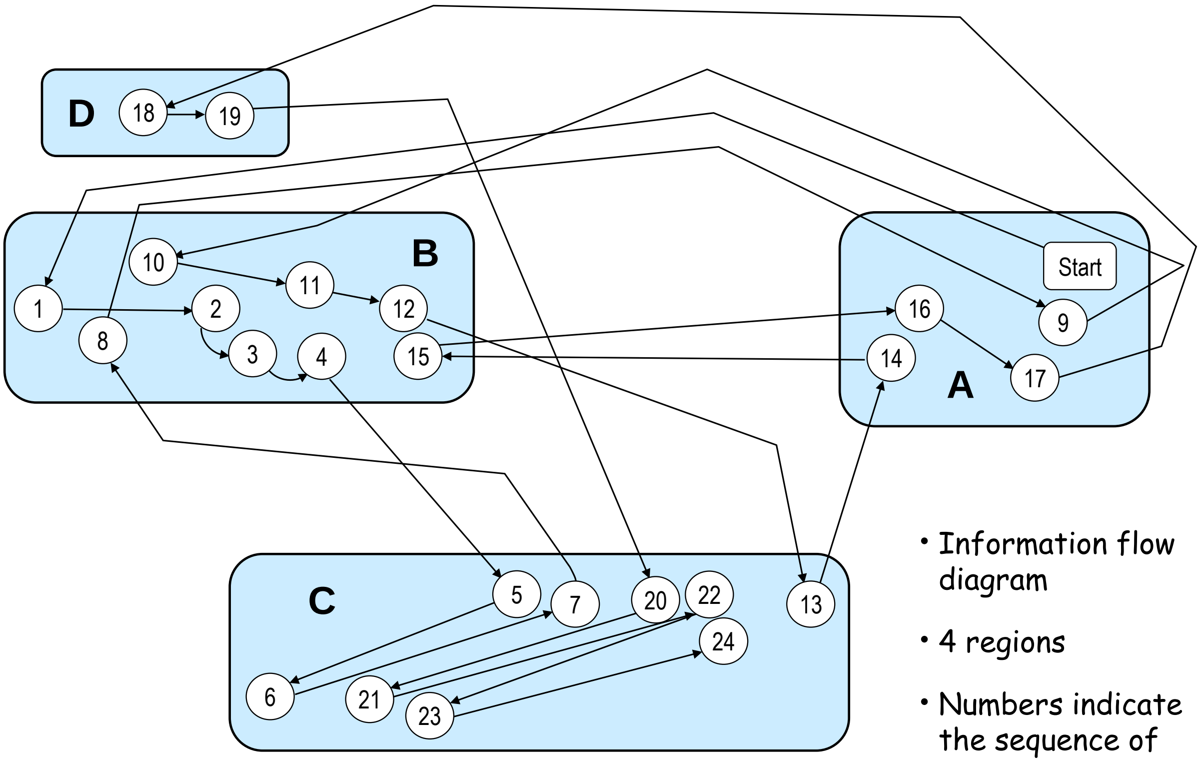


- Too much transport
- Should rearrange to minimize transport

Spaghetti Diagram: future state



Topological map



- Information flow diagram
- 4 regions
- Numbers indicate the sequence of activities

Topological map (cont'd)

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

A topological map is similar to a geographic map, but without the geography. 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.

An example of a topological map is shown above. It shows the information flow among several departments, organizations, or regions. It makes no attempt to depict location or distance. The numbers in the circles indicate the process sequence.

Information flow in swimlane format

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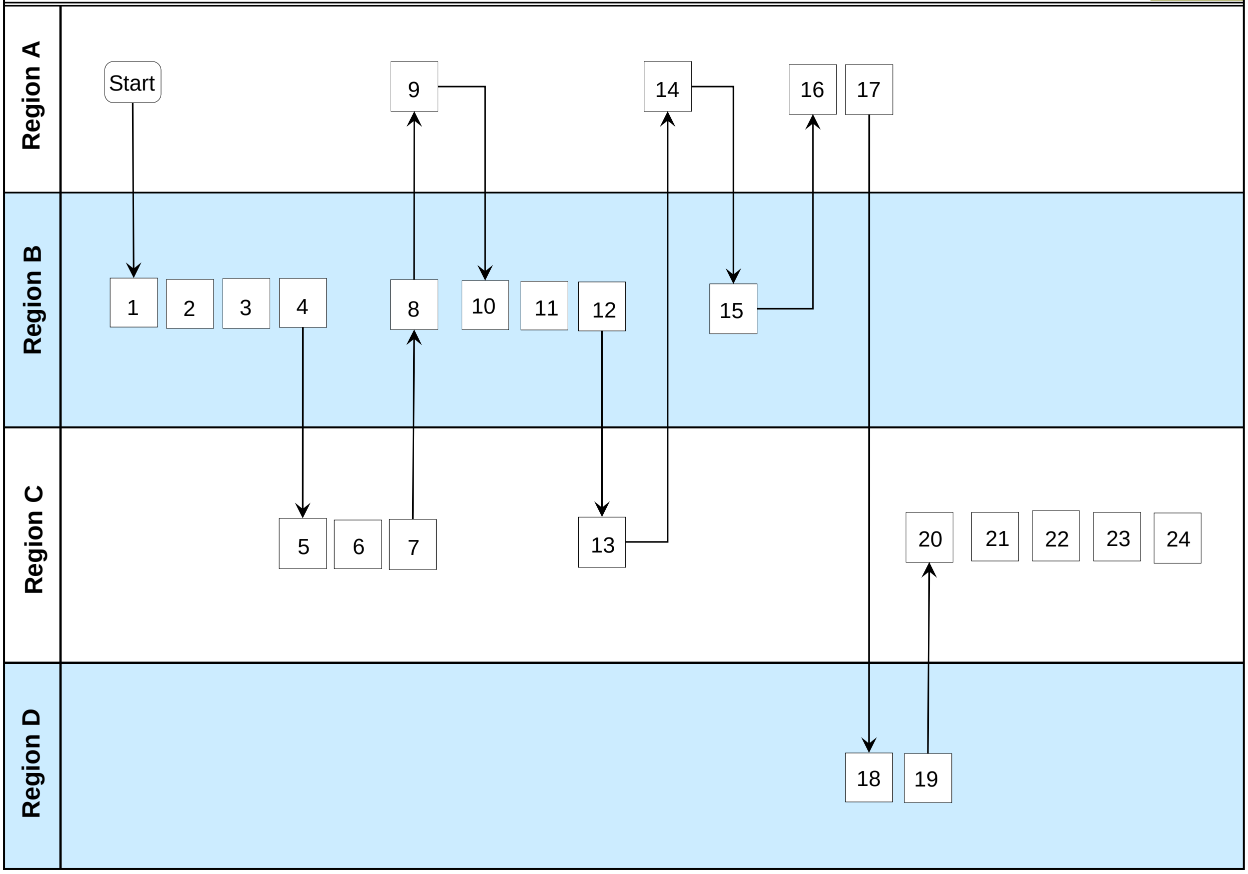

Information flow (cont'd)

- Swimlane map of the same information flow
- Shows the back-and-forth among regions
- Gives a visual representation of the time sequence
- Easy to follow

Exercise 2

The instructor will divide the class into teams. Each team is to create a cross functional process map of the prototype development process described on the next page. The instructor will provide all necessary materials.

Enter swimlanes (departments) as they occur in the narrative. (Make the swimlanes at least two sticky notes wide.) Add a sticky note for each step or decision in the process. Use marker for the text. Use masking tape to attach additional paper if needed. Add flow lines in pencil as you go. Trace flow lines with marker once your map is finished.

Notes

Description of the prototype development process

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When a customer sends Sales a purchase order (PO) to produce a prototype for a non-standard bracket, Sales meets with Product Engineering (PE) to review the functional requirements, specifications, sketch, and desired delivery date. PE creates an initial design specification, then reviews it with the customer. If the customer is not satisfied, PE makes the required changes, then meets with the customer again.

After the customer approves the design spec, copies go to Quality Engineering (QE) and Manufacturing Engineering (ME) for review. If either group has any problems with it, PE makes the required changes, then meets with the customer again. If the customer is happy with the revised design spec, copies go back to QE and ME.

After QE and ME approve the design spec, it goes to Drafting to create an assembly drawing. The first draft goes to PE for review. If PE is not satisfied with the drawing, it goes back to Drafting for revision, then back to PE.

After PE approves the drawing, it goes to QE and ME for review. If either group has any problems with it, it goes back to Drafting to make the required changes. Drafting sends the drawing back to PE for review. If PE is satisfied with the changes, the drawing goes back to QE and ME again.

Prototype development process (cont'd)

After QE and ME approve the drawing, it goes to Proto. This is a special production area, separate from manufacturing, whose purpose is to build prototypes quickly. The Proto operators have a lot of experience, and can build almost anything.

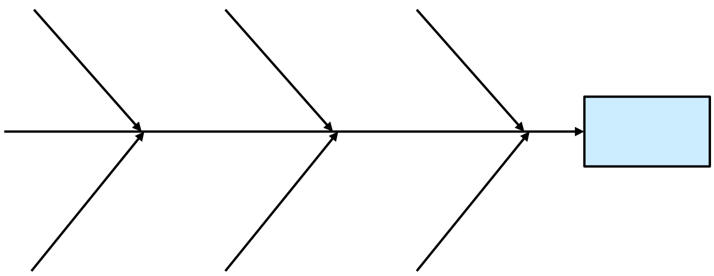
Proto builds the prototype, then tests it for conformance with the functional requirements and specifications. If the prototype passes the tests, PE arranges for it to be shipped to the Customer.

What happens if a prototype fails one or more of the tests? No one on the team seems to know.

Identifying potential causes

The Fishbone Diagram is:

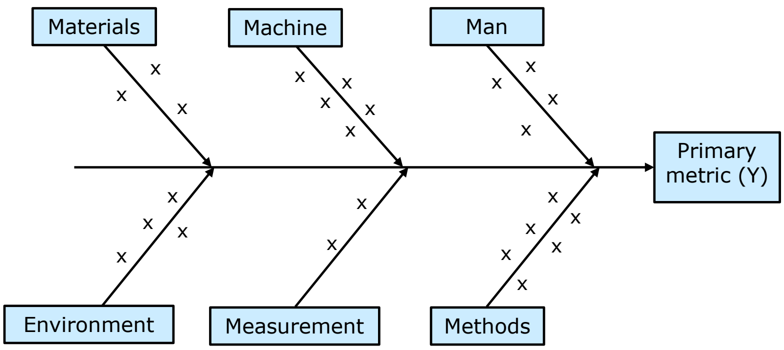
- used to identify all potential causes (X's or inputs) of the effect (output or problem of interest), usually the primary metric.
- part of identifying process inputs during the Measure Phase
- also known as Cause-and-Effect Diagram and Ishikawa Diagram



Fishbone Diagram

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 shown below ("5 M's and an E")
  - Standard (renamed) categories are recommended for first uses of Fishbone Diagrams
  - With experience, different categories can be used

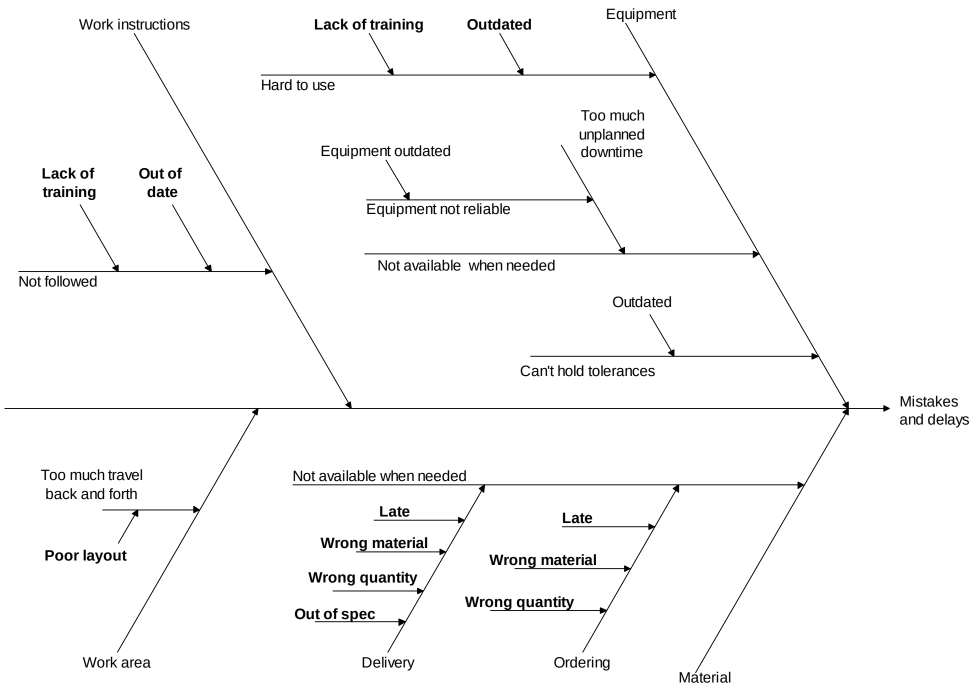


Steps for Creating a Fishbone Diagram

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)



Exercise: Fishbone diagram

A project has been launched to improve the mounting bracket development process (MBDP) in a company that makes mounting brackets.

Based on the process map you created earlier, create a Fishbone Diagram for this project.

Have some fun! Add items from your experience and imagination.

Notes

Planning data collection

- Why do we need data?
- Project metrics and underlying data
- Types of data
- Y variables and X variables
- Operational definitions
- Getting representative data

Why do we need data?

"If you don't measure it, you don't understand it.

If you don't understand it, you can't improve it."

If that doesn't work, try this:

"In God we trust. All others, bring data."

Project metrics and underlying data

Metric	*Data*
Average number of rework cycles	Number of rework cycles for each tool, for some number of tools
Average order to sell time	Order to sell time for each tool, for some number of tools
Average weight of shipments	Weight of each shipment, for some number of shipments
% of shipments exceeding an upper limit	
Average time from purchase order (PO) to prototype delivery (PD)	PO-PD time for each prototype, for some number of prototypes
% PO-PD time exceeding 25 days	

Metrics and data (cont'd)

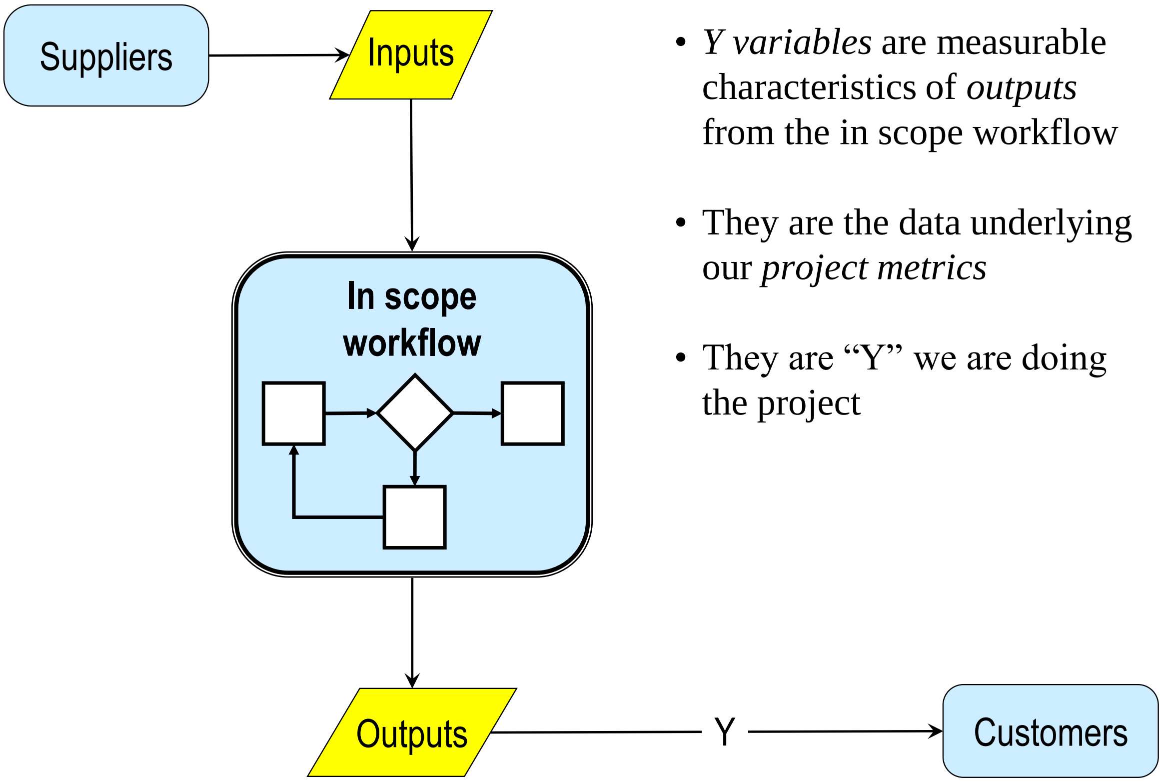
Metric	*Data*
Average lead time	Lead time for each part or transaction, for some number of parts or transactions
% of lead times exceeding an upper limit	
% Defective	Defective (Y/N) for each part, for some number of parts
Average number of errors	Number of errors in each transaction, for some number of transactions
Average bond strength	Strength of each bond, for some number of bonds
% of bond strengths below a lower limit	

Types of data

	Also known as	*Examples*
Quantitative	Measurement Continuous Parameter Variable	Properties (physical/chemical/electrical/optical) Dimensions Distance Time Counts
Categorical	Qualitative Attribute Nominal Ordinal	Pass/fail, failure modes Quality ratings Customer, supplier, product Machine, operator Method, type Batch, lot, work order, serial number Time period

Notes

Y variables



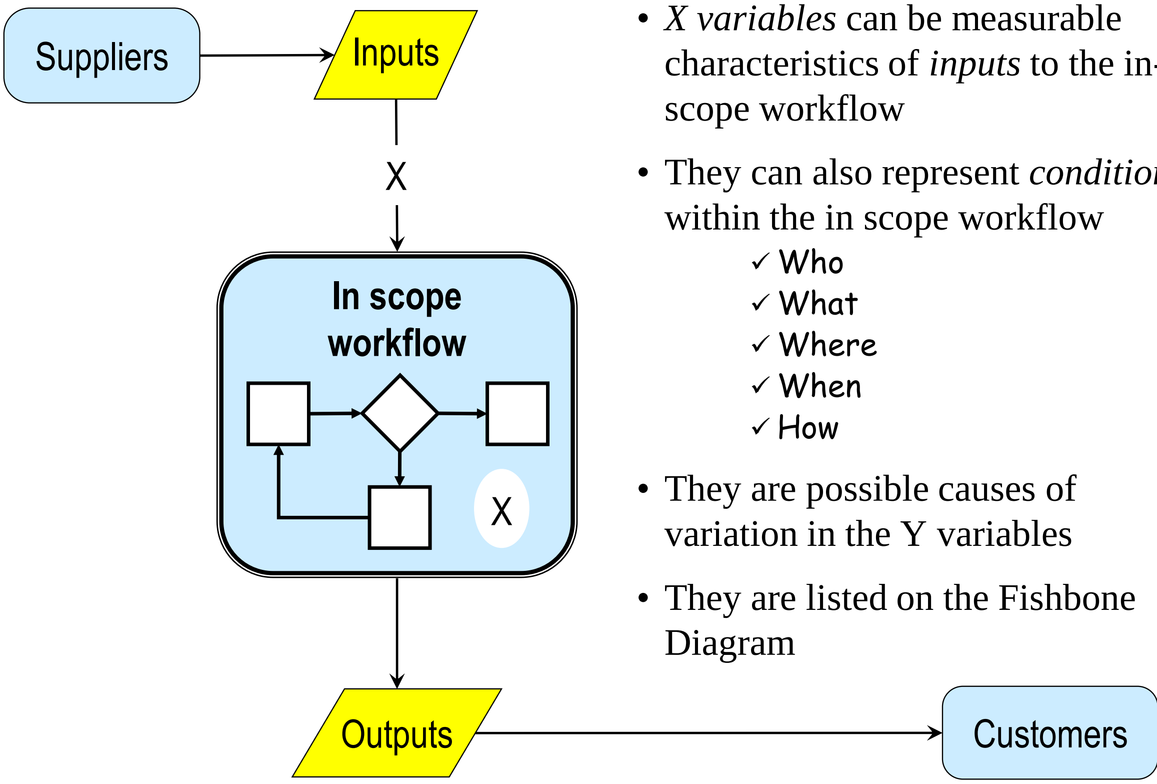
- *Y variables* are measurable characteristics of *outputs* from the in scope workflow
- They are the data underlying our *project metrics*
- They are "Y" we are doing the project

Examples of Y variables

Project Title	Tool Testing Process Improvement
Project Scope	PVC products only, not composite

Process boundaries	Outputs	Y variables	Customers
Starts with a blueprint from external customer defining the desired profile. Ends with an approved tool and run conditions released to manufacturing.	Approved tool	Number of revisions Order to sell time	Manufacturing External customer
	Run conditions	Line speed Weight	Manufacturing
	Samples of extruded product with desired profile	Dimensions Cosmetic quality rating	External customer

X variables



- *X variables* can be measurable characteristics of *inputs* to the in-scope workflow
- They can also represent *conditions* within the in scope workflow
  - ✓ Who
  - ✓ What
  - ✓ Where
  - ✓ When
  - ✓ How
- They are possible causes of variation in the Y variables
- They are listed on the Fishbone Diagram

Examples of X variables

Project Title	Tool Testing Process Improvement
Project Scope	PVC products only, not composite

Suppliers	Inputs	X variables	Workflow boundaries	X variables
External customer	Blueprint	Profile complexity Single or dual orifice Dimensional tolerances	Starts with a blueprint from external customer defining the desired profile. Ends with an approved tool and run conditions released to manufacturing.	Which tester Which machine Material (PVC or composite)
External suppliers	Raw materials	Cost Quality Delivery		

Exercise 4

We want to do a study of automotive performance using the data set below. Which are the Y variables?

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

Notes

Getting representative data

- More data is better than less
- Longer time period is better than shorter
- Try to cover all the *typical sources of variation* (see slide below)
- This usually gives you a representative sample of adequate size

Representative data (cont'd)

Typical sources of variation

People

Equipment

Time of day

Time of week

Time of month

Raw materials

Measurement systems

Locations

.
.
.

Calculating statistical metrics

- Pass/fail data — percent failing

- Quantitative data — average *and* percent failing

Notes

Recording pass/fail data

- Create a data collection form (see example to the right)
- Enter the number of items tested and the number failed for each time period (hourly, for each shift, daily, weekly – whatever makes sense)
- When finished, calculate the column totals
- Divide the total failed by the total tested to get the % failing

Test Date	No. Tested	No. Failed
1-Mar		
2-Mar		
3-Mar		
6-Mar		
7-Mar		
8-Mar		
9-Mar		
10-Mar		
13-Mar		
14-Mar		
15-Mar		
16-Mar		
17-Mar		
20-Mar		
21-Mar		
22-Mar		
23-Mar		
24-Mar		
27-Mar		
28-Mar		
29-Mar		
30-Mar		
31-Mar		
Total		

Analyzing pass/failing data

Test Date	No. Tested	No. Failed
1-Mar	492	59
2-Mar	454	50
3-Mar	228	45
6-Mar	489	117
7-Mar	463	106
8-Mar	432	79
9-Mar	466	80
10-Mar	362	42
13-Mar	433	77
14-Mar	502	155
15-Mar	467	91
16-Mar	572	141
17-Mar	455	109
20-Mar	496	135
21-Mar	533	130
22-Mar	554	166
23-Mar	469	69
24-Mar	467	104
27-Mar	424	73
28-Mar	455	63
29-Mar	461	92
30-Mar	573	113
31-Mar	476	150
Total		

Test Date	No. Tested	No. Failed	
1-Mar	492	59	
2-Mar	454	50	
3-Mar	228	45	
6-Mar	489	117	
7-Mar	463	106	
8-Mar	432	79	
9-Mar	466	80	
10-Mar	362	42	
13-Mar	433	77	
14-Mar	502	155	
15-Mar	467	91	
16-Mar	572	141	
17-Mar	455	109	
20-Mar	496	135	
21-Mar	533	130	
22-Mar	554	166	
23-Mar	469	69	
24-Mar	467	104	
27-Mar	424	73	
28-Mar	455	63	
29-Mar	461	92	
30-Mar	573	113	
31-Mar	476	150	
Total	**10723**	**2246**	**20.9%**

Percent
<u>defective</u>

20.9%

Recording quantitative data

- Create a data collection form (see example shown below)
- Record the value for each time period or part
- Calculate the average value*
- Calculate the percent of values that are too high or too low

		Day		
		1	2	3
Time of day	7:00			
	9:00			
	11:00			
	1:00			
	3:00			
	5:00			
	7:00			

*Add them up, divide by how many there are.

Analyzing quantitative data

		1	2	3
Time of day	**7:00**	1370	1312	1438
	9:00	1462	1405	1506
	11:00	1437	1398	1574
	1:00	1476	1466	1440
	3:00	1389	1406	1372
	5:00	1288	1459	1267
	7:00	1304	1369	1395

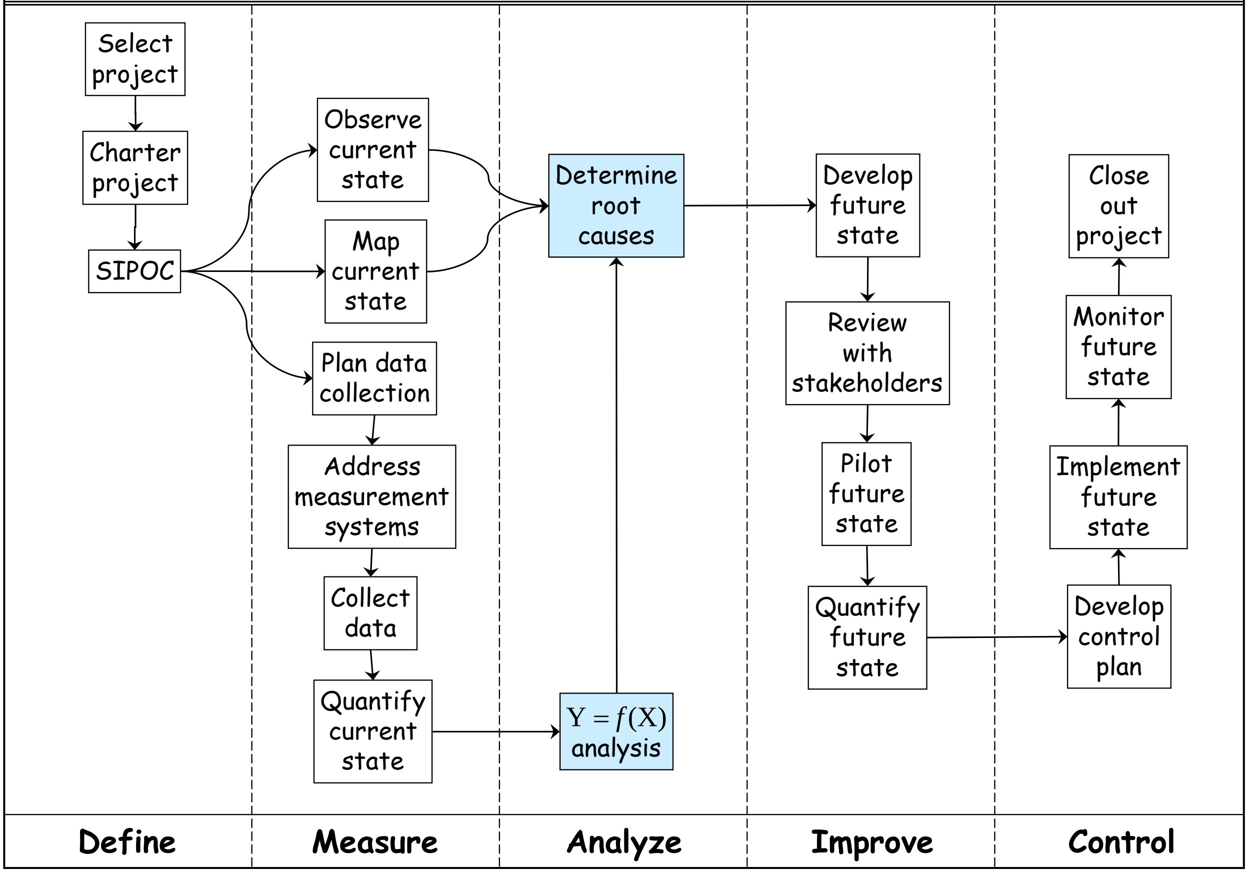
Average = **1406.3**

		1	2	3
Time of day	**7:00**	1370	**1312**	1438
	9:00	1462	1405	1506
	11:00	1437	1398	1574
	1:00	1476	1466	1440
	3:00	1389	1406	1372
	5:00	**1288**	1459	**1267**
	7:00	**1304**	1369	1395

% Defective = **19.0%**

% Below 1350
(4 out of 21 days)

7 Analyze Phase of DMAIC



Topics

- Run chart from pass/fail data
- Pareto chart of failure modes
- Stratification with pass/fail data
- Run chart from quantitative data
- Stratification with quantitative data
- Root cause analysis

Run chart from pass/fail data

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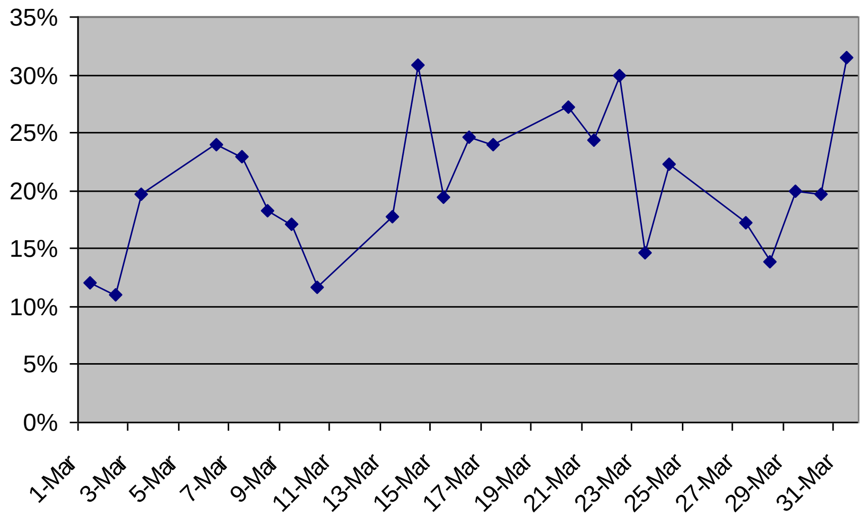
We want to look for a trend in daily failure rates

Test Date	No. Tested	No. Failed	
1-Mar	492	59	
2-Mar	454	50	
3-Mar	228	45	
6-Mar	489	117	
7-Mar	463	106	
8-Mar	432	79	
9-Mar	466	80	
10-Mar	362	42	
13-Mar	433	77	
14-Mar	502	155	
15-Mar	467	91	
16-Mar	572	141	
17-Mar	455	109	
20-Mar	496	135	
21-Mar	533	130	
22-Mar	554	166	
23-Mar	469	69	
24-Mar	467	104	
27-Mar	424	73	
28-Mar	455	63	
29-Mar	461	92	
30-Mar	573	113	
31-Mar	476	150	
Total	**10723**	**2246**	**20.9%**

→

Test Date	No. Tested	No. Failed	
1-Mar	492	59	12.0%
2-Mar	454	50	11.0%
3-Mar	228	45	19.7%
6-Mar	489	117	23.9%
7-Mar	463	106	22.9%
8-Mar	432	79	18.3%
9-Mar	466	80	17.2%
10-Mar	362	42	11.6%
13-Mar	433	77	17.8%
14-Mar	502	155	30.9%
15-Mar	467	91	19.5%
16-Mar	572	141	24.7%
17-Mar	455	109	24.0%
20-Mar	496	135	27.2%
21-Mar	533	130	24.4%
22-Mar	554	166	30.0%
23-Mar	469	69	14.7%
24-Mar	467	104	22.3%
27-Mar	424	73	17.2%
28-Mar	455	63	13.8%
29-Mar	461	92	20.0%
30-Mar	573	113	19.7%
31-Mar	476	150	31.5%
Total	**10723**	**2246**	**20.9%**

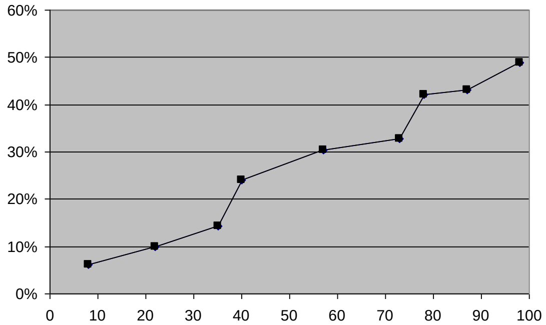
Run chart



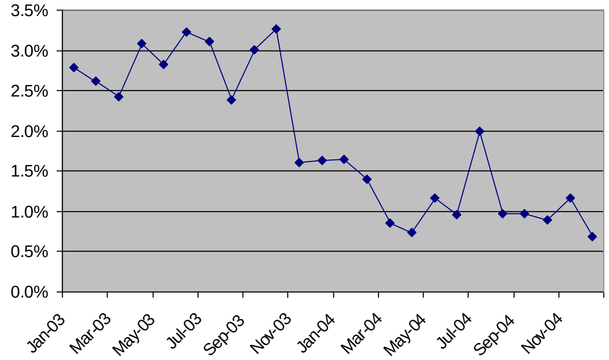
- A very slight upward trend
- Probably not statistically significant

Run chart (cont'd)

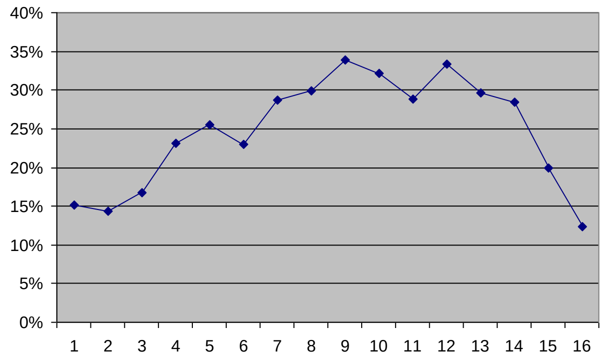
Strong upward trend



Step change



Nonlinear trend



Notes

Pareto chart of failure modes

Daily tally of failure modes

	1-Mar	2-Mar	3-Mar	6-Mar	7-Mar	8-Mar	9-Mar	10-Mar	13-Mar	14-Mar	15-Mar	16-Mar	17-Mar	20-Mar	21-Mar	22-Mar	23-Mar	24-Mar	27-Mar	28-Mar	29-Mar	30-Mar	31-Mar	Total
Ambient too loud														17	4									
Backlight Test	3	1	1						3	4	1	3	2	1		1						3	2	
Backlight&LCDTest	14	10	8	13	12	13	5	6	12	12	12	13	3	18	17	15	16	8	13	12	12	14	17	
BatteryMeasurementCalibration	2	4	4	7	4	3	3	1	8	10	2	10	5	10	11	14	5	9	8	10	9	11	15	
Beeper not loud enough											2			3	27								1	
BeeperTest				4	3	1	3		1				1						2		1	1	2	
CommunicationsTest	3	2	7	22	11	3	19	6	6	20	7	4	1		1	3			3	5	11	11	8	
Display Test			3	1	3	4			1		1	1		6		1						2		
Event Log Size		1											2	1	1	1			1			1	1	
FinalConfig	1		2	5	2	7	7		2	2	3					2	2				4	3	1	
Operating current out of range	9	7	1	14	13	10	5		2	2	3		1	7	4			1	4		4	2	10	
OperatingCurrentTest	1	8	3	15	5	10	4	5	2	3	8	4	5	3	13	14	11	10	7	5	5	8	6	
POSTTest		1			4		3		2	3	1	1	1	3	1	3	2	2	1			2	5	
SetSerialNumber&ModelSettings				1																				
Sleep current out of range	4	2	1	14	24	21	10	6	30	70	43	90	60	41	41	92	25	55	17	15	29	37	57	
SureTempPlusTest	5	9	2	1	5	1		9		18	5	3	8	6	7	12	5	16	14	7	8	16	11	
SwitchTest	17	5	12	20	20	6	21	7	7	10	3	12	15	19	3	6	3	3	3	8	8	2	14	
RepeatabilityAccuracyTest			1					2	1	1			5			2				1	1			

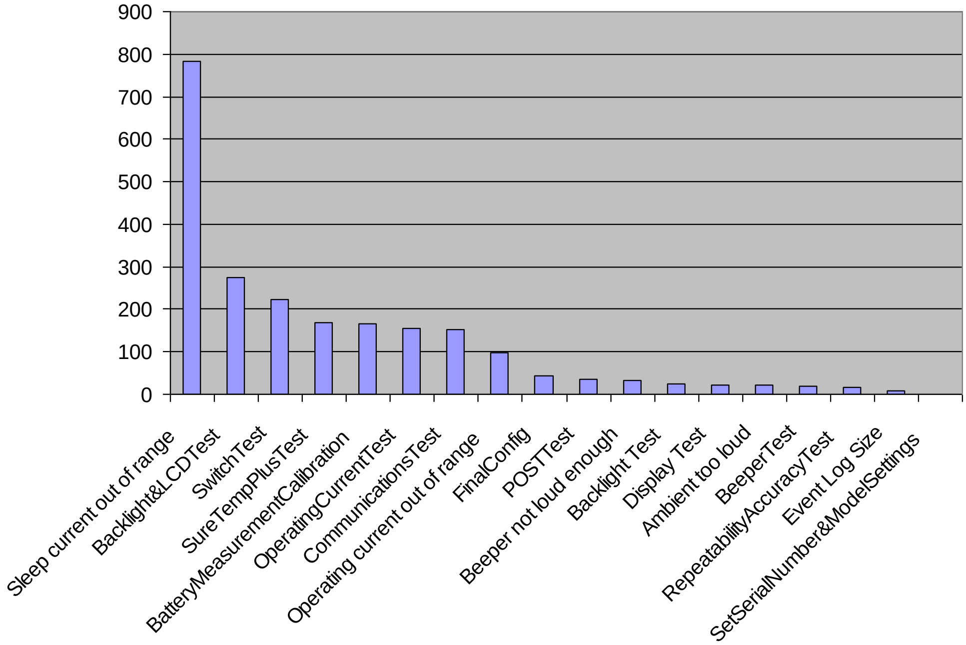
Pareto chart (cont'd)

Failure modes with totals

	1-Mar	2-Mar	3-Mar	6-Mar	7-Mar	8-Mar	9-Mar	10-Mar	13-Mar	14-Mar	15-Mar	16-Mar	17-Mar	20-Mar	21-Mar	22-Mar	23-Mar	24-Mar	27-Mar	28-Mar	29-Mar	30-Mar	31-Mar	Total
Ambient too loud														17	4									21
Backlight Test	3	1	1						3	4	1	3	2	1		1						3	2	25
Backlight&LCDTest	14	10	8	13	12	13	5	6	12	12	12	13	3	18	17	15	16	8	13	12	12	14	17	275
BatteryMeasurementCalibration	2	4	4	7	4	3	3	1	8	10	2	10	5	10	11	14	5	9	8	10	9	11	15	165
Beeper not loud enough											2			3	27								1	33
BeeperTest				4	3	1	3		1				1						2		1	1	2	19
CommunicationsTest	3	2	7	22	11	3	19	6	6	20	7	4	1		1	3			3	5	11	11	8	153
Display Test			3	1	3	4			1		1	1		6		1						2		23
Event Log Size		1											2	1	1	1			1			1	1	9
FinalConfig	1		2	5	2	7	7		2	2	3					2	2				4	3	1	43
Operating current out of range	9	7	1	14	13	10	5		2	2	3		1	7	4			1	4		4	2	10	99
OperatingCurrentTest	1	8	3	15	5	10	4	5	2	3	8	4	5	3	13	14	11	10	7	5	5	8	6	155
POSTTest		1			4		3		2	3	1	1	1	3	1	3	2	2	1			2	5	35
SetSerialNumber&ModelSettings				1																				1
Sleep current out of range	4	2	1	14	24	21	10	6	30	70	43	90	60	41	41	92	25	55	17	15	29	37	57	784
SureTempPlusTest	5	9	2	1	5	1		9		18	5	3	8	6	7	12	5	16	14	7	8	16	11	168
SwitchTest	17	5	12	20	20	6	21	7	7	10	3	12	15	19	3	6	3	3	3	8	8	2	14	224
RepeatabilityAccuracyTest			1					2	1	1			5			2				1	1			14

Pareto chart (cont'd)

Main problem is "sleep current out of range"



Which failure mode is the biggest problem?

Whenever possible, you should also make a Pareto of the *costs* associated with the failure modes.

Stratification with pass/fail data

	Model 690		Model 692	
Date	Tested	Failed	Tested	Failed
1-Mar	166	12	326	47
2-Mar	347	36	107	14
3-Mar	111	21	117	24
6-Mar	289	76	200	41
7-Mar	220	62	243	44
8-Mar	330	63	102	16
9-Mar	288	56	178	24
10-Mar	283	32	79	10
13-Mar	268	44	165	33
14-Mar	158	52	344	103
15-Mar	179	36	288	55
16-Mar	329	81	243	60
17-Mar	220	37	235	72
20-Mar	280	61	216	74
21-Mar	293	57	240	73
22-Mar	273	64	281	102
23-Mar	181	21	288	48
24-Mar	198	46	269	58
27-Mar	187	31	237	42
28-Mar	219	35	236	28
29-Mar	257	60	204	32
30-Mar	414	86	159	27
31-Mar	233	59	243	91

	Model 690		Model 692	
Date	Tested	Failed	Tested	Failed
1-Mar	166	12	326	47
2-Mar	347	36	107	14
3-Mar	111	21	117	24
6-Mar	289	76	200	41
7-Mar	220	62	243	44
8-Mar	330	63	102	16
9-Mar	288	56	178	24
10-Mar	283	32	79	10
13-Mar	268	44	165	33
14-Mar	158	52	344	103
15-Mar	179	36	288	55
16-Mar	329	81	243	60
17-Mar	220	37	235	72
20-Mar	280	61	216	74
21-Mar	293	57	240	73
22-Mar	273	64	281	102
23-Mar	181	21	288	48
24-Mar	198	46	269	58
27-Mar	187	31	237	42
28-Mar	219	35	236	28
29-Mar	257	60	204	32
30-Mar	414	86	159	27
31-Mar	233	59	243	91
	5723	**1128**	**5000**	**1118**
		19.7%		**22.4%**

- Model 692 has a higher failure rate than 690
- There are larger differences among the 3 testers (see next slide)

Stratification (cont'd)

	Tester 1		Tester 2		Tester 3	
Date	Tested	Failed	Tested	Failed	Tested	Failed
1-Mar	142	13	183	34	167	12
2-Mar	155	20	168	12	131	18
3-Mar	87	10	73	17	68	18
6-Mar	184	42	153	33	152	42
7-Mar	159	25	164	29	140	52
8-Mar	196	37	177	29	59	13
9-Mar	137	12	203	33	126	35
10-Mar	132	15	170	22	60	5
13-Mar	114	22	189	25	130	30
14-Mar	166	54	198	65	138	36
15-Mar	148	32	176	35	143	24
16-Mar	185	50	221	48	166	43
17-Mar	181	54	115	26	159	29
20-Mar	162	33	148	39	186	63
21-Mar	165	25	187	41	181	64
22-Mar	198	41	176	49	180	76
23-Mar	181	21	146	21	142	27
24-Mar	199	45	145	25	123	34
27-Mar	192	31	106	21	126	21
28-Mar	167	33	139	10	149	20
29-Mar	113	28	189	37	159	27
30-Mar	213	52	199	33	161	28
31-Mar	175	37	133	24	168	89

	Tester 1		Tester 2		Tester 3	
Date	Tested	Failed	Tested	Failed	Tested	Failed
1-Mar	142	13	183	34	167	12
2-Mar	155	20	168	12	131	18
3-Mar	87	10	73	17	68	18
6-Mar	184	42	153	33	152	42
7-Mar	159	25	164	29	140	52
8-Mar	196	37	177	29	59	13
9-Mar	137	12	203	33	126	35
10-Mar	132	15	170	22	60	5
13-Mar	114	22	189	25	130	30
14-Mar	166	54	198	65	138	36
15-Mar	148	32	176	35	143	24
16-Mar	185	50	221	48	166	43
17-Mar	181	54	115	26	159	29
20-Mar	162	33	148	39	186	63
21-Mar	165	25	187	41	181	64
22-Mar	198	41	176	49	180	76
23-Mar	181	21	146	21	142	27
24-Mar	199	45	145	25	123	34
27-Mar	192	31	106	21	126	21
28-Mar	167	33	139	10	149	20
29-Mar	113	28	189	37	159	27
30-Mar	213	52	199	33	161	28
31-Mar	175	37	133	24	168	89
	3751	**732**	**3758**	**708**	**3214**	**806**
		19.5%		**18.8%**		**25.1%**

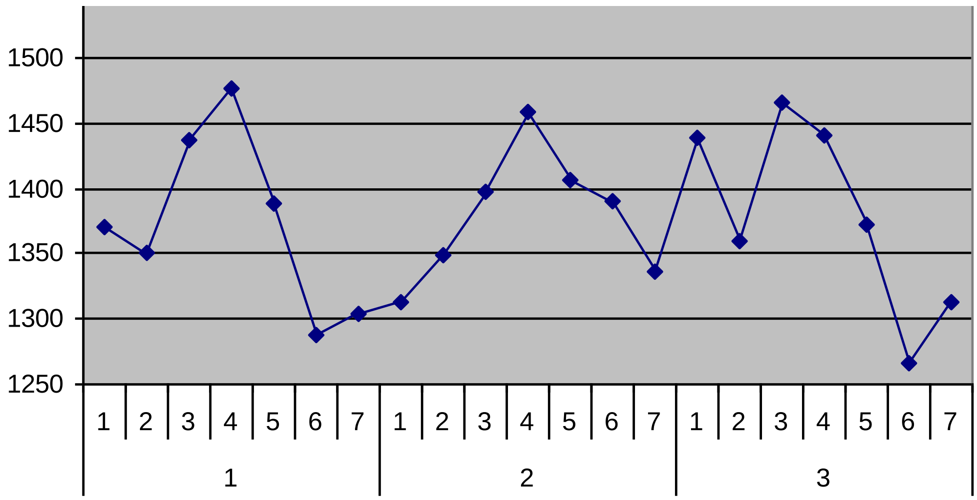
Run chart from quantitative data

Data values for 3 days

		Day		
		1	**2**	**3**
Time of day	**7:00**	1370	1312	1438
	9:00	1462	1405	1506
	11:00	1437	1398	1574
	1:00	1476	1466	1440
	3:00	1389	1406	1372
	5:00	1288	1459	1267
	7:00	1304	1369	1395

Run chart (cont'd)

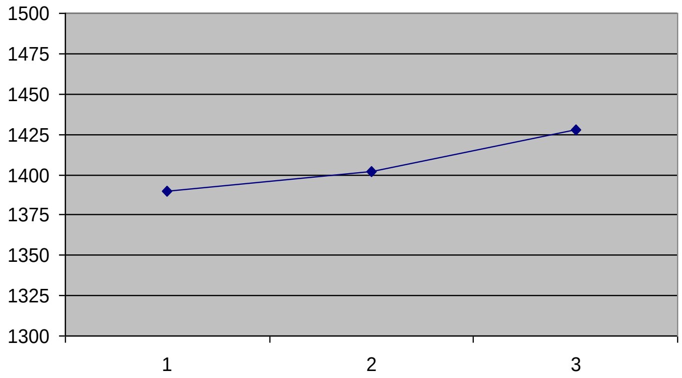
Data values for 3 days



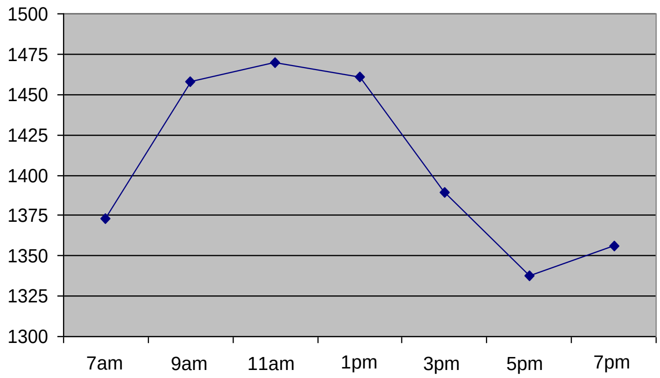
Stratification with quantitative data

		Day			
		1	2	3	Avgs.
Time of day	7:00	1370	1312	1438	1373.3
	9:00	1462	1405	1506	1457.7
	11:00	1437	1398	1574	1469.7
	1:00	1476	1466	1440	1460.7
	3:00	1389	1406	1372	1389.0
	5:00	1288	1459	1267	1337.8
	7:00	1304	1369	1395	1355.8
	Avgs.	1389.4	1402.0	1427.4	

Stratification (cont'd)



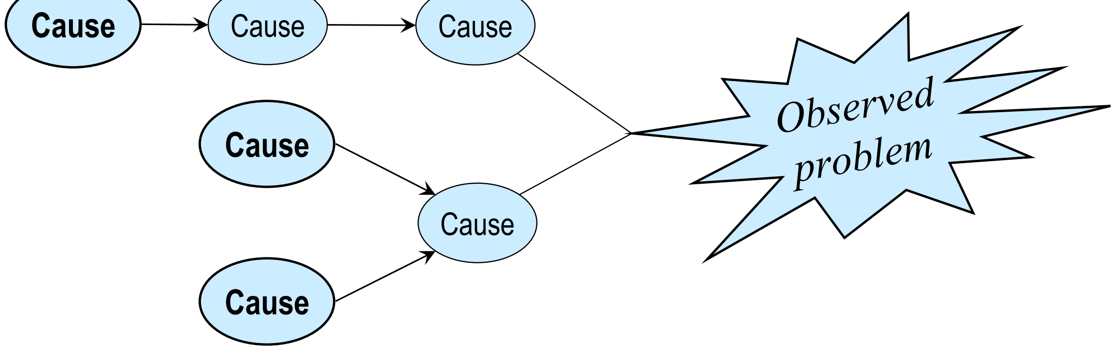
Slight upward trend in the daily averages



Distinct pattern in the averages by time of day

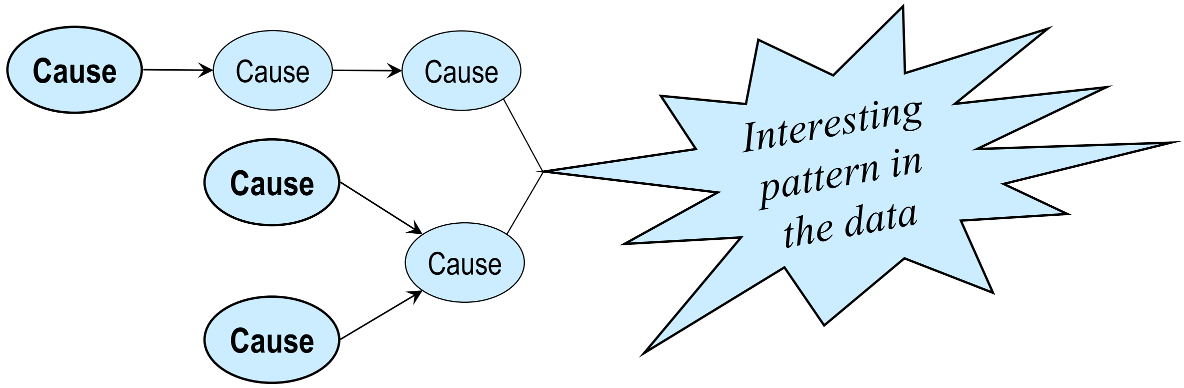
Root cause analysis

- Mapping and observing the in scope workflow usually reveals opportunities for improvement
- These are starting points for root cause analysis



- Data analysis often produces additional starting points

Root cause analysis



- "Why is the failure rate for Tester 3 higher than for Testers 1 and 2?"
- "Why is the resistivity higher on Tuesdays, Wednesdays and Thursdays than on the other days of the week?"

Getting to root cause — "five whys"

- For each problem or observation, ask a series of questions
- The purpose of each question should be to take you closer to the root cause of the problem or observation
- The questions do not have to start with "why"
- Put some thought into how you phrase your questions — you don't want to annoy or antagonize the person you are talking to
- Bring the conversation back to the root cause path if it wander into "solution space" or "who's to blame"
- Whenever possible, gather additional data to verify the root cause
- Once you have the root cause, the solution is not far away

Five whys exercises

- Your instructor will now lead you through three verbal exercises 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!

"The number of accidents in the plant was way up last month"

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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?	The glass in the skylight is cracked.
How did the glass get cracked?	A branch broke off a tree during the recent storm and hit the skylight.
How did the branch manage to hit the skylight?	The tree it came from was close to the building.
Why do we allow trees to be planted so close to the building?	I don't know. You'll have to talk to the Plant Manager.

“We are not able to communicate with each other”

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Why are you not able to communicate with each other?	We are not able to send and receive emails.
Why are you not able to send and receive emails?	The email server is often down for long periods of time.
What causes the downtime?	We don’t know. You will have to ask someone in the IT Department.
⋮	
What causes the large amount of downtime on the email server?	We don’t have enough people to adequately support it.
Why not?	We don’t have the budget to hire additional people.
How are priorities assigned for the people you do have?	You’ll have to talk to my boss about that.

“There’s too much scrap in the Coiling Department”

What kinds of defects are causing the scrap?	The vast majority is due to bad welds.
Why do we have so many bad welds?	The welders aren’t very good.
Why aren’t they very good?	It’s an entry level position, and they don’t get much training.
Why aren’t they given more training?	I don’t know. I guess there isn’t enough time. This is the way we’ve always done it.
Why don’t you use certified welders?	Are you kidding? We would have to pay them too much.
Don’t your welders get better as they become more experienced?	No, because they don’t stay in this department long enough for that to happen.

(cont'd)

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?	We have the highest accident rate in the company. The working conditions in the other department are much better. Also, they get paid a dollar an hour more than here.
What is the annual cost of scrap in the Coiling Department?	I don't know, but every day they fill a large dumpster with scrap metal.

Identifying root causes

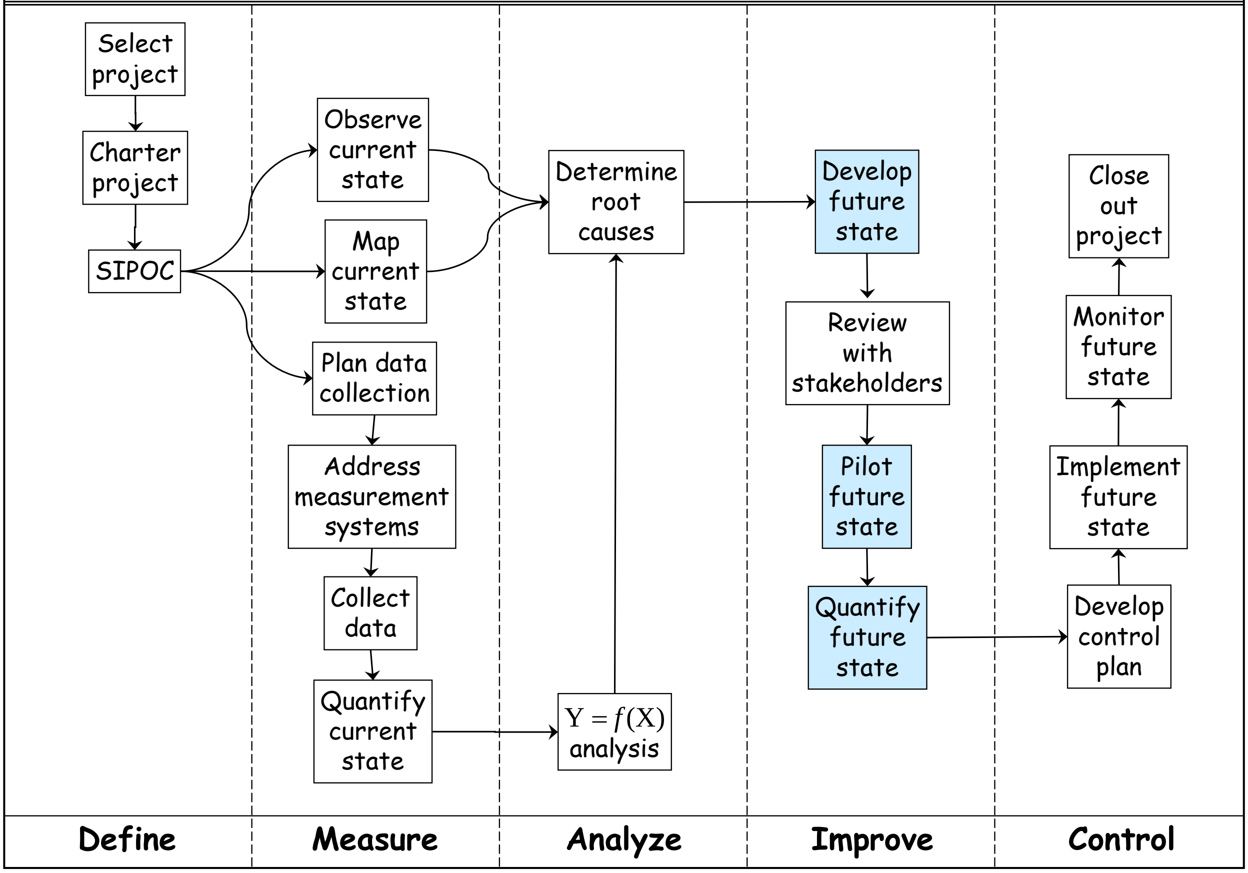
At the conclusion of the Analyze Phase, the team must list those specific root causes or critical x's to be acted upon during the Improve Phase

- 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

Notes

8 Improve Phase of DMAIC



Topics

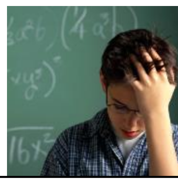
- Developing solutions
- Prioritizing solutions
- Piloting the future state

Developing solutions

Solution ideas come from many sources

?

- Obvious once the root cause is found
- Best practices revealed by stratification
- Observations and interviews
- Lean solutions
- Design of Experiments
- Best practices from benchmarking
- Brainstorming on accumulated information



Solution ideas often come directly from root causes

Root causes	*Solution ideas*
Equipment outdated	Replace equipment
Poor work area layout	Redesign work area layout
Material not ordered	Project on ordering process
Wrong material ordered	
Wrong quantity ordered	
Material delivered late	Project on supplier order fulfillment
Wrong material delivered	
Wrong quantity delivered	
Material out of spec	Project on supplier quality
Work instructions out of date	Update work instructions
Lack of training on equipment	Implement document control system
	Training on document control system

Brainstorming

- A structured team activity for generating ideas
- Can produce many ideas in a short period of time
- Separates *generation* of ideas from *organization* and *assessment* of ideas
- In the traditional brainstorming process, ideas are expressed verbally
- Often, it is better to have people write their ideas on pieces of paper (why?)

The team should generate as many potential solutions as possible for each validated root cause.

Brainstorming "rules of engagement"

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Do	*Do not*
• Allow individuals to complete their thoughts	• Discuss or criticize ideas during the process
• Build on existing ideas or ideas of others	• Paraphrase an individual's idea when scribing
• State ideas as concisely as possible	• Dominate the session
• State and accept "ridiculous" ideas	• Allow someone else to dominate the session
• Strive for quantity	• Organize, categorize or evaluate ideas during the process

Benchmarking

- Compare your performance with that of other organizations
- Identify best practices
- Borrow good ideas
- Methods
  - ✓ Mail surveys
  - ✓ Databases
  - ✓ Phone surveys
  - ✓ Consortia
  - ✓ Personal interviews
  - ✓ Publications
  - ✓ Trade magazines
  - ✓ Company tours
  - ✓ Professional associates
  - ✓ Trade meetings
  - ✓ Conversations

Notes

Prioritizing solutions

- Multi-voting (N/3 technique)
- Cause & effect matrix

These techniques can also be used to prioritize potential causes, after creating the Fishbone Diagram.

Multi-voting

- A team has developed a list of improvement ideas or projects
- They have clarified meanings and eliminated duplicates
- Each team member gets N/3 votes*, where N is the number of items on the list
- Team decides whether or not to allow voting more than once for one item
- Each team member assigns their allotted votes by placing marks beside items on the list

	IMPROVE INFORMATION FLOW
	VERIFY INSURANCE AT SCHEDULING
	STAFF TO DEMAND, NOT CAPACITY
	IMPROVE IMPORT OF HOSPITAL INFORMATION
	REDUCE PATIENT PHONE WAIT TIMES
	ENABLE E-RECEIPT OF DEMOS
	STANDARDIZE TRAINING FOR NEW HIRES
	STANDARDIZE ORAL CONTRAST FOR CT
	BALANCE PATIENT DISTRIBUTION AMONG SITES
	REDUCE REPORT TURNAROUND TIME

*Rounded to the nearest whole number

Multi-voting example

10 items, 15 people, 3 votes each

///// /	IMPROVE INFORMATION FLOW
///// ///// ////	VERIFY INSURANCE AT SCHEDULING
///	STAFF TO DEMAND, NOT CAPACITY
////	IMPROVE IMPORT OF HOSPITAL INFORMATION
	REDUCE PATIENT PHONE WAIT TIMES
	ENABLE E-RECEIPT OF DEMOS
///	STANDARDIZE TRAINING FOR NEW HIRES
/	STANDARDIZE ORAL CONTRAST FOR CT
///// /	BALANCE PATIENT DISTRIBUTION AMONG SITES
/	REDUCE REPORT TURNAROUND TIME

Multi-voting example

How each person voted

	PAUL	CHRIS	TOM	DENNIS	JENNIFER	MICHELLE	ALICE	ERIN	DOLORES	SALLY	SHANNON	PATTY	JUDY	NICOLE	BRIAN	Total
IMPROVE INFORMATION FLOW		1	1	1			1		1						1	**6**
VERIFY INSURANCE AT SCHEDULING	2	1	2	1		1	1	1	1	1	1	1	1			**14**
STAFF TO DEMAND, NOT CAPACITY					1									1	1	**3**
IMPROVE IMPORT OF HOSPITAL INFORMATION								1		1	1	1				**4**
REDUCE PATIENT PHONE WAIT TIMES	1			1	1	1		1					1	1		**7**
ENABLE E-RECEIPT OF DEMOS																**0**
STANDARDIZE TRAINING FOR NEW HIRES							1			1	1					**3**
STANDARDIZE ORAL CONTRAST FOR CT														1		**1**
BALANCE PATIENT DISTRIBUTION AMONG SITES		1			1	1			1			1	1			**6**
REDUCE REPORT TURNAROUND TIME															1	**1**
																0
																0

Putting 2 votes on one item was allowed, but not 3

Cause & effect matrix

Root causes	*Solution ideas*
Equipment outdated	Replace equipment
Poor work area layout	Redesign work area layout
Material not ordered	Project on ordering process
Wrong material ordered	
Wrong quantity ordered	
Material delivered late	Project on supplier order fulfillment
Wrong material delivered	
Wrong quantity delivered	
Material out of spec	Project on supplier quality
Work instructions out of date	Update work instructions
Lack of training on equipment	Implement document control system
	Training on document control system

Notes

For a given team with a given list of items, ranking by means of the cause-and-effect method usually gives a different result than multi-voting. The difference is that the cause-and-effect method forces us to think about the *reasons* certain items should be given higher priority than others. For this reason, the cause-and-effect method is superior to multi-voting.

Of course, multi-voting is quicker and easier. The decision as to which method to use is a judgment the team leader or facilitator must make.

For the example shown above, we want to rate each solution idea for degree of impact on each root cause. Solutions that impact higher-weighted root causes will rank higher than solutions that impact only lower-weighted root causes.

Cause & effect matrix for solution impact

Solution ideas / Root causes	Equipment outdated	Poor work area layout	Material not ordered	Wrong material ordered	Wrong quantity ordered	Material delivered late	Wrong material delivered	Wrong quantity delivered	Material out of spec	Work instructions out of date	Lack of training on equipment	0	Overall rankings
Replace outdated equipment	H									M	M		15
Redesign work area layout		H											9
Project on ordering process			H	H	H								27
Project on supplier order fulfillment						H	H	H					27
Project on supplier quality									H				9
Update current documents										H	M		12
Implement document control system										M			3
Training on document control system										H			9
													0
													0
													0
													0
													0
													0
													0
													0

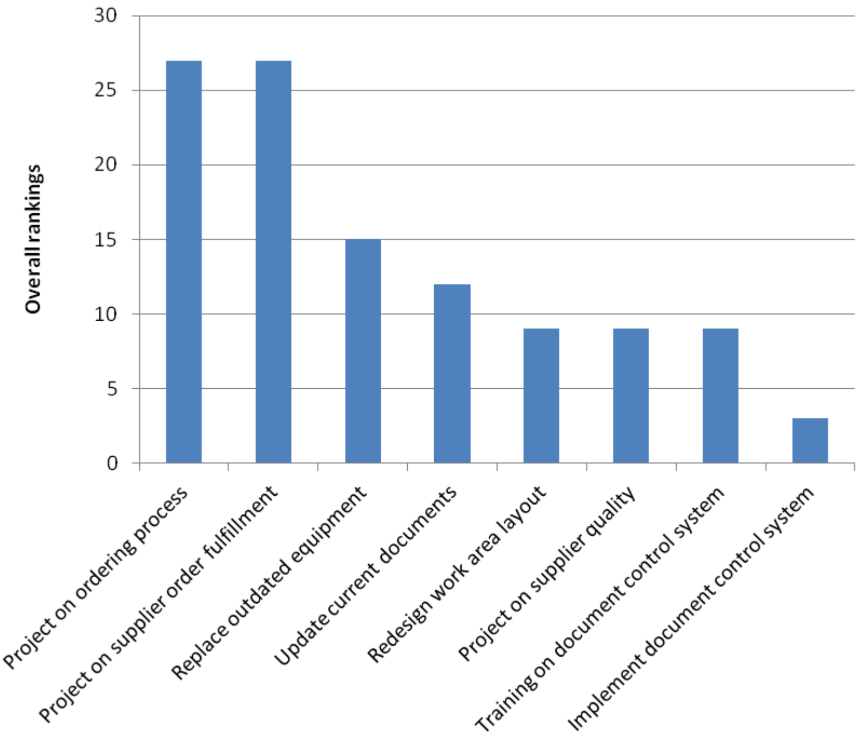
Notes

The solutions are listed on the left. Each solution is rated for impact on each root cause. It is customary to use a non-linear scale:

Low = 1
Medium = 3
High = 9

The overall rankings on the right are the sum of the ratings for each solution idea.

Pareto of solution impact



Notes

In a perfect world, the highest priority would be to implement the solution with highest impact score. The second highest priority would be to implement the solution with the second highest impact score. And so on.

In reality, issues of feasibility have to be taken into consideration. The project on supplier order fulfillment might have the highest impact score, but what if it is also the most difficult and time consuming solution to implement? In some cases it is better to start by implementing easier and less time consuming solutions further down the Pareto.

Selling the proposed solutions to stakeholders

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- Create documents describing the proposed changes
- Should include the analysis results and other findings that support the changes
- Present the proposed changes to stakeholders
- Encourage them to express any questions or concerns they may have
- Revise your proposal as needed
- Plan your future state pilot study in collaboration with process owners

Notes

Piloting the future state

- Pilot = small scale implementation under close observation
- Scope should be limited*
- Time period should be relatively short
- Test and evaluate improvement objectives
- Reality check prior to full scale implementation

*We try to scope improvement projects into manageable chunks. Because of this, the pilot scope may sometimes be the same as the project scope. In such cases, the only new issue for defining the pilot is to determine the duration.

Piloting checklist

- ❑ What is the scope? (Location, work area, products, . . .)
- ❑ What is the duration?
- ❑ Who are the participants? (Process owner, process participants, stakeholders, team members…)
- ❑ What data is to be collected? (Y variables and project metrics must be same as in Define and Measure phases.)
- ❑ Have we communicated plans to all concerned parties?

Analyzing pilot results

- Collect observations — what worked, what didn't
- Calculate project metrics based on pilot data
- Evaluate performance relative to project goals
- Compare "before" metrics to "after" metrics

Notes

Example

A project to reduce lead time and improve quality

	Current state	
Transaction	Lead time (days)	Complete & accurate
1	10	Yes
2	4	No
3	13	No
4	2	Yes
5	6	No
6	11	No
7	6	No
8	5	Yes
9	27	No
10	19	Yes
11	4	Yes
12	17	No
13	9	No
14	11	No
15	6	Yes
16	5	Yes
17	12	Yes
18	8	Yes
19	1	Yes
20	12	No
21	2	Yes
22	2	Yes
23	7	No
24	15	No
25	21	Yes

	Future state	
Transaction	Lead time (days)	Complete & accurate
1	4	Yes
2	2	Yes
3	4	Yes
4	8	No
5	3	Yes
6	5	Yes
7	12	No
8	4	Yes
9	10	Yes
10	2	Yes
11	3	Yes
12	4	Yes
13	3	Yes
14	3	Yes
15	4	Yes
16	10	Yes
17	9	Yes
18	3	Yes
19	5	Yes
20	4	Yes
21	2	Yes
22	5	Yes
23	3	Yes

	Current state	Future state
Avg. lead time		
% Lead times > 10		
% C & A		

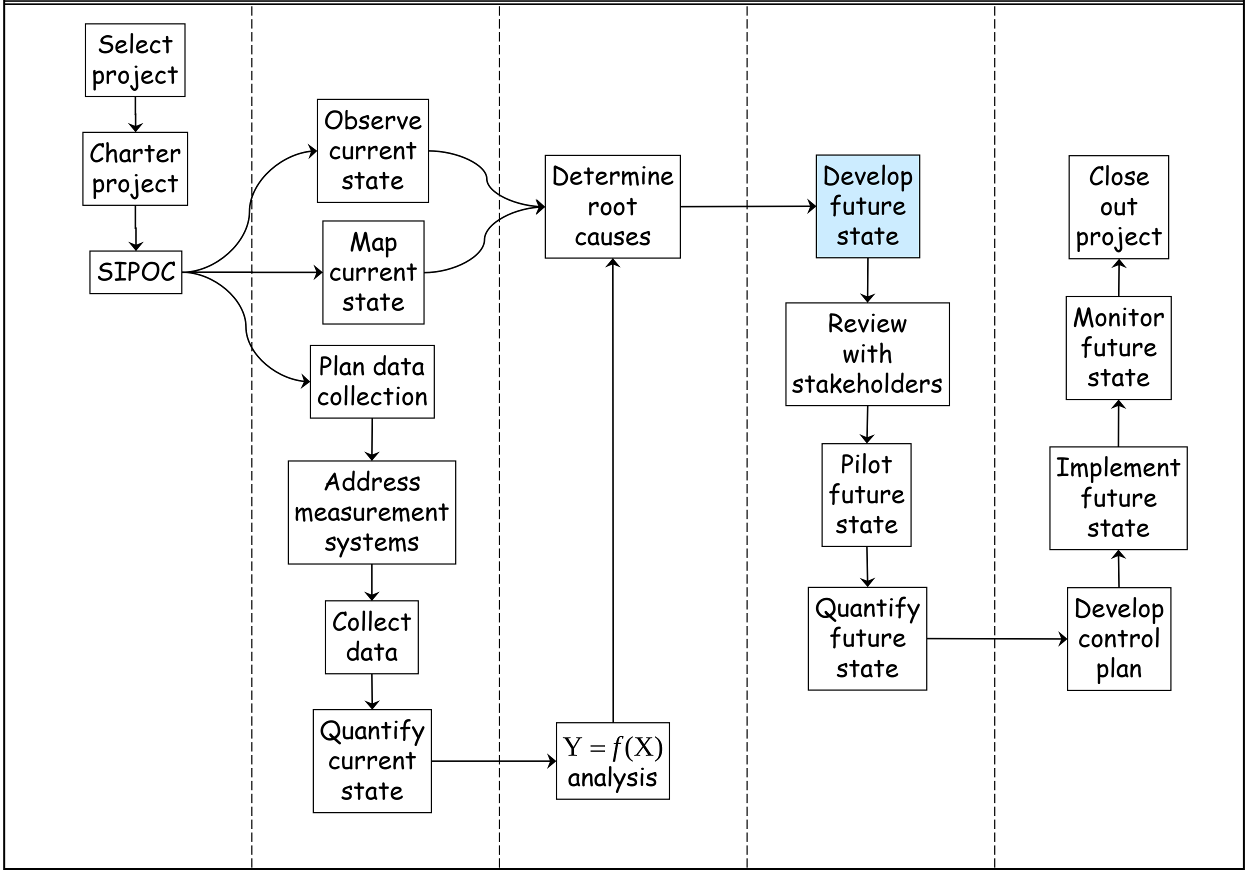
Example (cont'd)

Comparison of current state and future state metrics

	Current state	
Transaction	Lead time (days)	Complete & accurate
1	10	Yes
2	4	No
3	13	No
4	2	Yes
5	6	No
6	11	No
7	6	No
8	5	Yes
9	27	No
10	19	Yes
11	4	Yes
12	17	No
13	9	No
14	11	No
15	6	Yes
16	5	Yes
17	12	Yes
18	8	Yes
19	1	Yes
20	12	No
21	2	Yes
22	2	Yes
23	7	No
24	15	No
25	21	Yes

	Future state	
Transaction	Lead time (days)	Complete & accurate
1	4	Yes
2	2	Yes
3	4	Yes
4	8	No
5	3	Yes
6	5	Yes
7	12	No
8	4	Yes
9	10	Yes
10	2	Yes
11	3	Yes
12	4	Yes
13	3	Yes
14	3	Yes
15	4	Yes
16	10	Yes
17	9	Yes
18	3	Yes
19	5	Yes
20	4	Yes
21	2	Yes
22	5	Yes
23	3	Yes

	Current state	Future state
Avg. lead time	9.4	4.9
% Lead times > 10	40.0	4.3
% C & A	52.0	91.3


Select project
Charter project
SIPOC
Observe current state
Map current state
Plan data collection
Address measurement systems
Collect data
Quantify current state
Determine root causes
Y = f(X) analysis
Develop future state
Review with stakeholders
Pilot future state
Quantify future state
Close out project
Monitor future state
Implement future state
Develop control plan

Common Lean solutions

Stop-and-Fix

Pull systems

Standard Work

Changeover reduction

Work balancing

Mistake proofing

Reduce batch sizes

Value stream teams

Visual management / Visual Work

5S

.
.
.

5S

Much more than cleaning up!

1. Sort
2. Set in Order
3. Shine
4. Standardize
5. Sustain

Standard Work

To begin our discussion about Standard Work:

- Get a blank piece of 8 ½ X 11 paper (scratch paper is great!)
- Draw a pig (You know, the farm animal. Oink!)
- Do this quickly! Customers are waiting!
- Don’t fret about your drawing ability. Many of us will not be great at this!
- When everyone is done, we will share these pigs with each other

Pig Drawing Work Instruction (using Grid)

1. Draw a capital M, so the tip of the middle V of the M touches the intersection of the grid lines in the NW quadrant
2. Draw a capital W, so the tip of the middle V of the W touches the intersection of the grid lines in the SW quadrant
3. Draw a capital W, so the tip of the middle V of the W touches the intersection of the grid lines in the SE quadrant
4. Go back to the M you drew in Step 1, and draw a slightly upwardly bowed line that runs from the most eastern point of the M, to the intersection of the grid lines in the NE quadrant.
5. Continue that line from the intersection of the grid lines in the NE quadrant to the most easterly point of the W that you constructed in the 3rd step.
6. Draw a downwardly bowed line from the most western point of the W in the SE quadrant, to the most easterly point of the W in the SW quadrant.
7. In the exact middle of the box between the NW quadrant and the SW quadrant, draw a circle the size of a dime.
8. Draw an inwardly bowed line from the most westerly point of the M created in Step 1, to the top of the circle you just drew in Step 7.
9. Draw an inwardly bowed line from the most westerly point of the W created in Step 2, to the bottom of the circle you drew in Step 7.
10. Draw a horizontal straight line about ½ inch in length starting from the middle of the line you created in Step 8.
11. Draw a horizontal straight line about 1/3 inch in length starting from the middle of the line you drew in step 9.
12. Draw a curly-cue about 1 inch in length starting at the upper third of the line you created in Step 5, extending in an easterly direction.
13. Put two dots in middle of the circle you drew in Step 7, arranged horizontally, and about ¼ of an inch apart.

Standard Work (cont'd)

- How did the work instruction affect the consistency (variation) of the pigs?
- How could the work instruction be improved?
- How do Standard Work and 5S support each other?

Visual management

Visual management and visual work, refer to techniques used to create a more visual work environment:

- Visuals to aid in doing the job or organizing the area
  - Examples?
- Display boards to report on work being done
  - Every employee should know at the end of the day, whether it was a good day or a bad day
  - Examples?
- Warnings and visual cues that something isn’t right
  - Examples?

Mistake-proofing

Ideally, make it impossible to do the task incorrectly.

Examples:

- 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

What other examples can you think of?

Reduce batch sizes (keep the work moving)

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:

  - ✓ One mistake can ruin a whole batch before the problem is detected
  - ✓ A customer who wants just one item has to wait for a whole batch to be completed
  - ✓ Items accumulate until the batch quantity is reached — wastes space, creates opportunities for defects

Batching exercise

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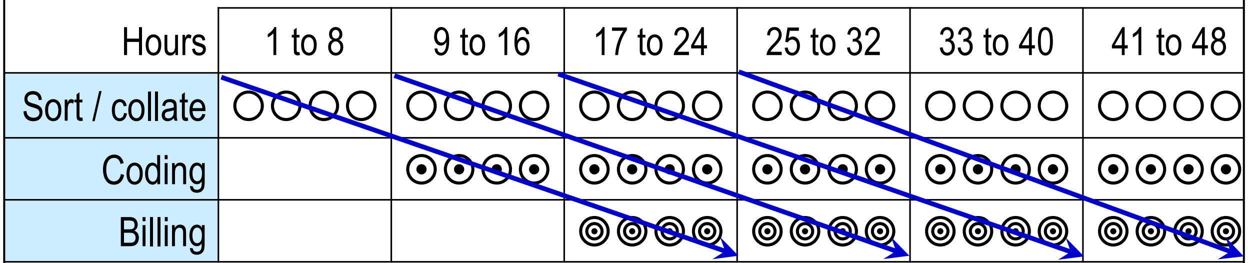
Current state: daily batching

3 operations
2 hours per transaction per operation



Cycle time = 24 hours (3 days)

Future state: continuous flow

3 operations
2 hours per transaction per operation

Hours	1 to 8	9 to 16	17 to 24	25 to 32	33 to 40	41 to 48
Sort / collate	○○○○	○○○○	○○○○	○○○○	○○○○	○○○○
Coding	⊙⊙⊙	⊙⊙⊙⊙	⊙⊙⊙⊙	⊙⊙⊙⊙	⊙⊙⊙⊙	⊙⊙⊙⊙
Billing	◎◎	◎◎◎◎	◎◎◎◎	◎◎◎◎	◎◎◎◎	◎◎◎◎

Cycle time = 6 hours (less than one day)

By reducing batch size, we also reduce:

- Cycle time
- Inventory needed to keep each operation working
- Space required for the operation

What's the downside?

Changeover reduction

Shorten downtime due to product changeovers

- Changeover reduction process can also be applied to preventive maintenance activities
- Also referred to as SMED: Single-Minutes Exchange of Die

Steps in Changeover reduction

1. Map the current process in detail
2. Determine which steps can be done outside of the machine downtime (before the machine is shut down or after it is restarted)
3. Determine which steps must be done while the machine is down
4. Simplify and shorten steps that must be done while the machine is down

Which "lean solutions" support changeover reduction?

Pull Systems

Produce only what the customer (next operation) needs, when they need it

- Also, stock supplies in quantities needed to meet the demand, in the warehouse and in the operational area
- Requires data on demand, processing variation, etc.
- The goals:
  - Minimize inventory while avoiding stock-outs
  - Minimize over-production while keeping the line running and material flowing

Do you use any pull systems in your operations?

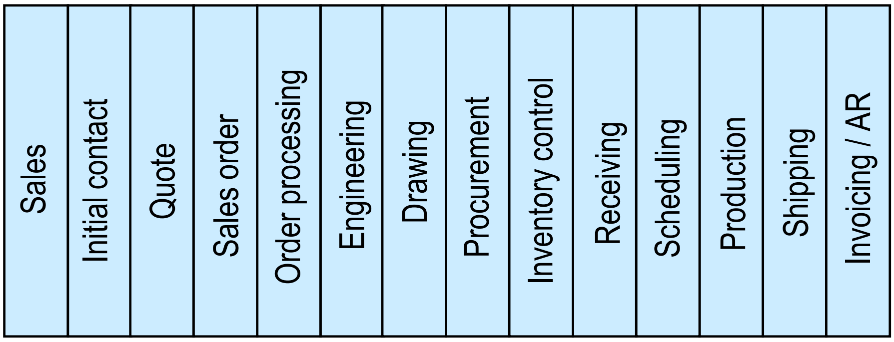
Stop-and-Fix

Stop the operation when it's not working properly, and fix it before starting again

- What happens when we continue running, when thing are not working properly?

- What do you think happens to all of those failure modes, when an organization commits to stop-and-fix?

Organizing by value stream



- Departmental boundaries create “silos”
- Vestige of industrial revolution — need for specialization
- Silos are “islands” of responsibility
- Hand offs between silos are opportunities for poor communication and lack of coordination

Organizing by value stream (cont'd)

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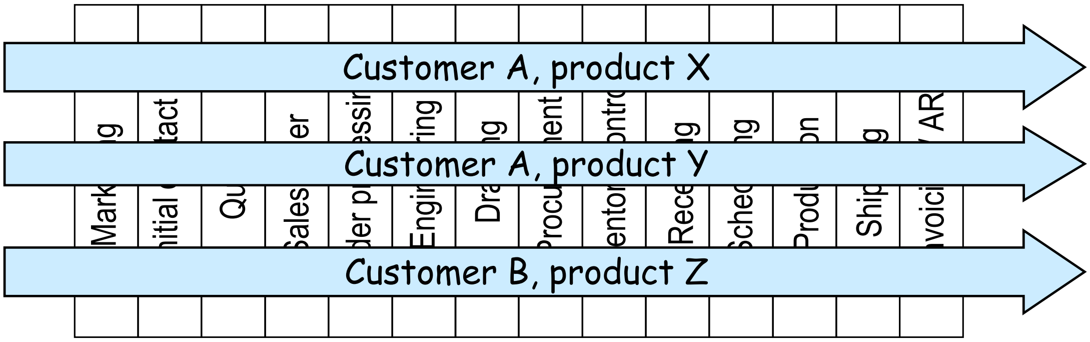
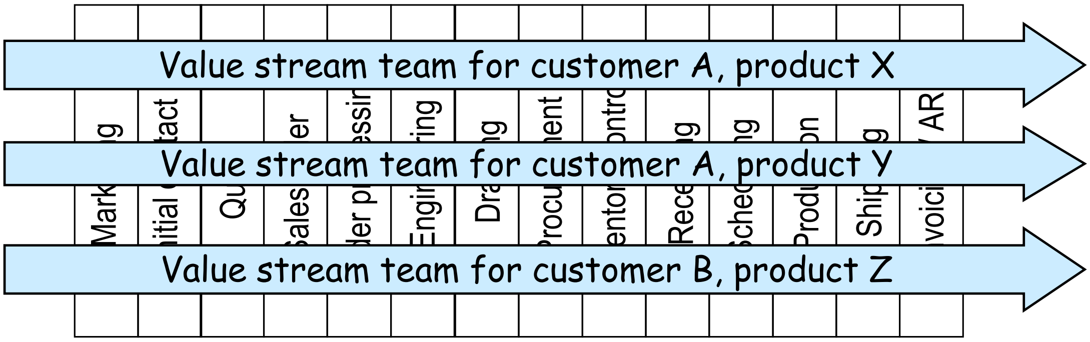


- Customer value streams span all silos
- Often, no single entity has overall responsibility for customer satisfaction

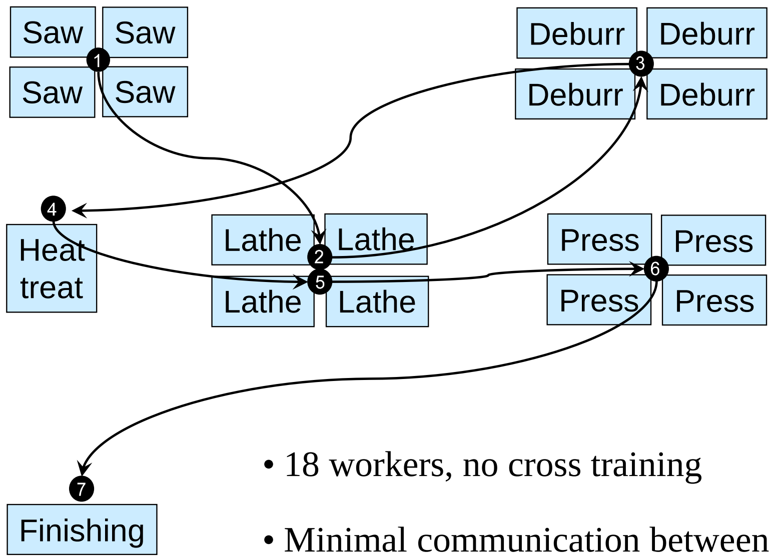
Organizing by value stream (cont'd)



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

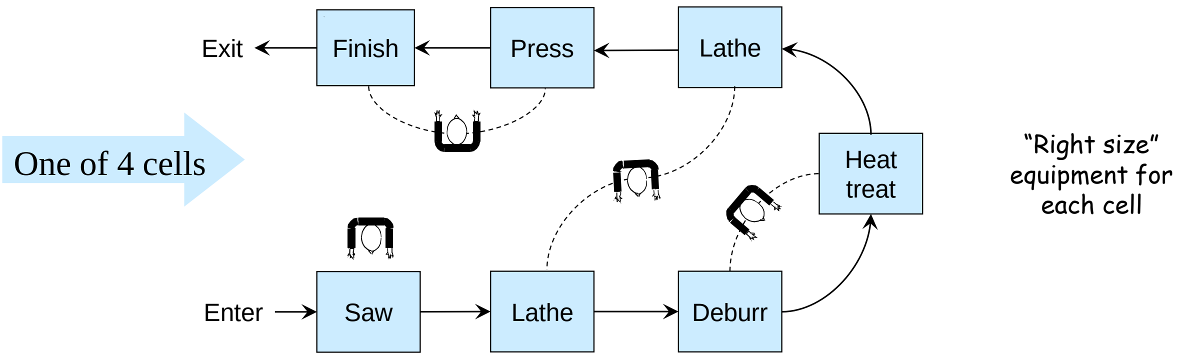
Notes

Manufacturing operation in silos



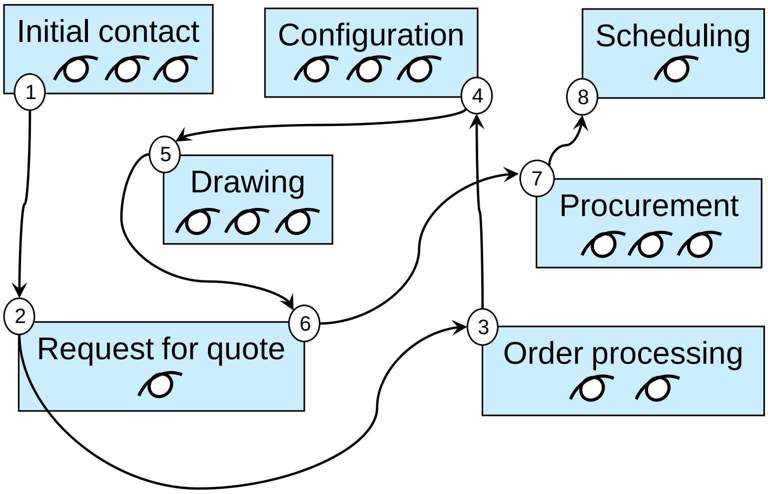
- 18 workers, no cross training
- Minimal communication between silos
- Each silo handles all products
- Silos produce as much as possible, all the time (push system)
- WIP moves between silos in large batches → long lead time

Manufacturing operation in U-shaped work cells



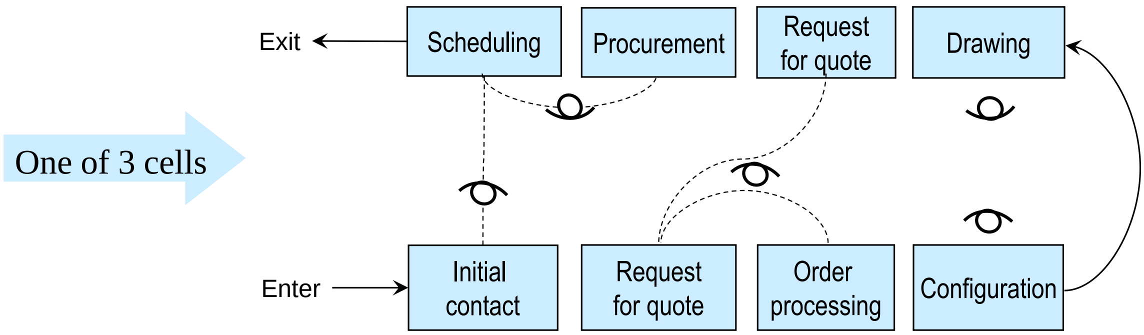
- Each cell handles all operations for one product family, and produces just what is needed to meet current demand (pull system)
- Continuous flow → minimal WIP → short lead time
- Rapid response to workflow or quality problems
- 16 workers instead of 18 — what happens to the other 2?

Transactional process in silos



- 16 workers (), no cross training
- Each silo handles all transactions
- Minimal communication between silos
- Lots of do overs (not shown in diagram)
- Lots of WIP → long turnaround time

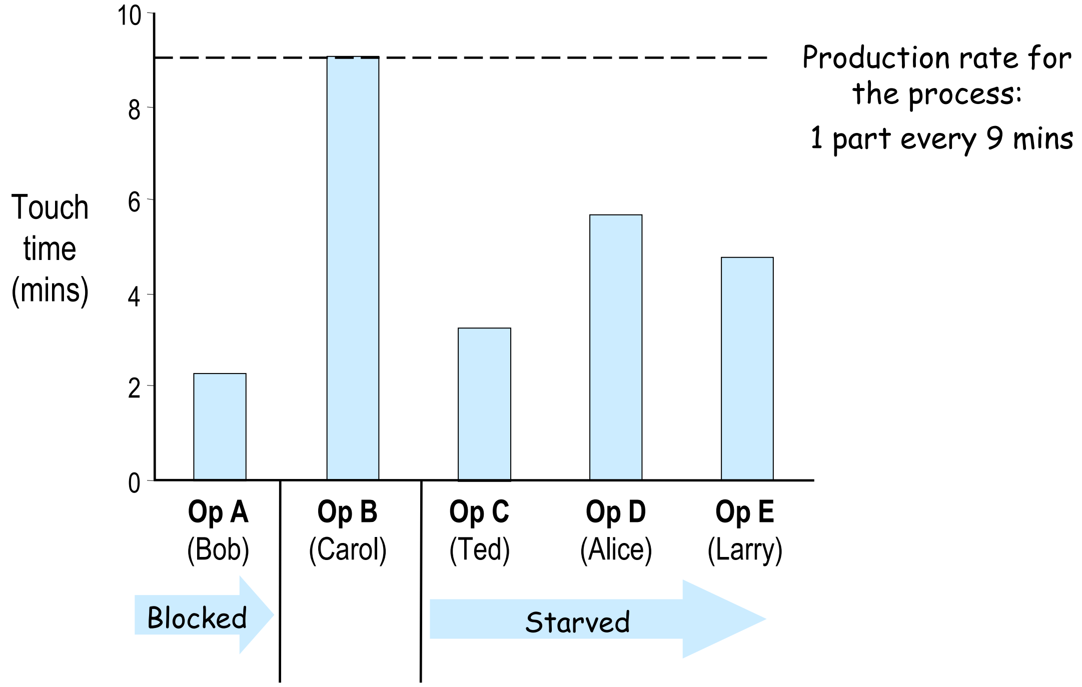
Transactional process in U-shaped work cells



- 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 happens to the other one?

Work balancing

Production rate for a process = production rate for the *slowest* operation



Improving work balance by cross training

- Teach Bob how to do B, teach Carol how to do A, have them both do A & B

- Touch time for A & B = 9.0 + 2.2 = 11.2

- Together, Bob and Carol can produce 1 part every 5.6 minutes (2 parts every 11.2 minutes)

Cross training (cont'd)

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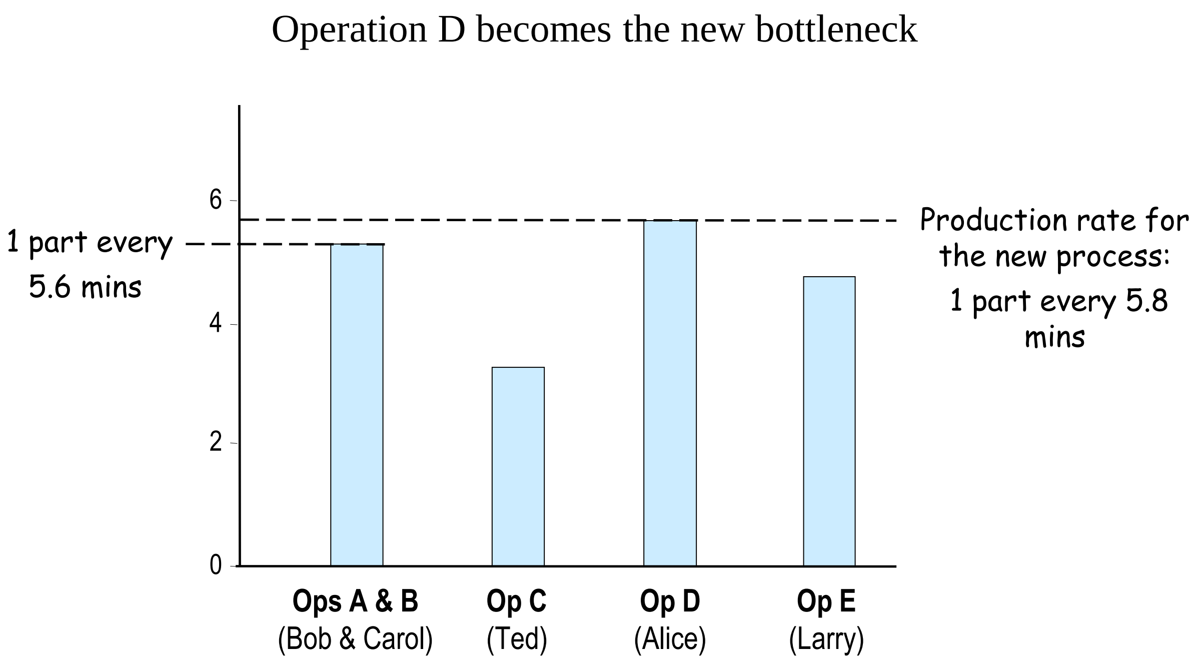
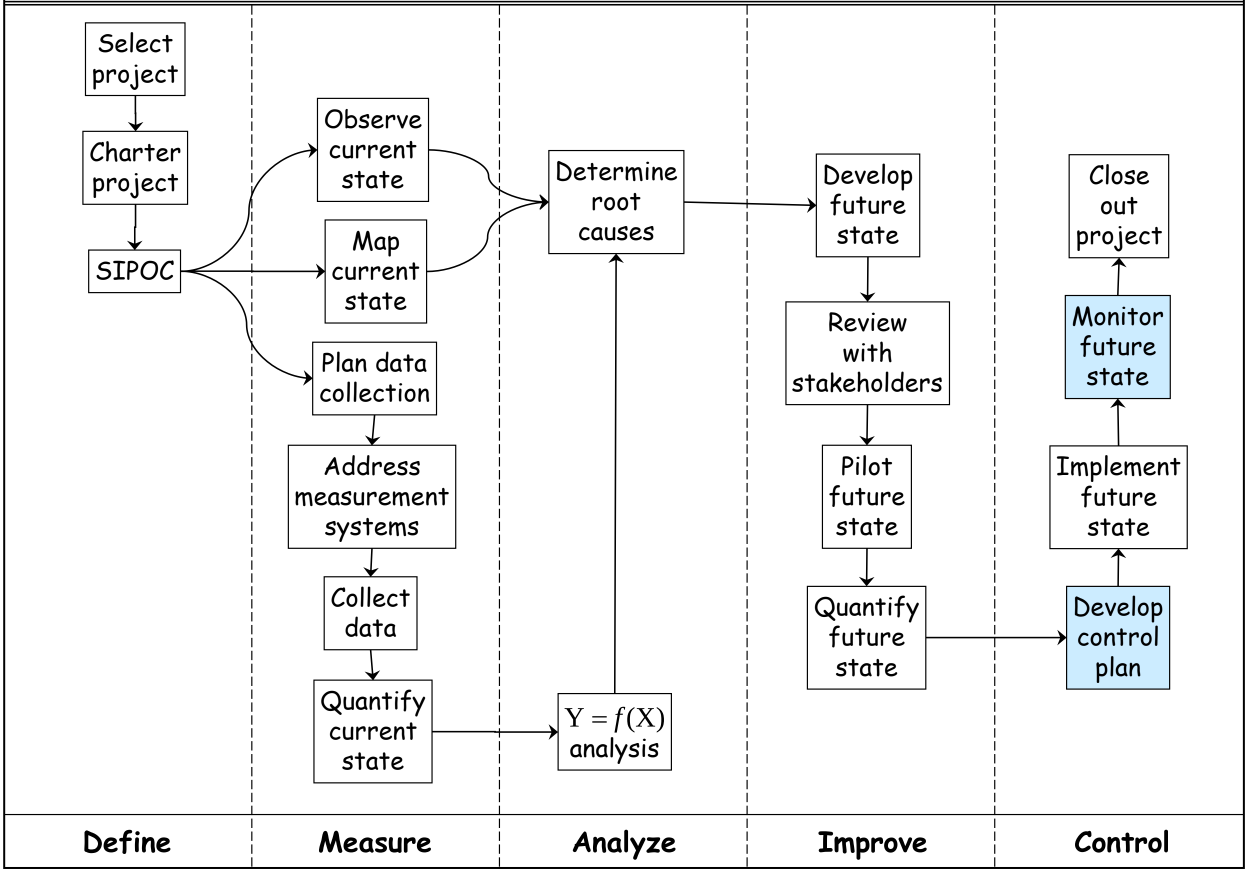


Notes

10 Control Phase of DMAIC



Topics

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- Control plan
- Statistical monitoring
- Control limits
- Taking action

Example of a control plan

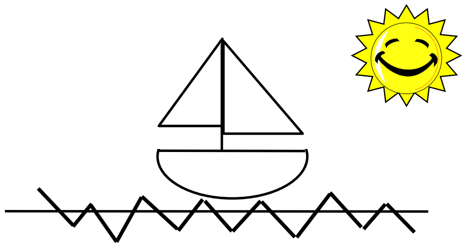
Process name:	Tool Testing Process
Process owner:	Testing Area Manager
Revision date:	

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 trainer testers to use it								
Dimensional inspection	Periodic gage R&R	TBD	Spec dimensions	DVT	% of Tolerance		TBD	Testing Engineer	TBD

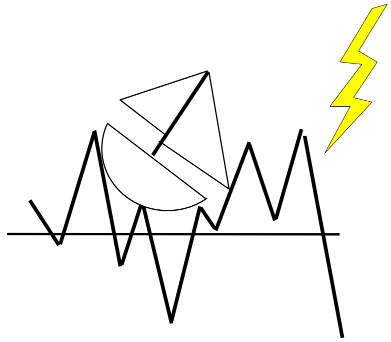
Notes

Two kinds of variation

- Common causes



- Assignable causes



Exercise

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

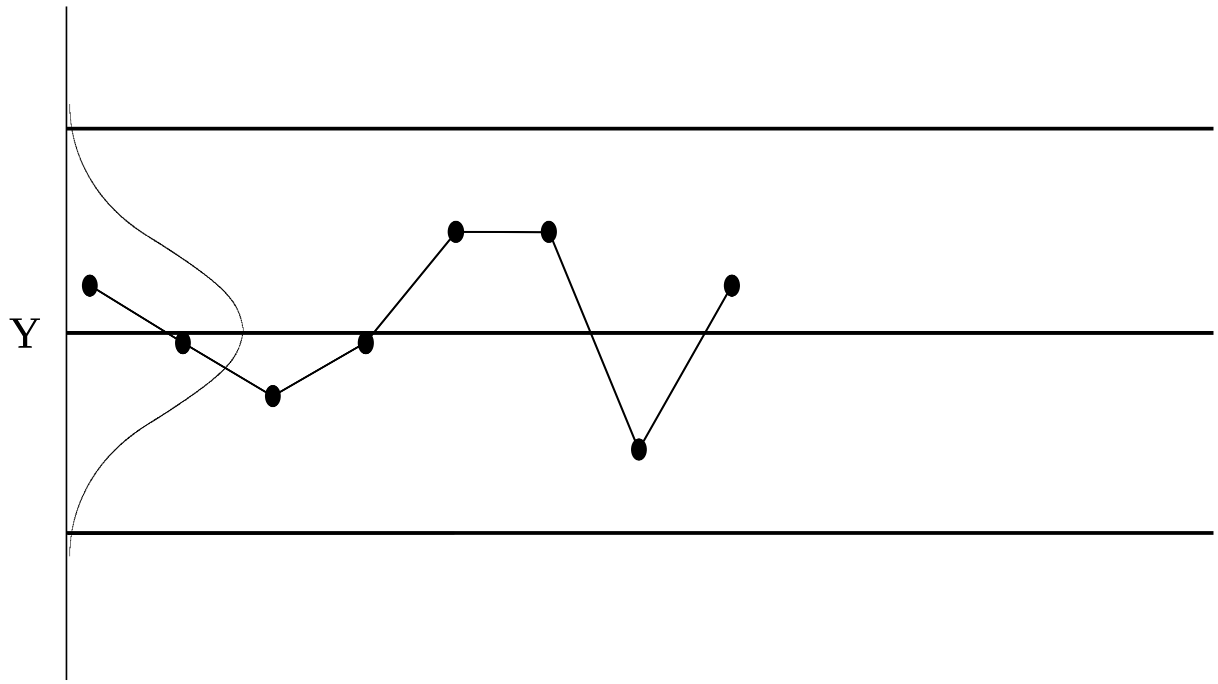
b) Put your pencil or pen into the other hand. Sign your name once in the space provided below.

Two kinds of variation

Common causes	*Assignable causes*
Random variation	Systematic variation
Inherent in the process as currently defined	External factors, mistakes, mal-functions, miscommunications, . . .
Myriad small fluctuations, causes cannot be assigned	Relatively few large fluctuations, causes can be determined and removed
Outcomes are predictable within statistical limits	Outcomes are not predictable at all

Statistical monitoring

Establish control limits using process data



Statistical monitoring (cont'd)

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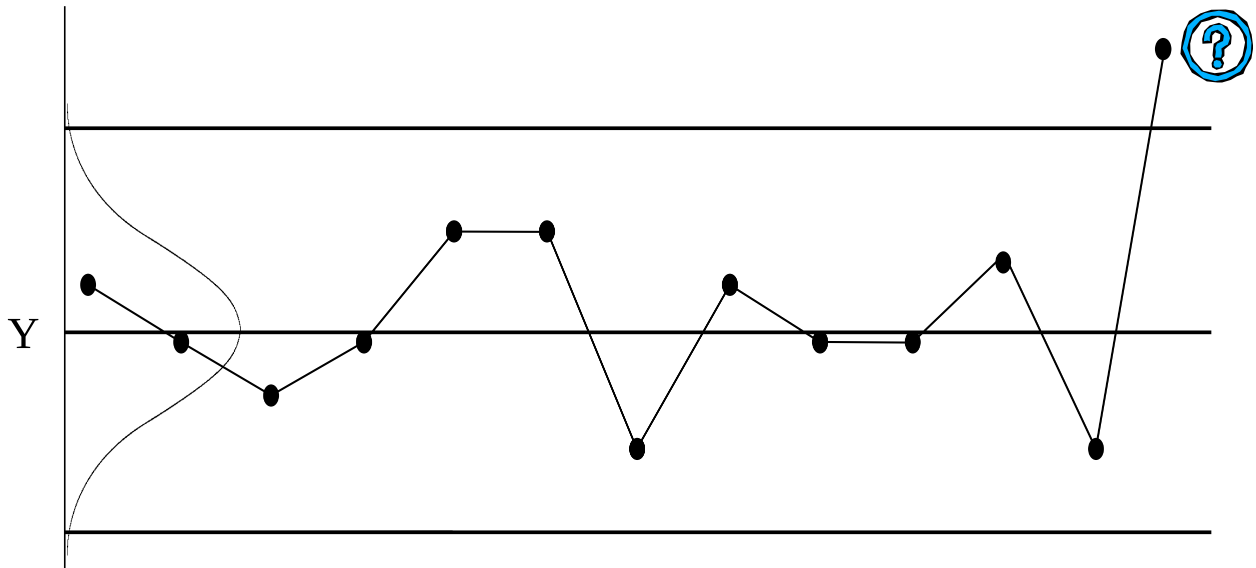
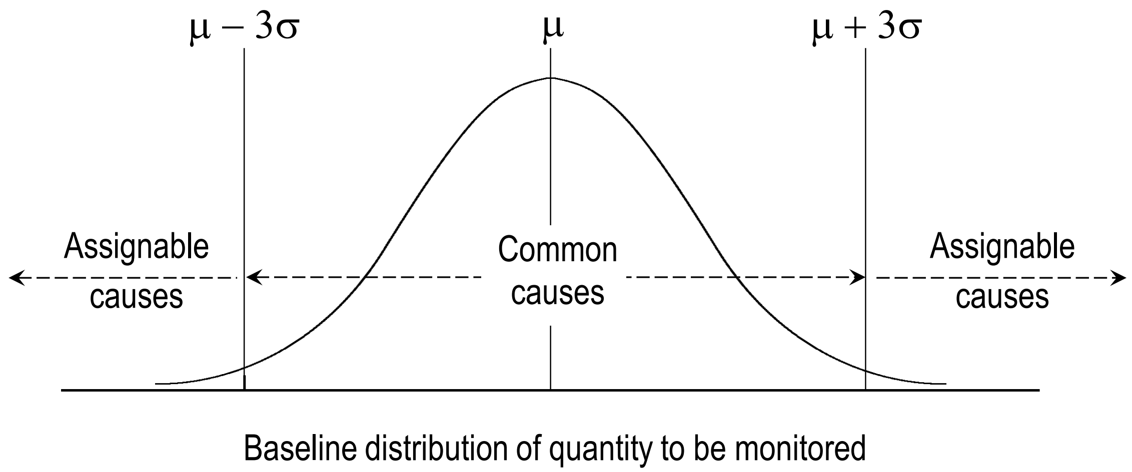
If and when Y falls outside the control limits?



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

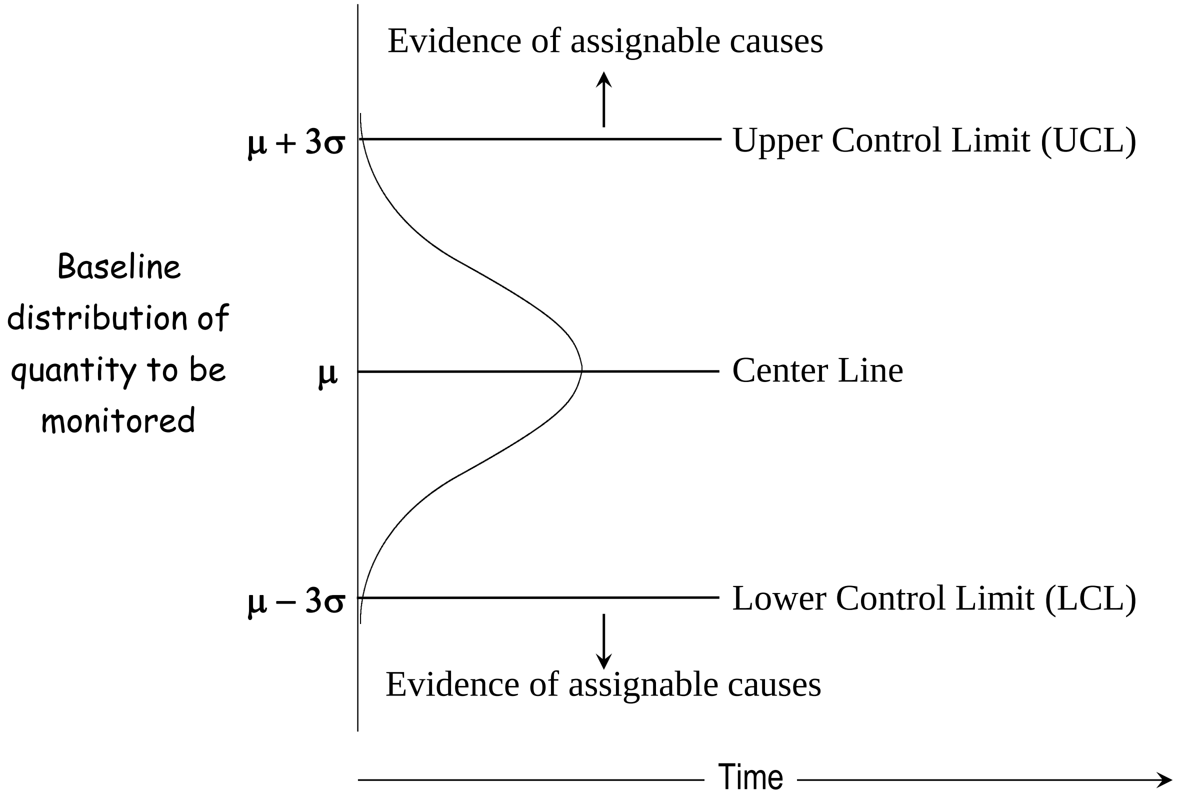
Control limits

We use *three-sigma limits** to distinguish operationally between assignable causes and common causes



** The actual calculation depends on the type of data and sampling plan*

Control chart



Calculating Control Limits

- Control Limits are calculated using process data and statistical constants
- 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
- At least 20 – 25 samples 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 to be implemented.

Types of Control Charts

Common Shewhart Control Charts are:

- $\overline{X}$R and $\overline{X}$s (sample average; range or std dev)
- Individuals and Moving Range (or XmR)
- p (fraction defective)
- np (number of defective items)
- c (count of defects)
- u (count of defects/unit)

We'll look closer at the $\bar{X}R$ chart.

$\overline{X}$R ("Xbar-R") Chart

The $\overline{X}R$ Chart is two graphs working together,
the $\overline{X}$ Chart and the R Chart.

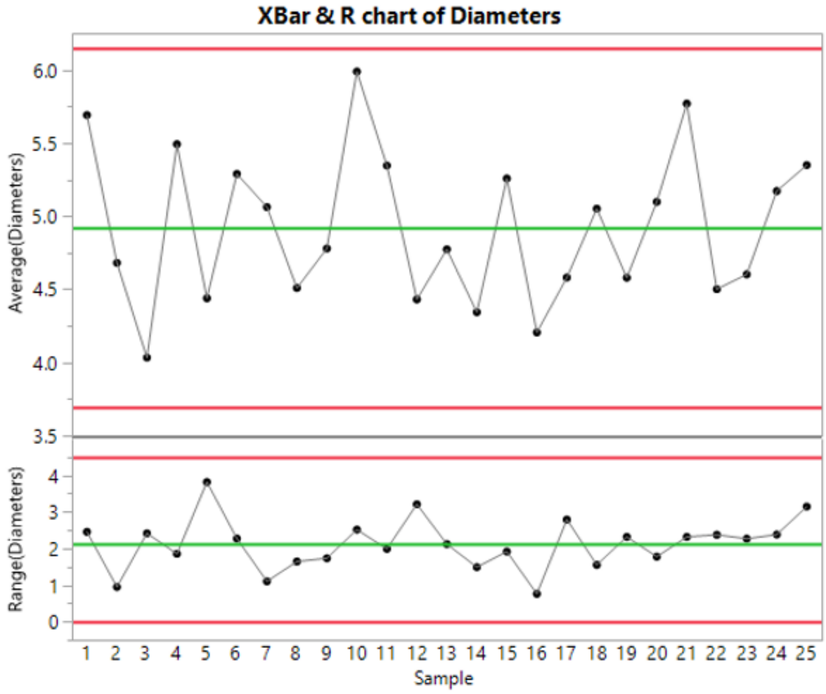
The $\overline{X}R$ Chart is used when:

- Equal size samples are periodically taken and measured
- Every unit is not measured
- The measurement is continuous (quantitative, can take on any value on the measurement scale)

Samples typically consist of units processed consecutively.

$\overline{X}$R Chart (cont'd)

For each sample, the average is plotted on the $\bar{X}$ chart and the range (largest-smallest) is plotted below on the R chart.



$\overline{X}$R Chart (cont'd)

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$\overline{X}$ Chart Control Limits:

$$UCL = \bar{\bar{x}} + A_2\overline{R}$$

$$CL = \bar{\bar{x}}$$

$$LCL = \bar{\bar{x}} - A_2\overline{R}$$

R Chart Control Limits:

$$UCL = \overline{R}D_4$$

$$CL = \overline{R}$$

$$LCL = \overline{R}D_3$$

$\bar{\bar{x}}$ is the average of the sample averages;

$\bar{R}$ is the average of the sample ranges;

Constants A_2 , D_3 and D_4 are found in statistical tables.

Constants for Control Limit Calculations

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

Exercise

We want to use an $\overline{X}R$ control chart to monitor a critical dimension, diameter, of the parts we are producing. We measure 25 samples of 5 parts each, and calculate the average and range (largest minus smallest) for each sample.

We calculate the average of all of the sample averages: $\overline{\overline{x}} = 4.92\text{cm}$

We calculate the average of all of the sample ranges: $\overline{R} = 2.13\text{cm}$

a) Calculate the upper and lower control limits for the $\overline{X}$ chart:

$$UCL = \overline{\overline{x}} + A_2 * \overline{R} =$$

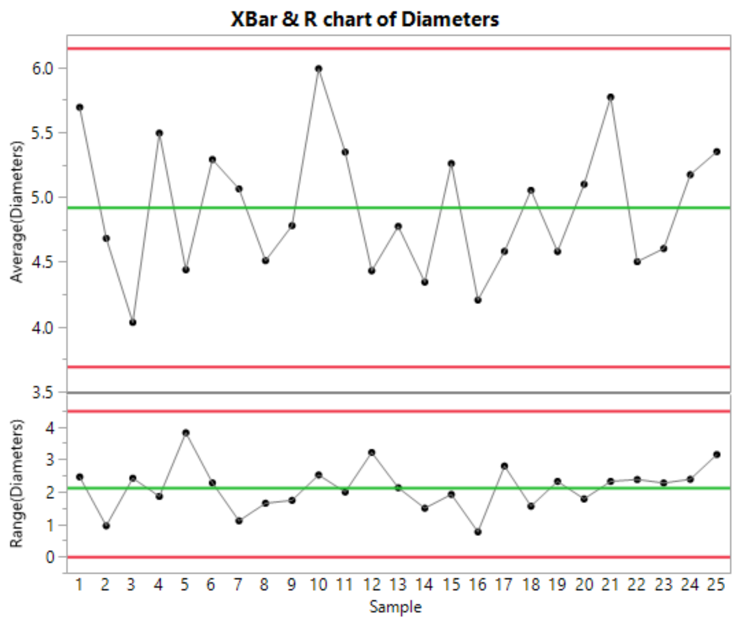
$$LCL = \overline{\overline{x}} - A_2 * \overline{R} =$$

b) Calculate the upper and lower control limits for the R chart:

$$UCL = \overline{R} * D_4 =$$

$$LCL = \overline{R} * D_3 =$$

$\overline{X}R$ Chart of *Diameters*



Diameters Limit Summaries

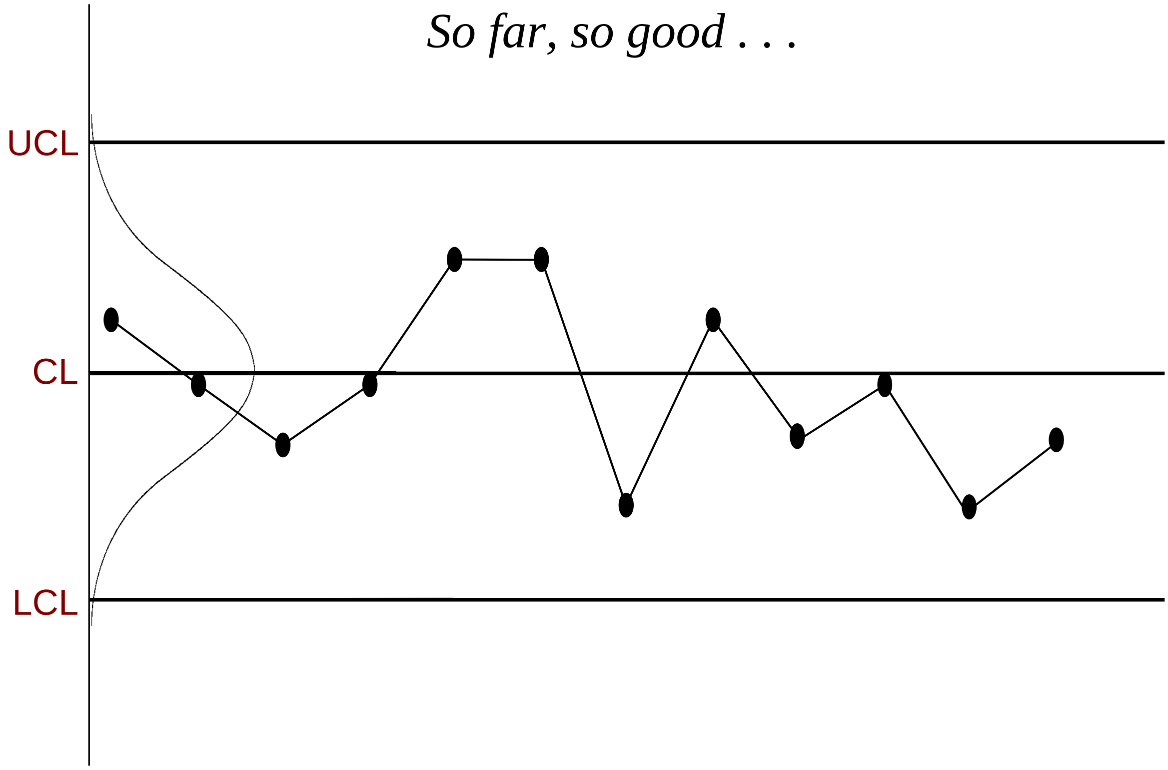
Points plotted	LCL	Avg	UCL	Limits Sigma	Sample Size
Average	3.694	4.921	6.148	Range	5
Range	0.000	2.127	4.497	Range	5

JMP Output of $\overline{X}R$ Chart of *Diameters* in Exercise

Notes

Taking action

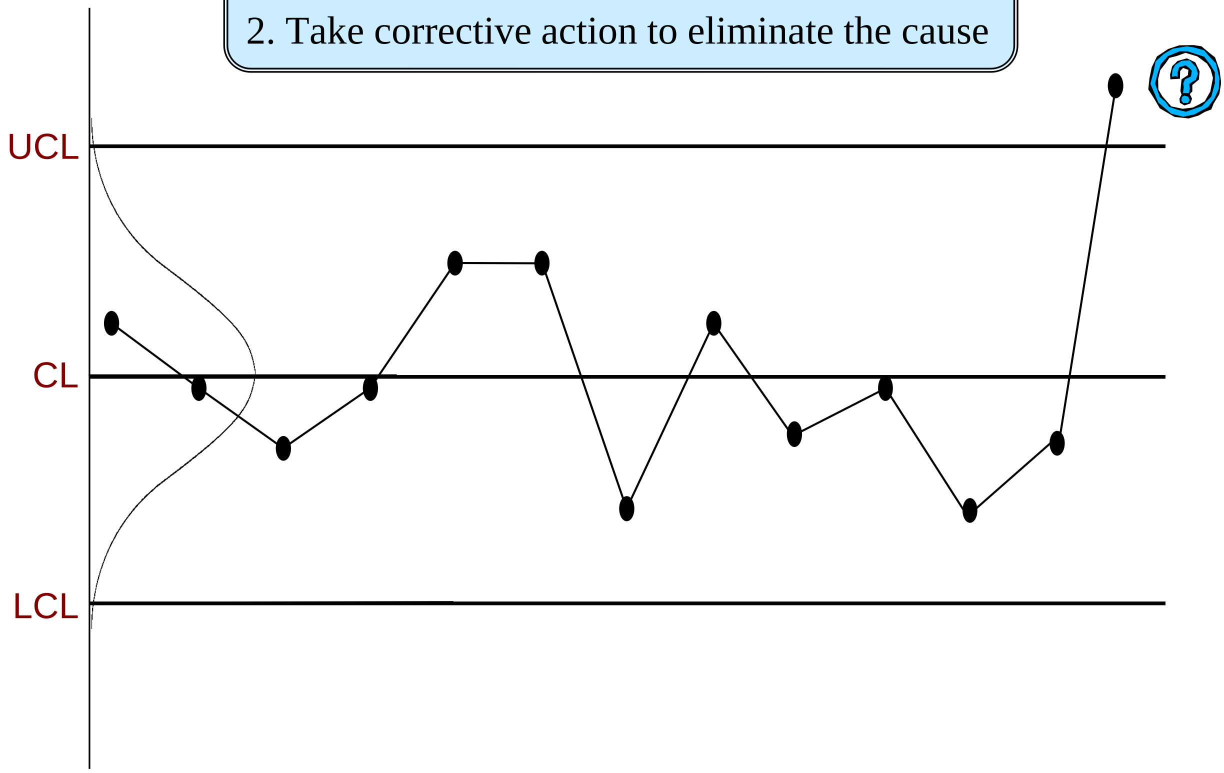
So far, so good . . .



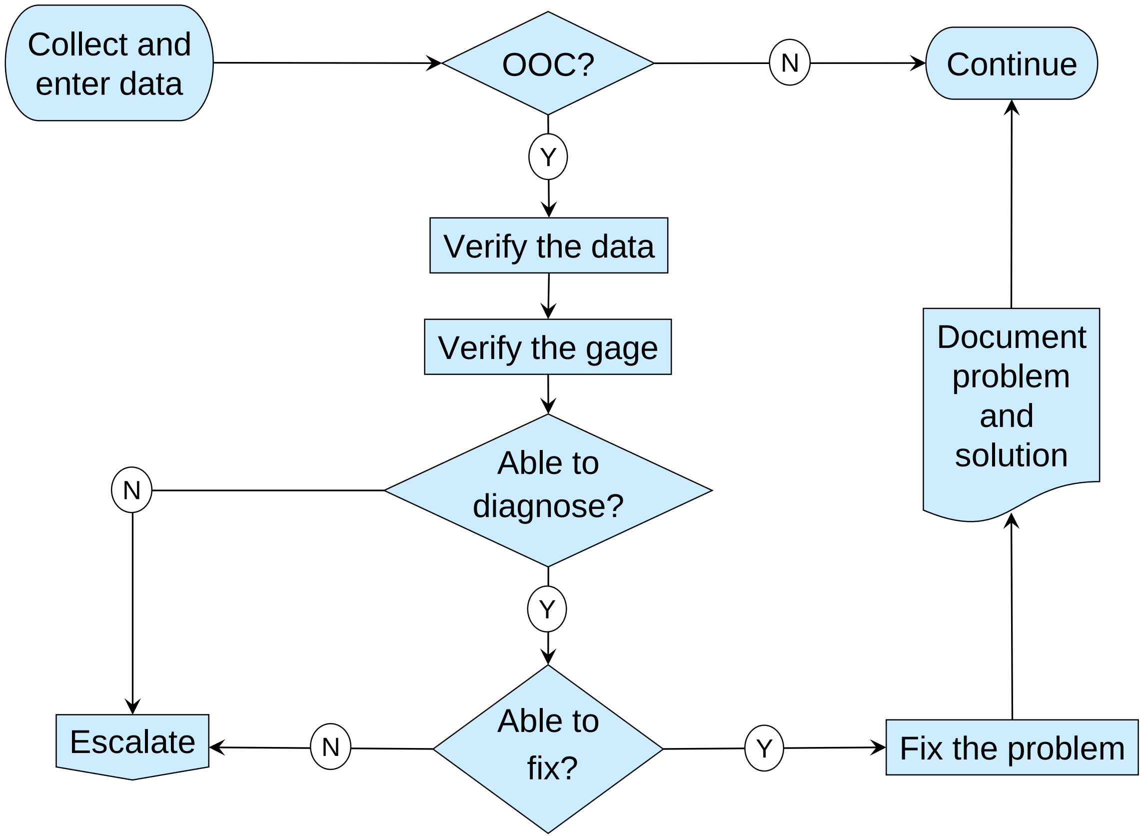
Out-of-control event (OOC)

1. Investigate to determine the cause

2. Take corrective action to eliminate the cause



Response plan "skeleton"

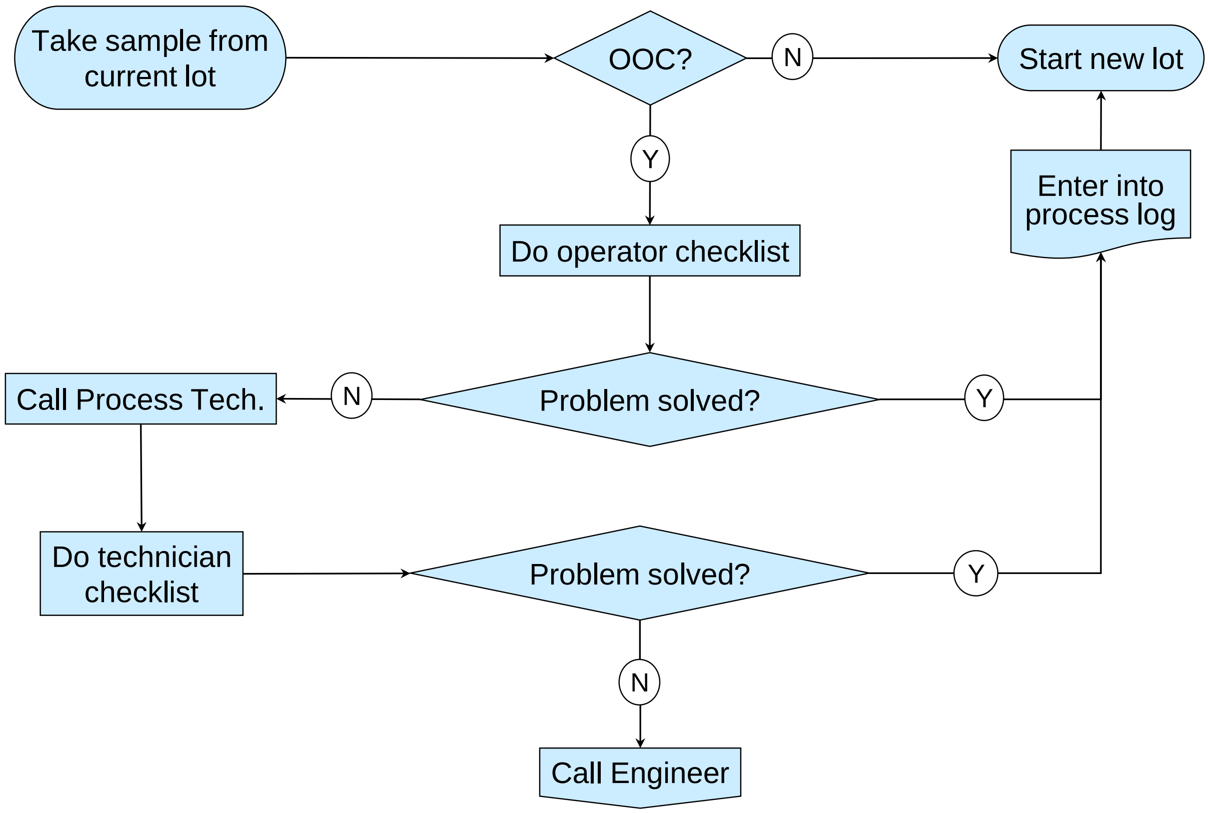


Notes

OOC stands for “out of control.” It means the control chart indicates an assignable cause according to one or more selected tests. A point outside the control limits is one such test. Some other tests will be described later.

The success of statistical monitoring depends on having a documented plan for responding to out-of-control signals. The most successful form of documentation for a response plan is a process map like the one shown here, posted in a place clearly visible to process participants.

Response plan example



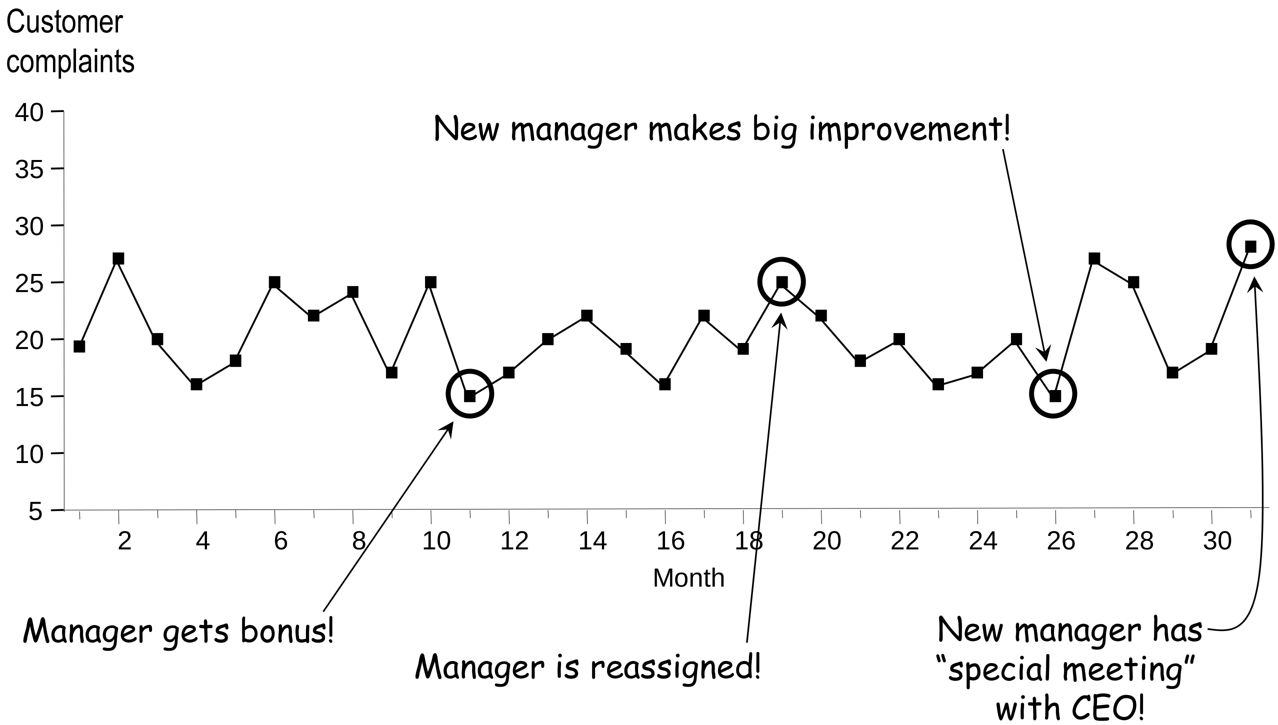
Notes

This is a real example ("sanitized" a little) from a high-volume automated assembly process. It was developed by a team including operators, technicians, engineers and the manufacturing area manager.

Based on experience, they wanted to verify an OOC on the first sample with a second sample from the same lot before going into investigation mode. Note the escalation from Operator to Technician to Engineer.

Once investigation mode was entered, production was halted until the *Start new lot* point in the response plan was reached. This may seem like harsh discipline, but it worked. Within a few months of implementation, previously chronic equipment and process issues were quickly sorted out. As a result, unplanned downtime and use of Engineering support plummeted. Manufacturing productivity increased dramatically, and engineers were able to spend more of their time on development projects.

Over-reacting to data



Over-reacting (cont'd)

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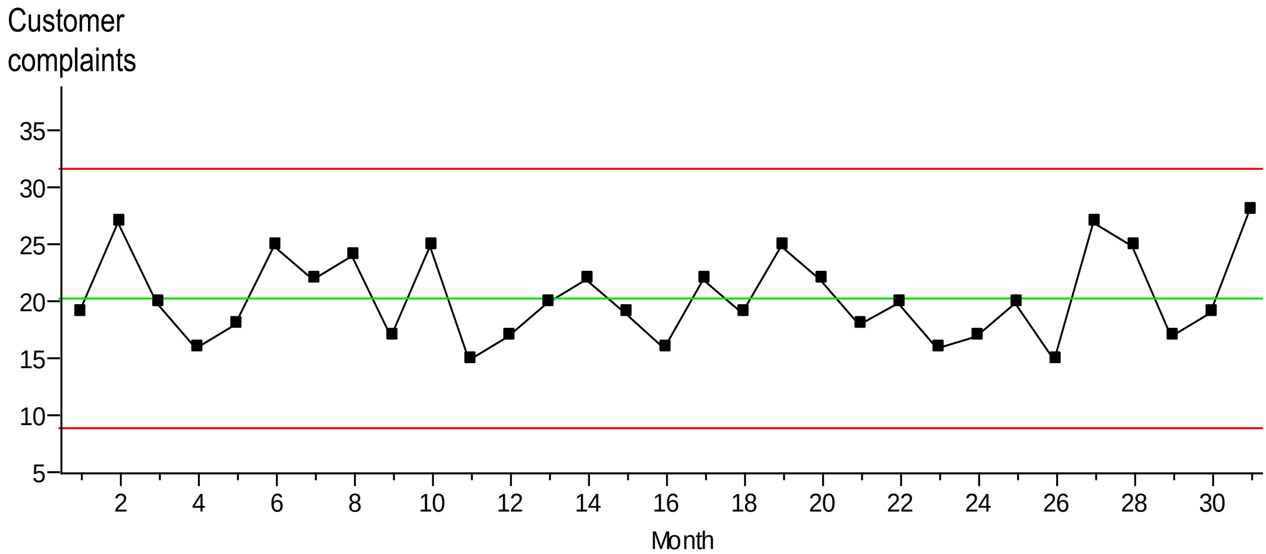
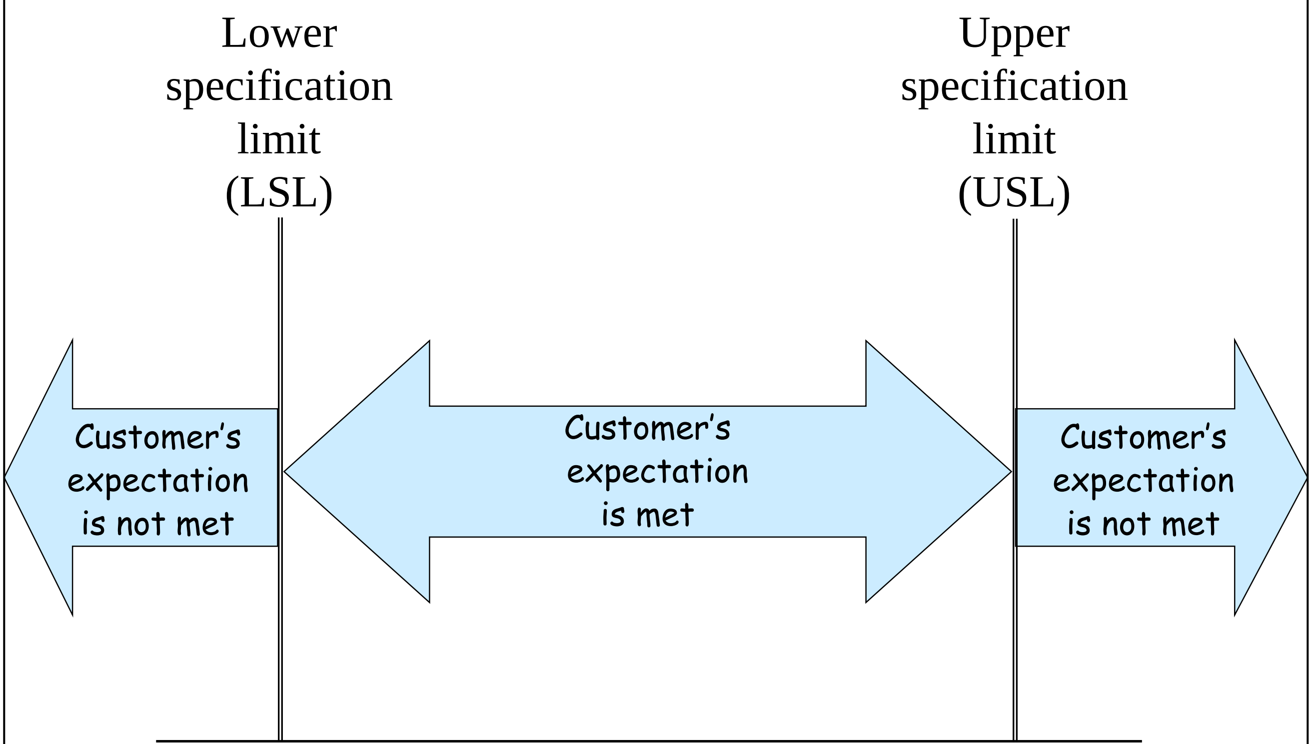
There are no assignable causes here!



- If there is a problem here, it is the **average** number of complaints
- This problem cannot be solved by reacting to individual data points
- What would be a **rational** approach to solving this problem?

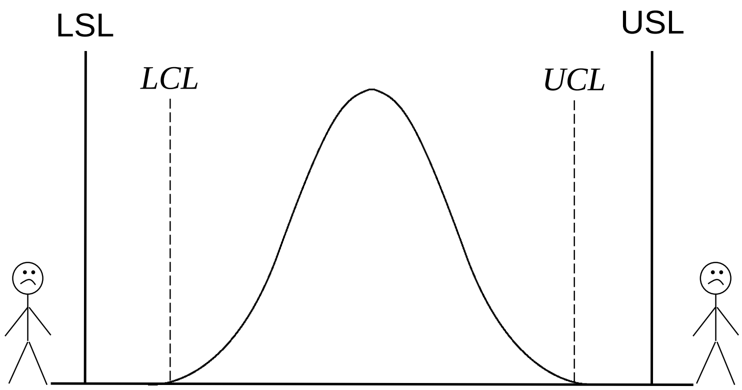
What about specification limits?



Notes

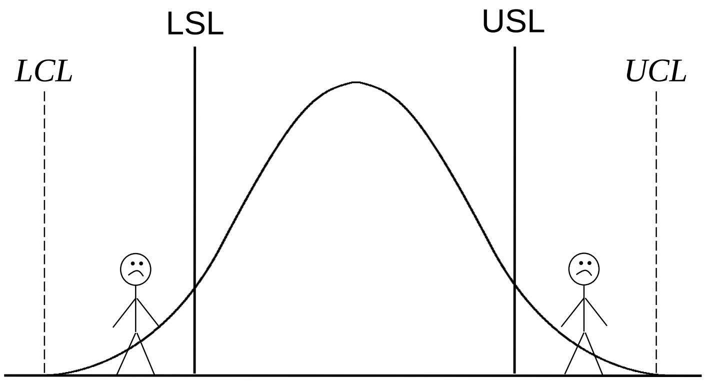
Specification limits represent what the customer will and with not accept. Data points outside the spec limits always trigger a disposition process, usually scrap or rework. However, data points outside the spec limits *may or may not* trigger the response plan. It all depends on whether the process in question has good or bad statistical capability.

The role of process capability



- If a process has good capability, the control limits are inside the spec limits
- Any data point outside the spec limits is automatically an assignable cause, and should trigger the response plan

Process capability (cont'd)



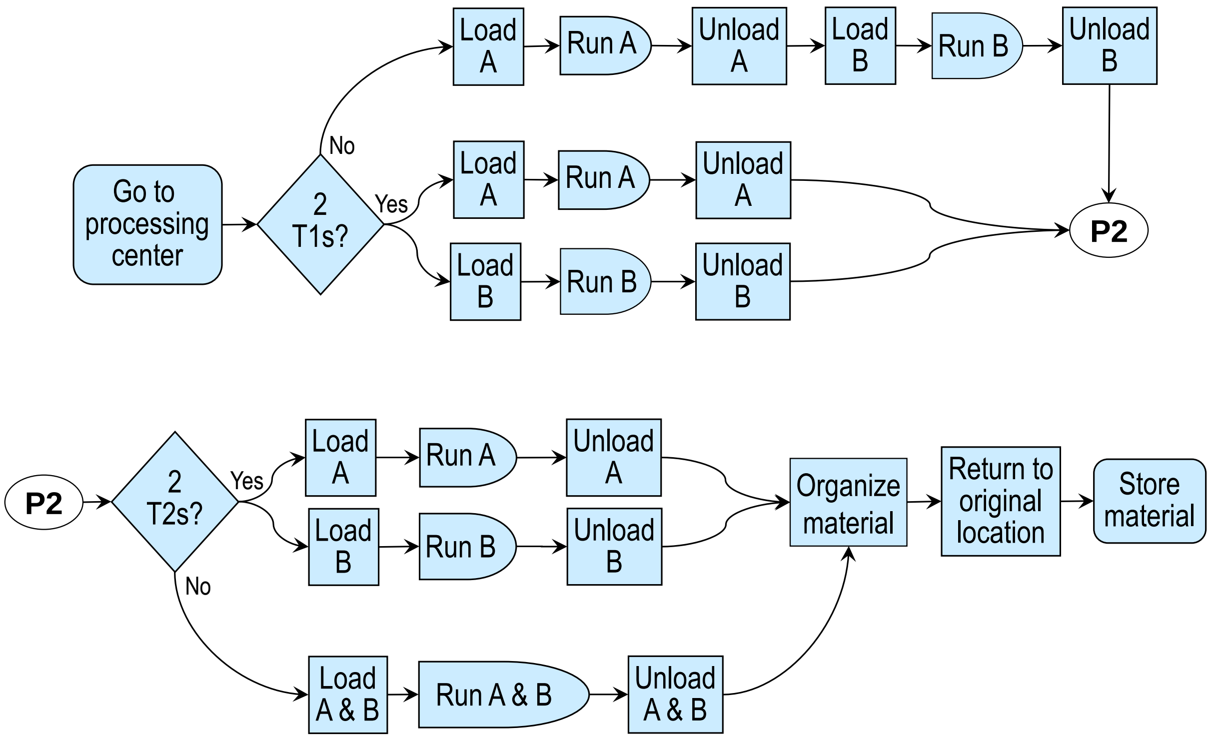
- If a process has bad capability, the control limits are outside the spec limits
- There will be data points outside the spec limits that are not assignable causes
- These points should *not* trigger the response plan

Notes

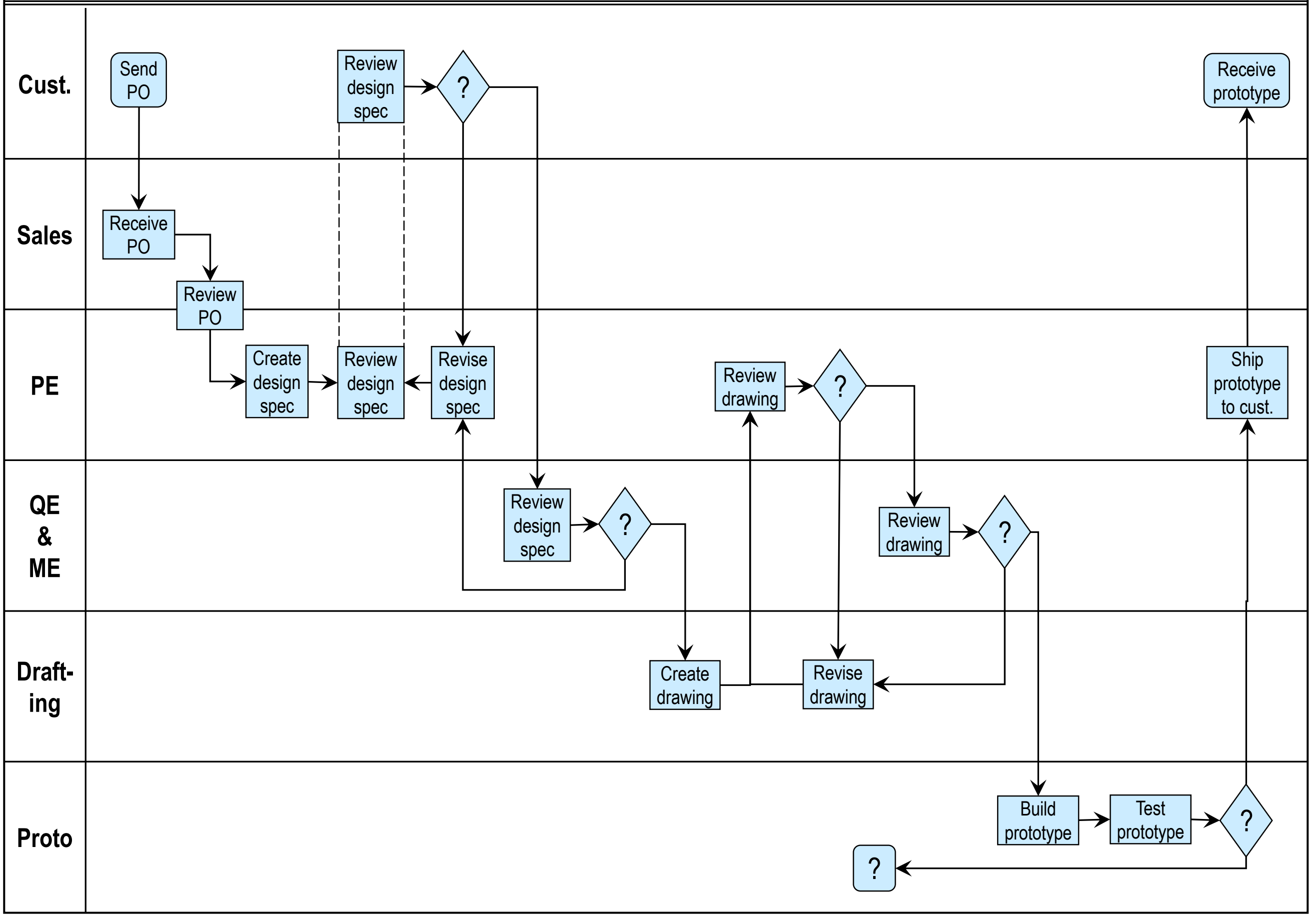
Notes

Solutions to Exercises

Section 6, exercise 1



Section 6, exercise 2



Section 6, exercise 3

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

Section 6, exercise 4

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

Section 10, control limit exercise

a) For the $\overline{X}$ chart: $UCL = 4.92 + (0.577 * 2.13) = 6.148$

$LCL = 4.92 - (0.577 * 2.13) = 3.694$

b) For the R chart: $UCL = 2.13 * 2.114 = 4.497$

$LCL = 2.13 * 0 = 0$