Anexas Consultancy Services

ANEXAS EUROPE ©
CERTIFICATION TRAINING

Lean Six Sigma Black Belt

Anexas Consultancy Services

Course Overview

Introductions and Expectations

Introduce yourself to the group:

- Name
- Job
- Any one thing not many people know about you!
- Expectations for the session

Ground Rules

- Be on time
- Start and end on time
- Take a spelling holiday
- Participate, don’t spectate
- Track issues and questions for later on the parking lot
- ON-LINE TRAINING
  - Keep cameras OFF during the training
  - Please interact using the chat box or comment box
  - If you wish to speak, please unmute yourself and speak and afterwards mute yourself once again
- CLASSROOM TRAINING
  - Don’t conduct any side-conversations
  - It’s OK to stand up and stretch
  - Turn off your cell phones or set them on vibrate
  - Conduct business at breaks and lunch
- Have fun!

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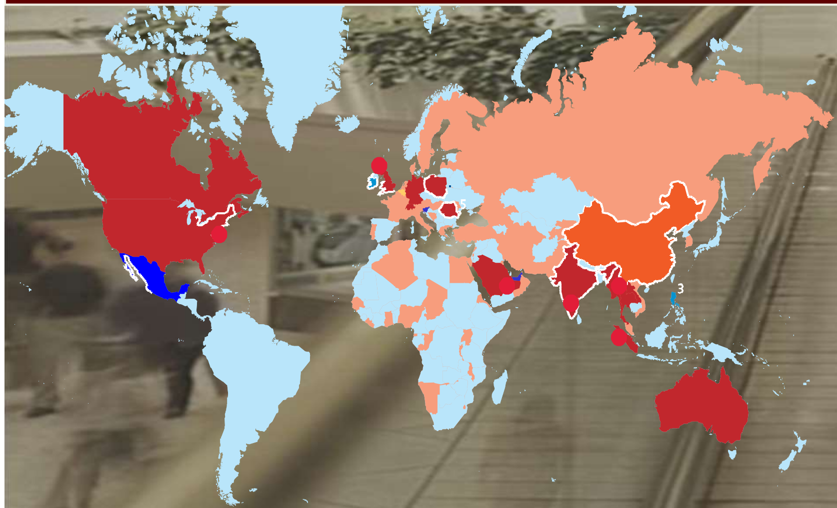
Introduction to Anexas

Objectives

- To introduce you to Anexas Consultancy Services
- Introduce the benefits available to Anexas alumni
- Project support details
- Certification process

About Anexas

Enabling individuals and organizations achieve excellence since 2006



- Anexas is a global network of lean six sigma and project professionals serving the wide spectrum of industries. We operate in 10 countries and have 25 professionals in the team.
- Our mission is to help organizations and individuals achieve excellence.
- Trained more than 150,000 professionals in Lean and Six Sigma, Project Management and quality related trainings across the world from various industries.
- Lean Green Belts and Black Belts certified by Anexas have completed more than 5000 successful projects under our guidance.

Completed Projects for Worldwide Organizations by Anexas

Some of Our Clients

-Al Futtaim

-DP World

-ADNOC

-Concentriix

-UAE Exchange

-Novartis

-Colgate Palmolive

-International Medical Centre

- And many more…

•Reduction of cycle times by more than 50%, at times to more than 90%

•Error reduction ranging from 50% to 100%

•Total project savings worth more than 50 Million Dollars

•Certified more than 10,000 Black Belts, 20,000 Green Belts and trained more than 50,000 professionals in Lean and Six Sigma, project management and strategic management

Anexas has won many Project and Quality Management Awards
Anexas projects presented in World Conferences in ASQ, IQPC, Dubai Quality Awards, ADIPEC, etc.

Satisfying Customers — The Problem

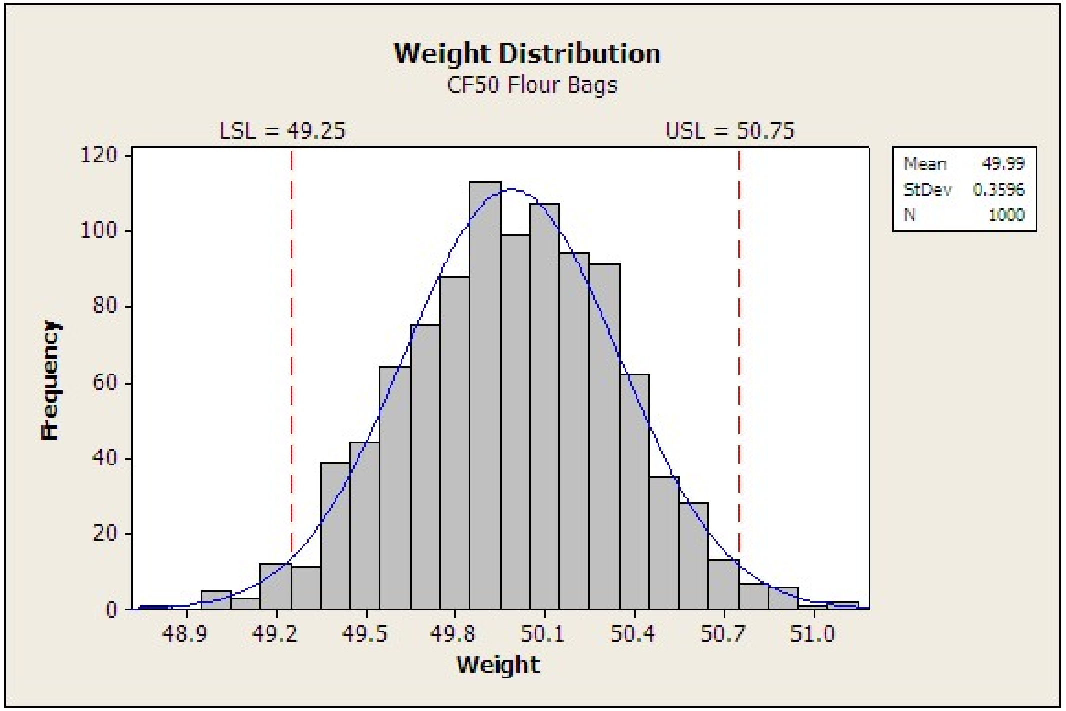
- Best Flour Milling produces and distributes white corn flour to a wide range of customers within the tortilla industry
- The product is shipped in 50-pound multiwall paper bags that are loaded and weighted at the end of the production line

- **Defining the problem:** Approximately 4% of the bags are found to be either overweight or underweight, an issue that the organization spends an average of approximately US$5 million per year to address

Satisfying Customers — The Measure

- Best Flour knows that customers will be satisfied if the bag weight remains within agreed-upon limits
- The chart below shows the weight distribution of 1,000 bags taken from the production line, along with the spec limits

4% fall beyond the spec limits



Measuring Process Capability

We will use the Best Flour example to illustrate how we can use Six Sigma to measure process capability

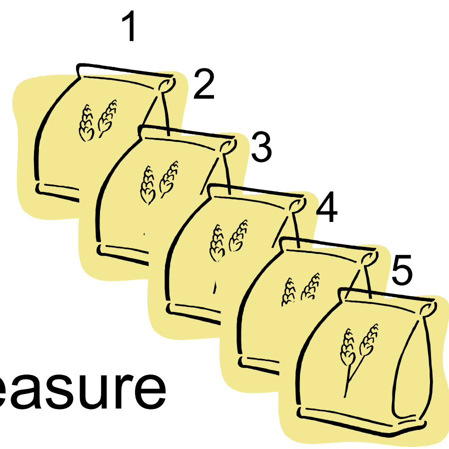
Processes have

- → A level (e.g., average or mean)
- → Some measure of variation

How do we measure level and variation?

Measuring the Average

Consider the production of the 50-pound flour bags



Let's take five bags from production and measure their weight

Bag No.	1	2	3	4	5
Weight (pounds)	48	49	50	51	52

Measuring the Average, cont.

We can then calculate the average as follows:

$$\text{Average} = \frac{48 + 49 + 50 + 51 + 52}{5} = 50 \text{ lb}$$

Or, using the formula…

$$\text{Average} = \frac{\Sigma X_i}{n} \rightarrow \mathbf{(i = 1, 2, 3, \ldots n)}$$

Also known as **mean**

Number of points in the data set

Measuring the Variation Around the Average

Let "S" be the variation around the average

$$S = \frac{\underbrace{(48-50)}_{-2} + \underbrace{(49-50)}_{-1} + \underbrace{(50-50)}_{0} + \underbrace{(51-50)}_{1} + \underbrace{(52-50)}_{2}}{5} = \text{ZERO}$$

But, if we square all quantities in the **numerator**…

$$S = \frac{(48-50)^2 + (49-50)^2 + (50-50)^2 + (51-50)^2 + (52-50)^2}{5} = 2 \text{ sq-lb}$$

Measuring the Variation Around the Average, cont.

Any issues with this?

This quantity does not add or "subtract any value. There are only 4 (i.e., 5 – 1) "independent" values in the data set

Variation is measured in squared units

$$S = \frac{(48-50)^2 + (49-50)^2 + (50-50)^2 + (51-50)^2 + (52-50)^2}{5} = 2 \text{ sq-lb}$$

Measuring the Variation Around the Average, cont.

So…

the square root brings it back to the original unit

$$S = \sqrt{\frac{(48-50)^2 + (49-50)^2 + (50-50)^2 + (51-50)^2 + (52-50)^2}{(5-1)}} = 1.58 \text{ lb}$$

The variation calculated this way is called **standard deviation** (S)

Subtracting 1 from “n” eliminates the “non-value-adding” quantity

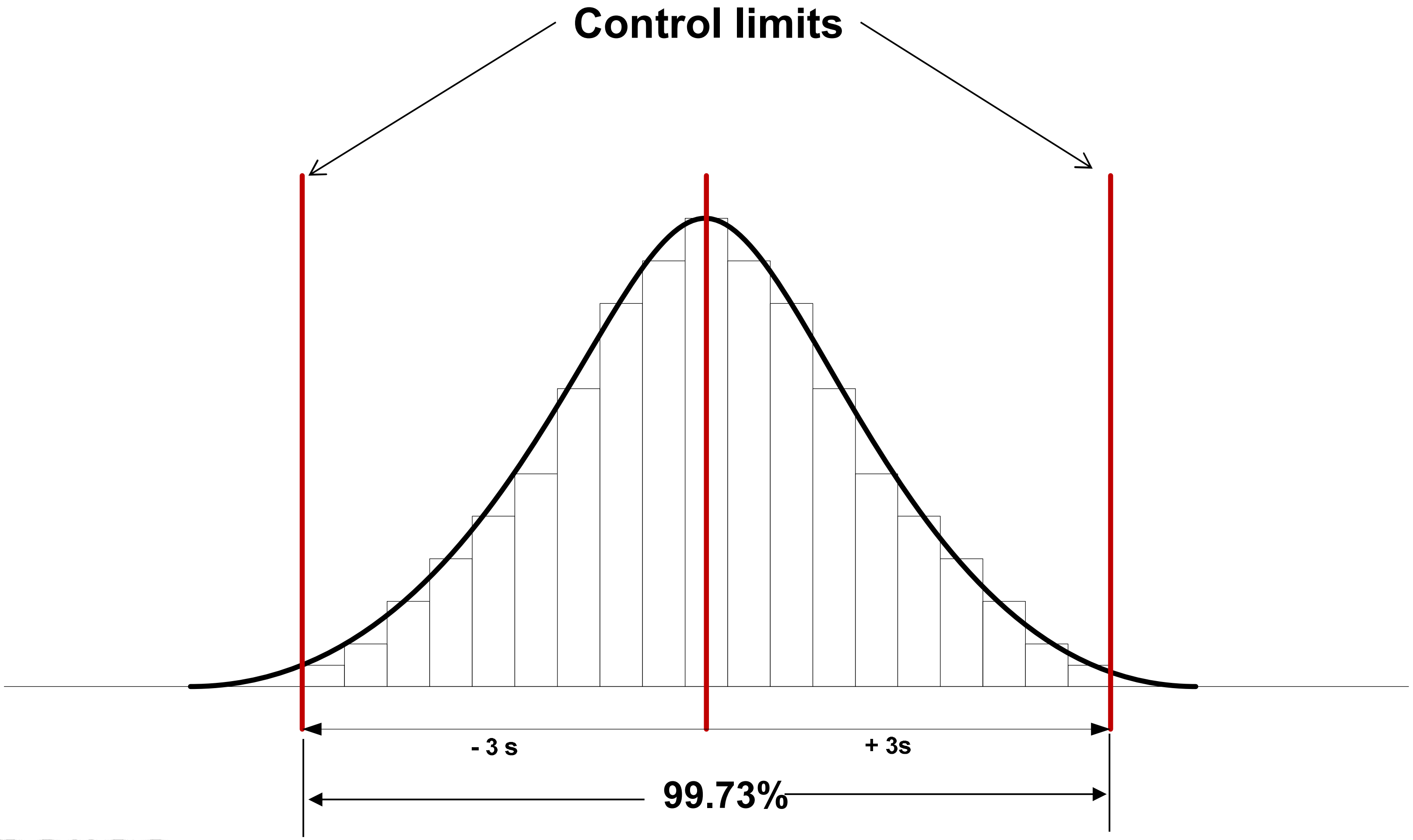
Measuring the Variation Around the Average, cont.

The standard deviation formula…

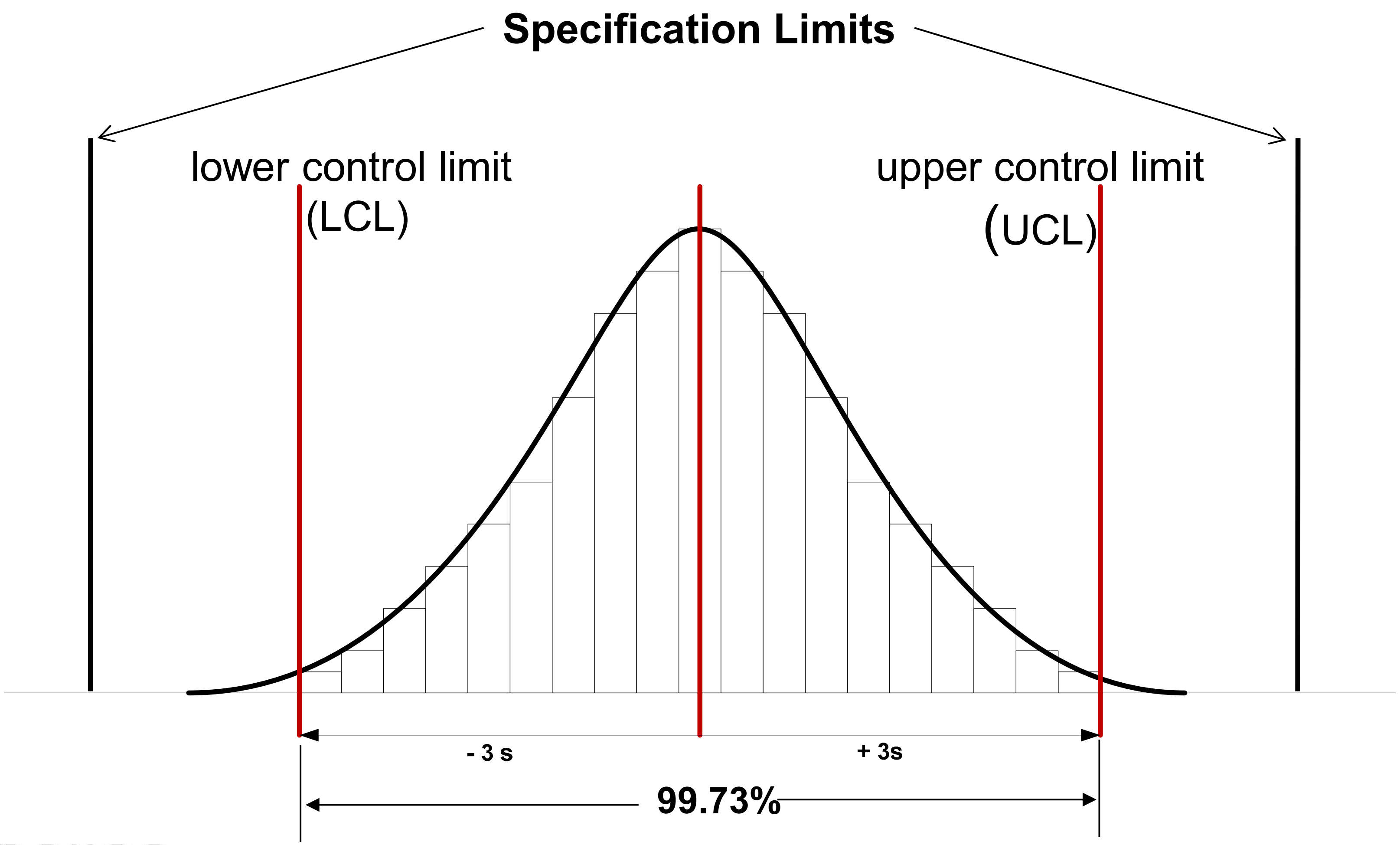
$$S = \sqrt{\frac{\Sigma (X_i - X_{bar})^2}{n - 1}} \qquad (i = 1, 2, \ldots n)$$

Notation		
	Sample	Population
Mean	Xbar	µ
Std. Dev.	S	σ

Understanding “6 Sigma”

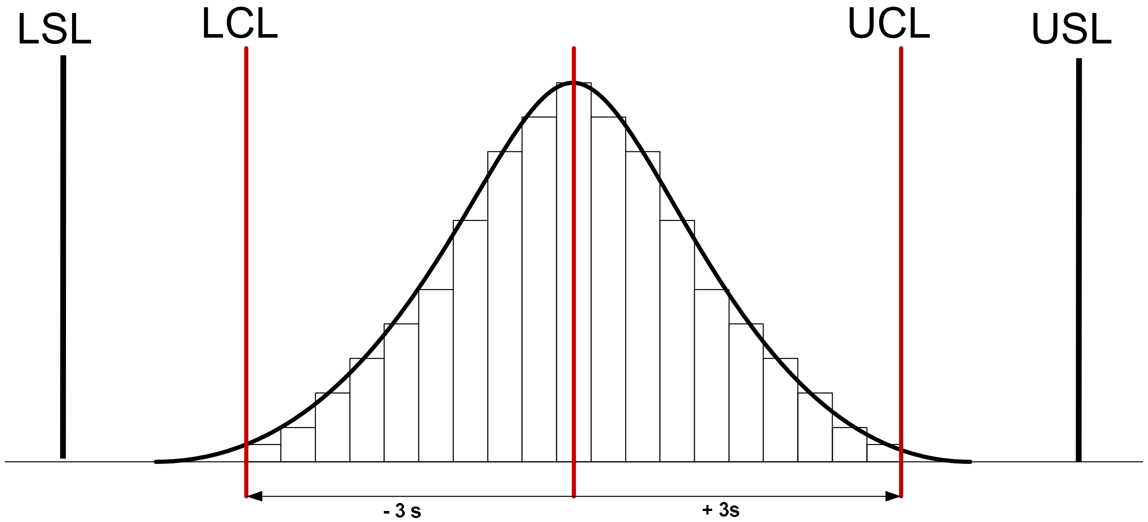


Understanding "6 Sigma," cont.



Understanding "6 Sigma"—Conclusion

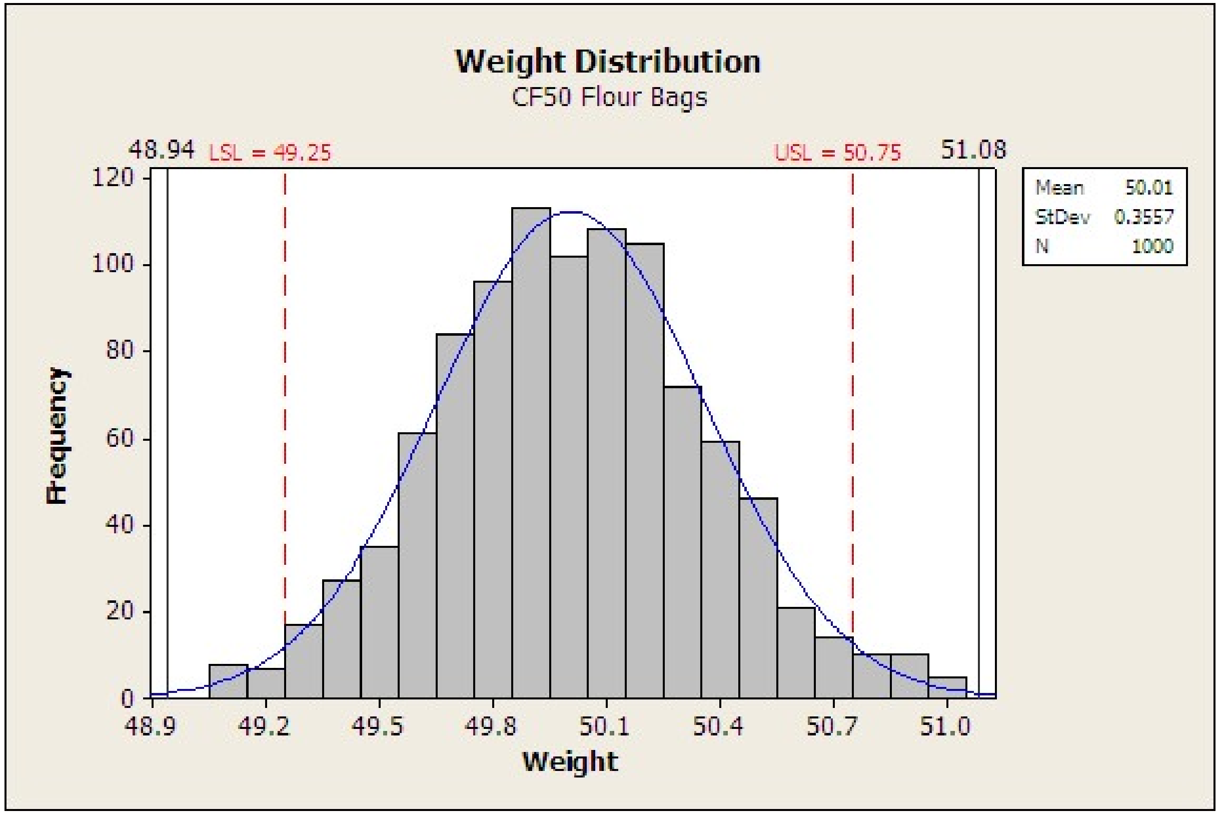
- Process sigma (a.k.a. sigma quality level):
  - An expression of process "yield" in relation to specification limits
  - It measures in **σ** units the distance between the mean and the spec limits
  - 6**σ** away from the mean → 3.4 defects per million opportunities
- Key concepts:
  - Control limits = Voice of the Process
  - Specification limits = Voice of the Customer



The Best Flour Problem

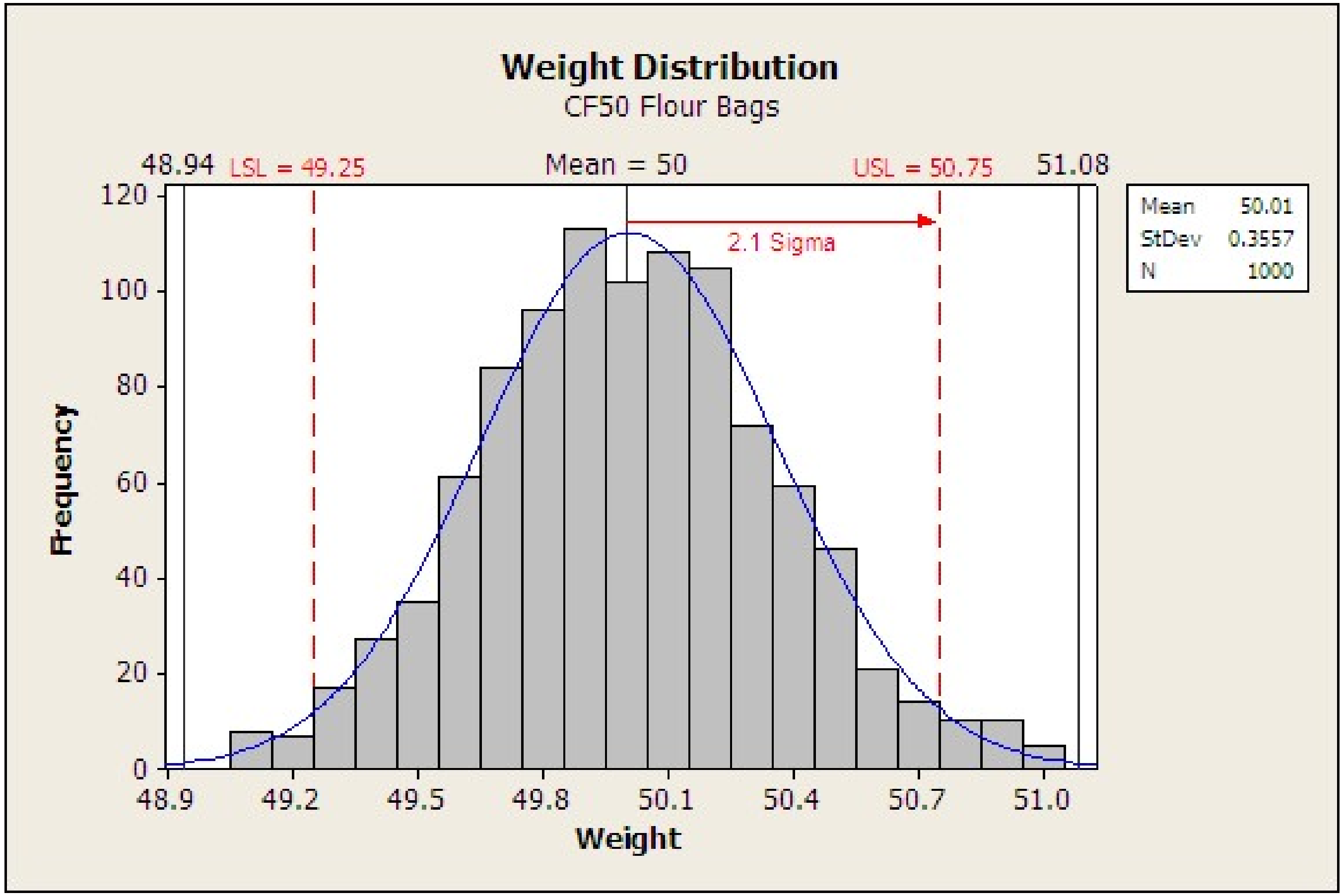
Here are the control limits and the specification limits

- What is happening with the process?
- What should Best Flour do?



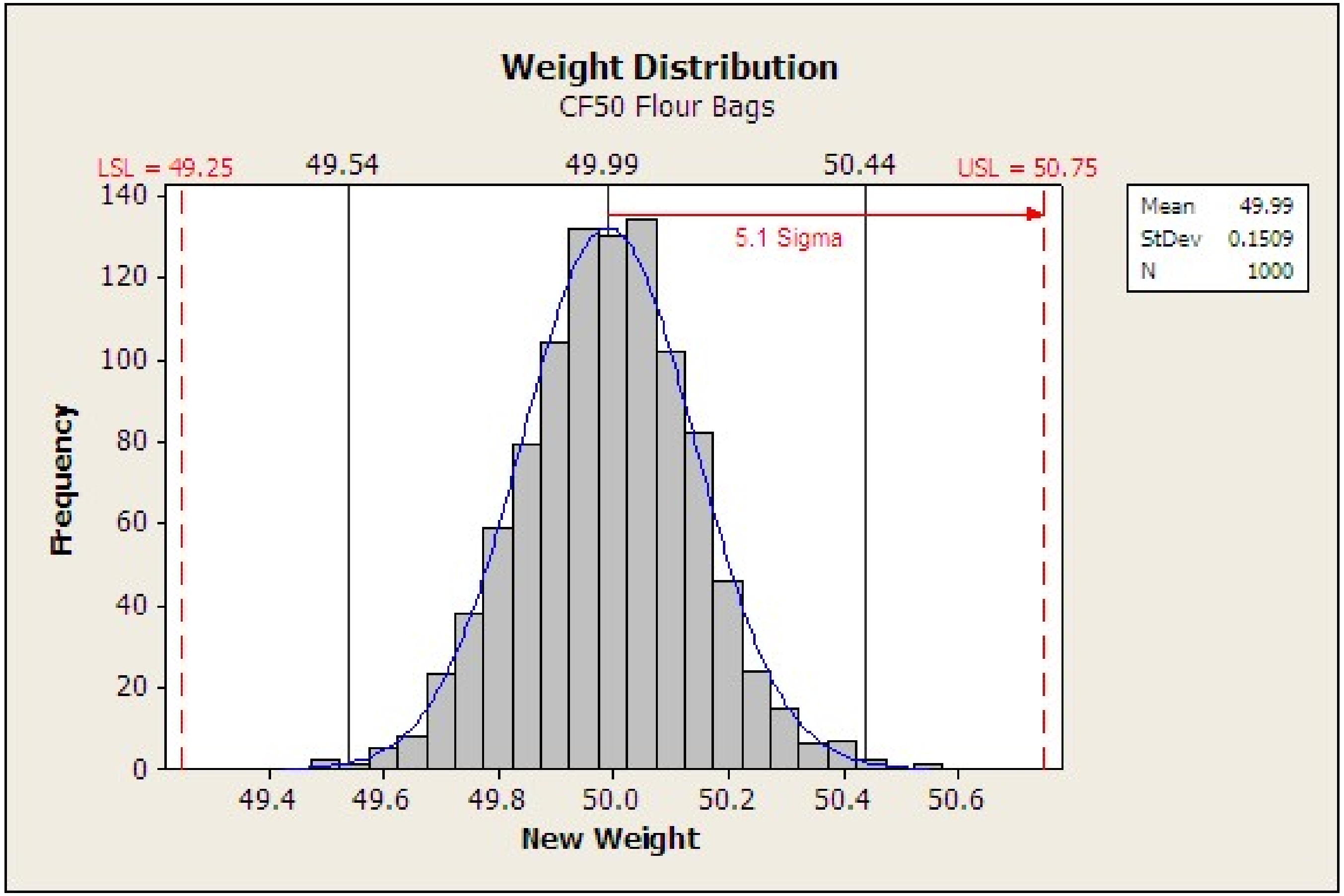
The Best Flour Problem, cont.

Before Improvement: sigma quality level at 2.1



The Best Flour Problem, cont.

After Improvement: sigma quality level at 5.1



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The Six Sigma Metric

Discrete Variables

Variables: Continuous vs. Discrete

- Continuous Variables
  - Can be measured on a continuous scale:
    - Length (inches)
    - Temperature (F)
    - Pressure (PSI)
    - Revenues (US$)
    - Time (hours)
    - Cholesterol (mg/dL)

- Discrete Variables
  - Cannot be measured, only observed, counted, or verified
    - Percent of nonconforming product or service
    - Number of customer complaints
    - Customer satisfaction on a scale from 1 to 10

In this module, we will focus on discrete variables only
Later modules address process sigma for continuous variables

Process Sigma — Discrete Variables

- First we calculate the process yield by obtaining the percent of items conforming to specifications over some given period

$$\text{Yield} = \frac{\text{\# in spec}}{\text{\# in spec + \# out of spec}} = \text{\% in spec}$$

- Then, we obtain process sigma from the Six Sigma table (below)
  - Example: over a 7-day period, we produced 200 batches of product and 20 were out of spec

$$\text{Yield} = \frac{180}{200} = 90\% \Rightarrow \text{Sigma} \approx 2.8$$

Different Levels of Process Sigma

- From a broad perspective, consider the following when reviewing different process sigma values:

Too much variation	Hard to produce output within specs	Low sigma values (0 – 2)
Moderate variation	Most output within specs	Middle sigma values (2 – 4.5)
Very little variation	Virtually all output within specs	Hi sigma values (4.5 – 6)

Process Sigma and DPMO

Increase in sigma requires exponential nonconformity reduction

DPMO	σ
308,537	2
66,807	3
6210	4
233	5
3.4	6

Why Use Six Sigma as a Metric?

Process sigma is a more sensitive indicator than percentage

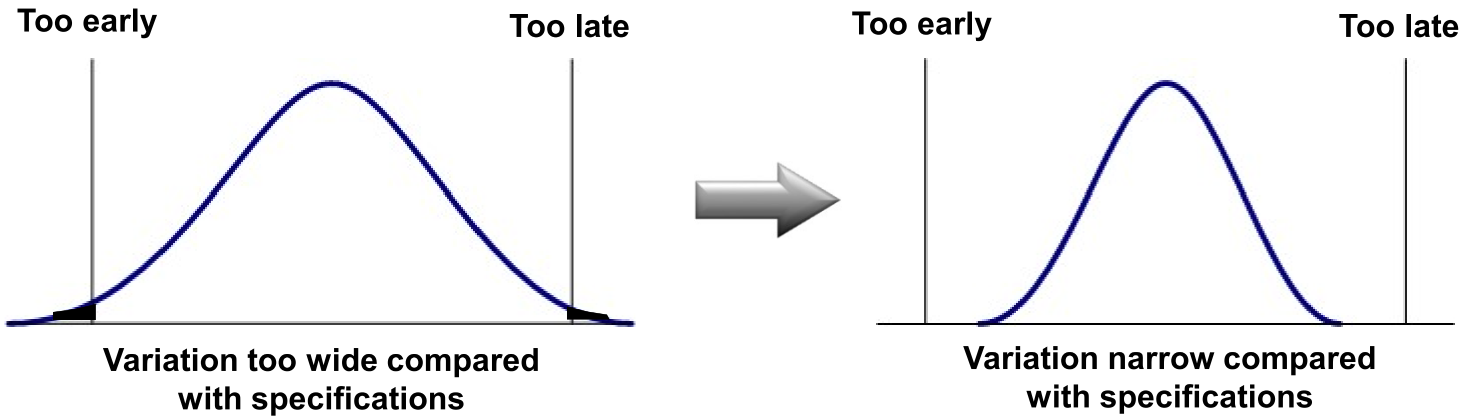
Percent	DPMO	σ
93	66,807	3.0
98	22,750	3.5
99	6,210	4.0
99.87	1,350	4.5
99.977	233	5.0
99.9997	3.4	6.0

Actual Sigma or Rate of Improvement?

- What is most important, the actual sigma level or the rate of improvement in sigma?
  - The calculated process sigma level is influenced by what you define as an "opportunity"—which can be subject to much debate
  - Often, a more enlightening measure of good management is to see how process sigma is changing
    - Increased customer focus and process improvement will be reflected with an increase in process sigma
    - A process sigma that goes up by one unit every year is much more indicative of a customer focus than a process sigma that is constant at 4

Importance of Reducing Variation

- To increase a process sigma level, you have to decrease variation



- Less variation means:
  - Greater predictability in the process
  - Less waste and rework, which lowers costs
  - Products and services that perform better and last longer
  - Happier customers

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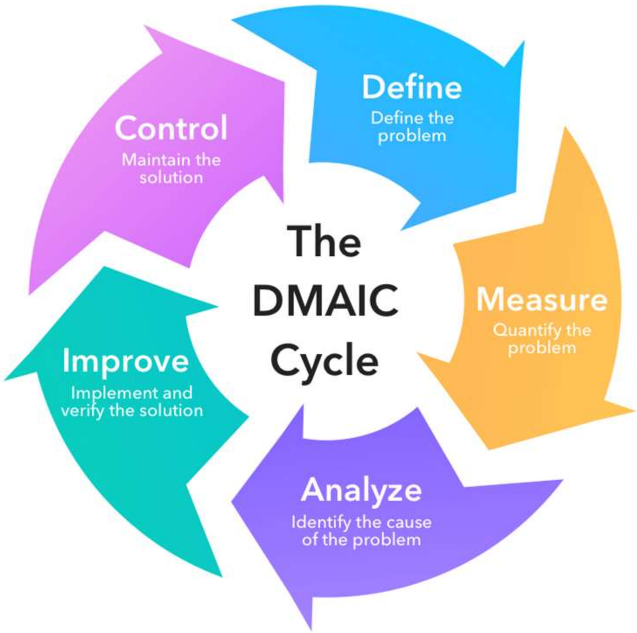
Overview of DMAIC

The Methodology for Process Improvement

The DMAIC Process

Monitor/Measure:
- Standardize process
- Train personnel
- Monitor performance

Define:
- Problem
- Team
- Customer



Generate solutions:
- Set criteria
- Develop/select solutions
- Conduct risk analysis

Implement solutions:
- Plan and implement
- Consider the human side

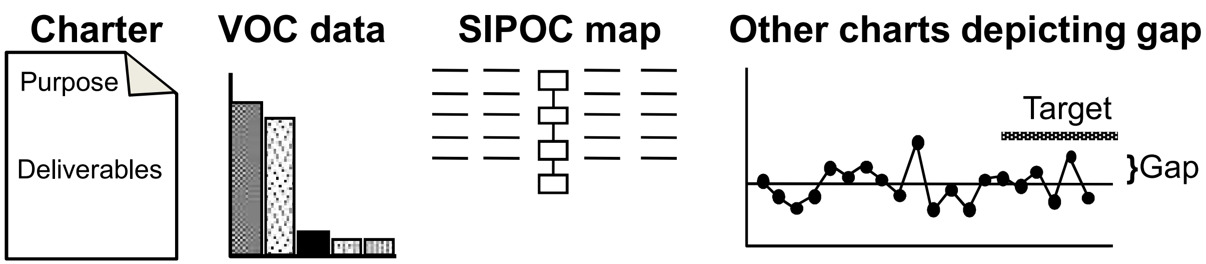
Data:
- Collect
- Plot and analyze

Process:
- Map process
- Narrow the focus

Root-cause analysis:
- Investigate root cause
- Verify potential causes

How Six Sigma Works — DEFINE

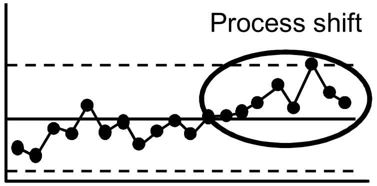
- **Goal:** Define the project's purpose and scope
- **Output:** A clear statement of the intended improvement and how it is to be measured
- **Sample tools:**



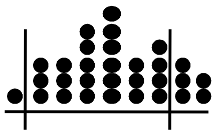
How Six Sigma Works — MEASURE

- **Goal:** Gather information on the current situation
- **Output:** A focused problem statement and baseline process sigma
- **Sample tools:**

Time plot or **control chart** showing patterns in variation over time

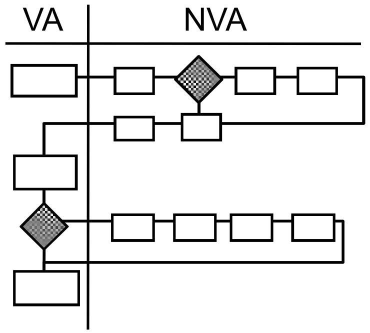


Frequency plot (Histogram) showing patterns in distribution and **process sigma calculations**



$\sigma = 1.4$

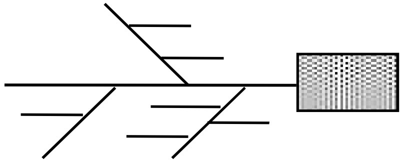
Process map depicting current process



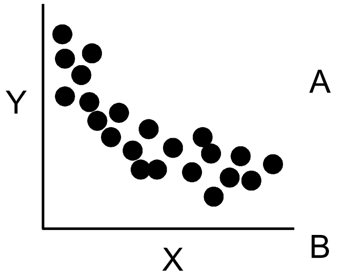
How Six Sigma Works — ANALYZE

- **Goal:** Identify deep causes and confirm them with data
- **Output:** A theory that has been tested and confirmed
- **Sample tools:**

Cause-and-effect diagram
(or other tool showing
potential causes identified)



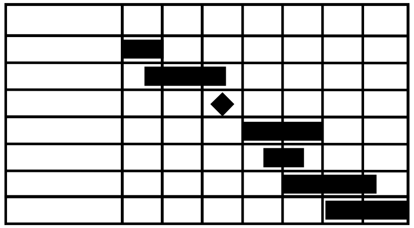
Scatter plot, **stratified frequency plots**, or **tables** showing verification data



How Six Sigma Works — IMPROVE

- **Goal:** Develop, test, and implement solutions that address deep causes
- **Output:** Planned, tested actions that should eliminate identified root causes or reduce their impact
- **Sample tools:**

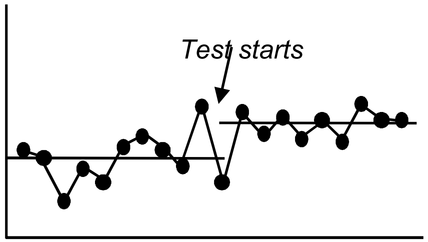
Plans for implementation



Solution matrix showing ranked criteria and scoring for each solution option

A	●		○	4
B	●	●	●	1
C	△	○	●	3
D	●	△	●	2

Results of pilot tests



How Six Sigma Works — CONTROL

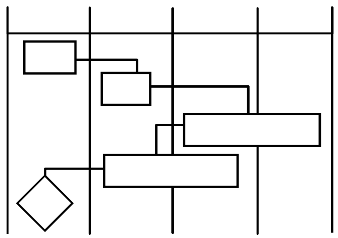
- **Goal:** Maintain the gains by consistently implementing the new work methods or processes
- **Output:**

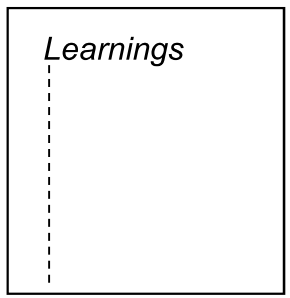
  Documentation of the new standardized method

  Training in the new method

  A system for monitoring consistent use of the new method and checking the results
- **Sample Tools:**

Samples of standardization documentation
including revised maps, process management chart, etc.





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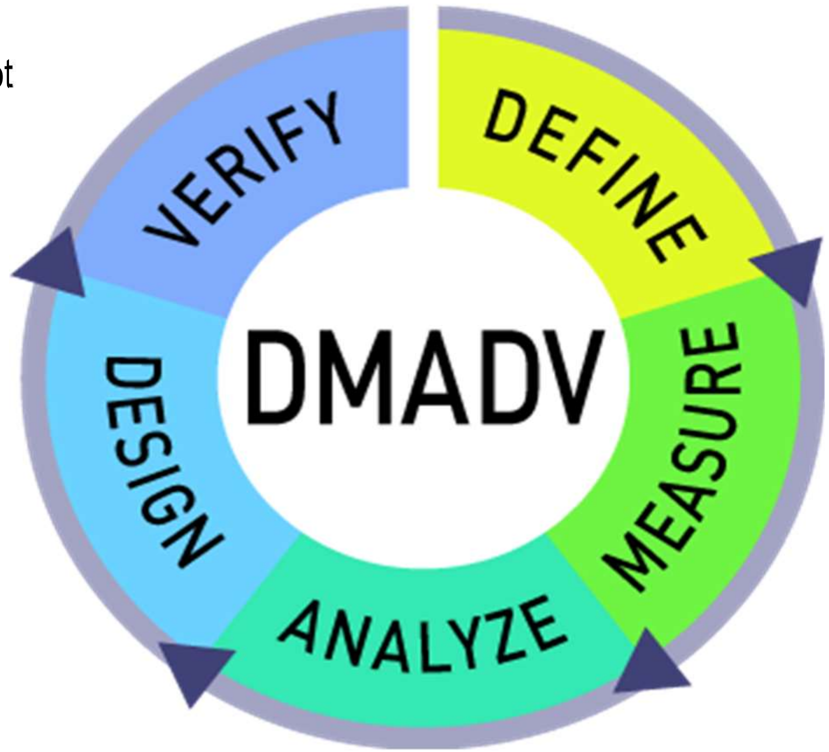
Overview of DMADV

The Methodology for Process Design

The DMADV Process

Verification/validation:
- Conduct and evaluate pilot
- Implement design
- Close project



Define project:
- Develop charter
- Develop project plans
- Develop change plans
- Assess risks
- Review tollgate requirements

Product/service design:
- Identify and prioritize design elements
- Develop design requirements
- Design product and process
- Predict design performance
- Optimize design
- Plan pilot

Get data:
- Collect VOC data
- Translate VOC into CTQs
- Prioritize CTQs
- Reassess risk

Conceptual design:
- Identify and prioritize key functions
- Generate, evaluate, select, and review key concepts

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Overview of DMAIC—The Process Improvement Methodology

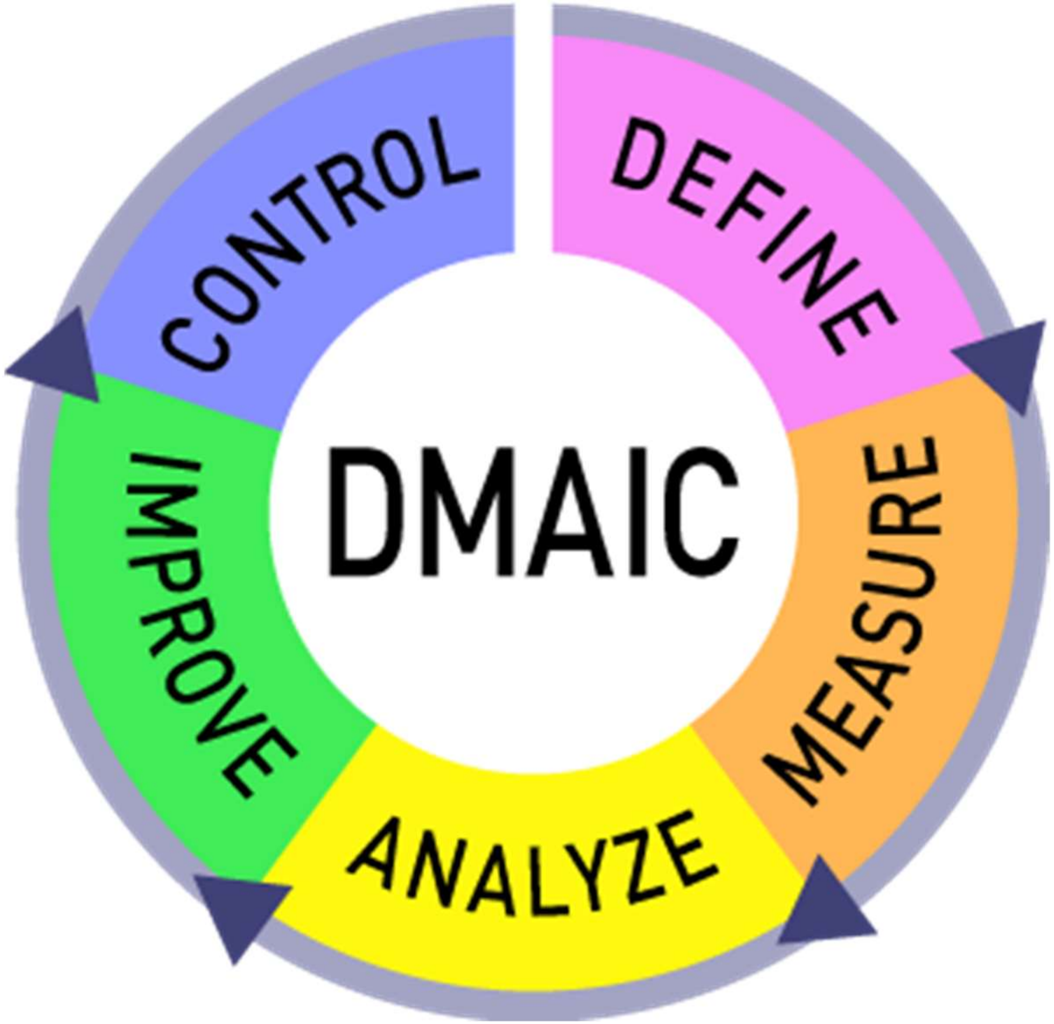
Goals

- Identify the steps and their sequence in DMAIC
- Match each of the steps with its outputs
- Be aware of tools and concepts useful in each step

Why Use an Improvement Methodology?

- Provides a framework
- Provides a common language
- Provides a checklist to prevent skipping critical steps
- Allows you to improve how you improve

Overview of DMAIC



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DEFINE: Define the Project

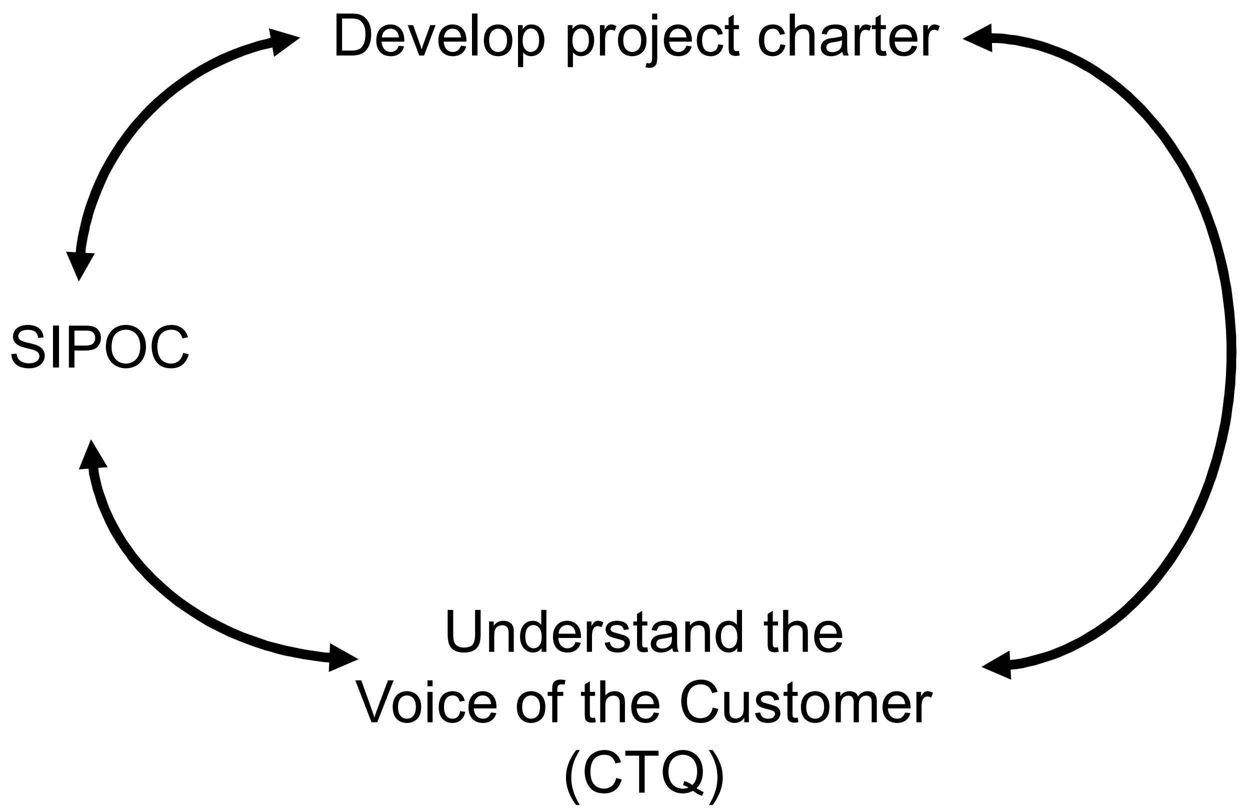
Overview

You Are Here — DEFINE

DEFINE: Define the Project

- **Goal**
  - Define the purpose and scope of the project and get background on the process and customer
- **Outputs**
  - A clear statement of the intended improvement and how it is to be measured
  - A high-level map of the process
  - A translation of the VOC into CTQ
  - An initial project plan

Approach to DEFINE



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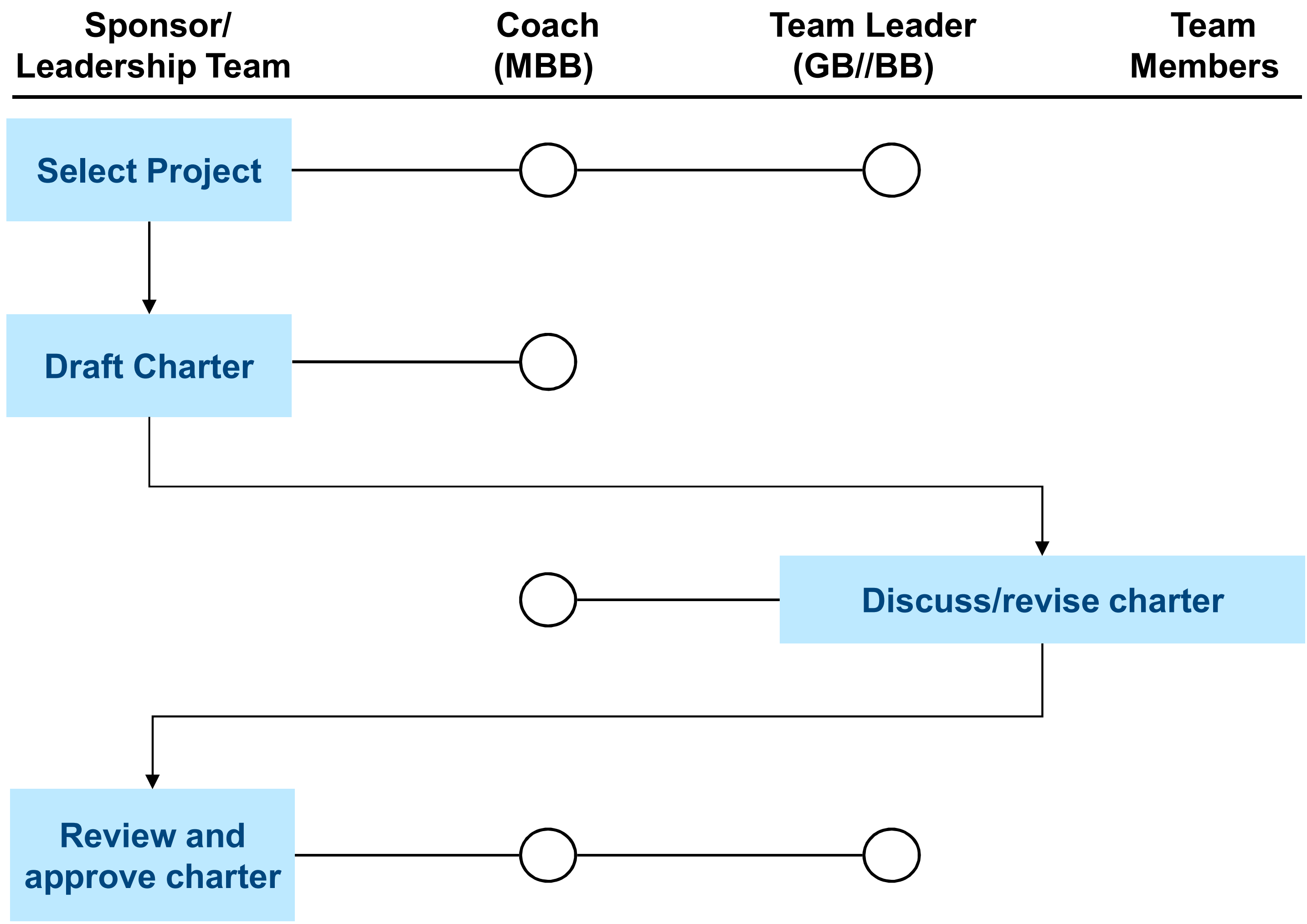
Starting Your Project

How This Work Gets Done



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Project Criteria

DMAIC Project Selection Criteria

DMAIC projects will likely have greater success if:

- The problem is related to a key business issue
- The problem is linked to a clearly defined process (you can identify the starting and ending points)
- You can identify the customers who use or receive the output from this process

DMAIC Project Selection Criteria, cont.

DMAIC projects will likely have greater success if (cont.):

- You can clearly identify what a defect is and count its occurrences
- You can demonstrate how improvements could enhance financial performance
- There is appropriate organizational support

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Drafting Your Charter

DMAIC Project Charter

Project No.:_____________

Project Name:	**Core Process:**
Resource Plan:	**Team Members/Support Resources:**
Black Belt : **Sponsor:** **Process Owner:** **Six Sigma Leader:** **Black Belt and Master Black Belt:**	*Text*
Problem Statement	**Scope**
For the last 2 years, procurement time in our organization is 120 days for XYZ type of items/services.	*Corporate services included* *Projects not included*
Goal Statement	**Customer CTQ's**
Reduce procurement from 120 days to 90 days by Feb 2021.	*Text*
Estimate Financial Opportunities / Intangible Benefits	**High Level Project Milestone**
Reduce the procurement time. *Ensures that we comply with the plan* *Ensures timely revenue*	*Define: 15th Nov* *Measure: 15th Dec* *Analyze: 5th Jan* *Improve: 31sb Jan* *Control: 15th Feb*

Validation

Functional Manager/Process Owner	Date:	Sponsor:	Date:	Financial Analyst::	Date:
Black/Green Belt:	Date:	Six Sigma Leader	Date:	Other:	Date:

DMAIC Project Charter

Project No.:_____________

Project Name: Reduce Change-over Time For Oil Types	**Core Process: Oil Refinery Process**
Resource Plan:	**Team Members/Support Resources:**
Green Belt : **Sponsor:** **Process Owner:** **Six Sigma Leader:** **Black Belt and Master Black Belt:**	*Text*
Problem Statement	**Scope**
For the last one year, The Refinery Change-over Time is 6 hours, which reduces the productivity.	*Oil refinery change over processes*
Goal Statement	**Customer CTQ's**
Reduce change-over time from 6 hours to 2 hours by 30th April, 2021.	*Change-over Time*
Estimate Financial Opportunities / Intangible Benefits	**High Level Project Milestone**
Productivity improvement ((XXXX SAR of additional revenue) Plan Adherence Enhanced OEE, Power saving, Utilities saving.	*Define: 15th Nov* *Measure: 15th Dec* *Analyze: 5th Jan* *Improve: 31sb Jan* *Control: 15th Feb*

Validation

Functional Manager/Process Owner	Date:	Sponsor:		Date:	Financial Analyst::	Date:	
Black/Green Belt:	Date:	Six Sigma Leader		Date:	Other:	Date:	

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Understanding and Mapping Processes

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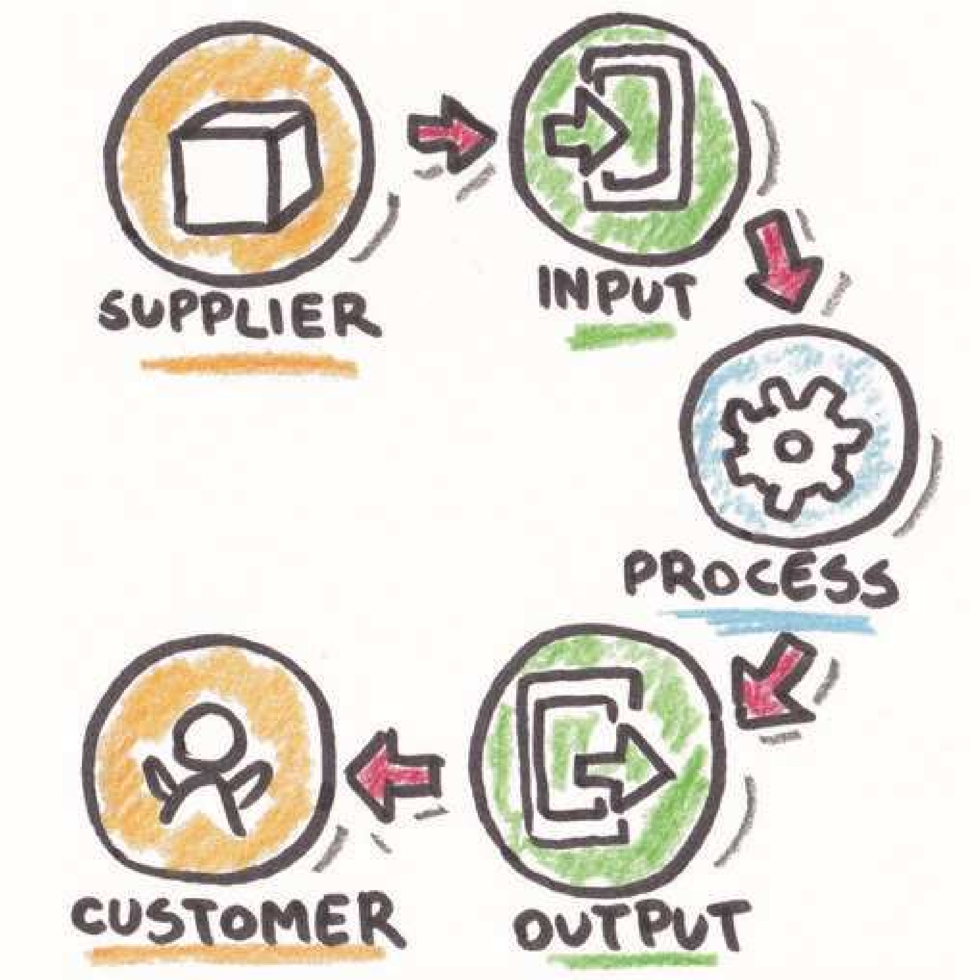
High-Level Process Mapping

SIPOC

SIPOC



SIPOC Example

Making a Photocopy

Suppliers	Inputs	Process	Outputs	Customers
		Put original on glass	Copies	You
		↓ Close lid		File
Office Supply Company →	**Paper**			Others
	Copier Setup	↓ Adjust settings		
You →	**Original**	↓ Press START		
		↓ Remove originals and copies		

SIPOC

Suppliers

Procurement team
Department
HR team
Portal
IT team

Inputs

Software
Purchase Order
Customer Requirements
Material Specifications
Vendors list
Purchase officer

Process

- Start
- Receive PR
- Release RFQ
- Receive Quotations
- Choose Vendor
- Prepare & Send PO
- Deliver Material
- End

Outputs

Procured Material

Customers

Operations

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Understanding the Voice of the Customer

What Is the Voice of the Customer?

- The term Voice of the Customer (VOC) is used to describe customers' needs and their perceptions of your product or service

VOC Process

1. Identify customers and determine what you need to know → 2. Collect and analyze reactive system data; then fill gaps with proactive approaches → 3. Analyze data to generate a key list of customer needs in their language → 4. Translate the customer language into CTQs → 5. Set specifications for CTQs

Outcomes

- A list of customers and customer segments
- Identification of relevant reactive and proactive sources of data
- Verbal (or numerical) data that identify customer needs
- Defined Critical to Quality characteristics
- Specifications for each CTQ

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VOC Data Collection, Step 1

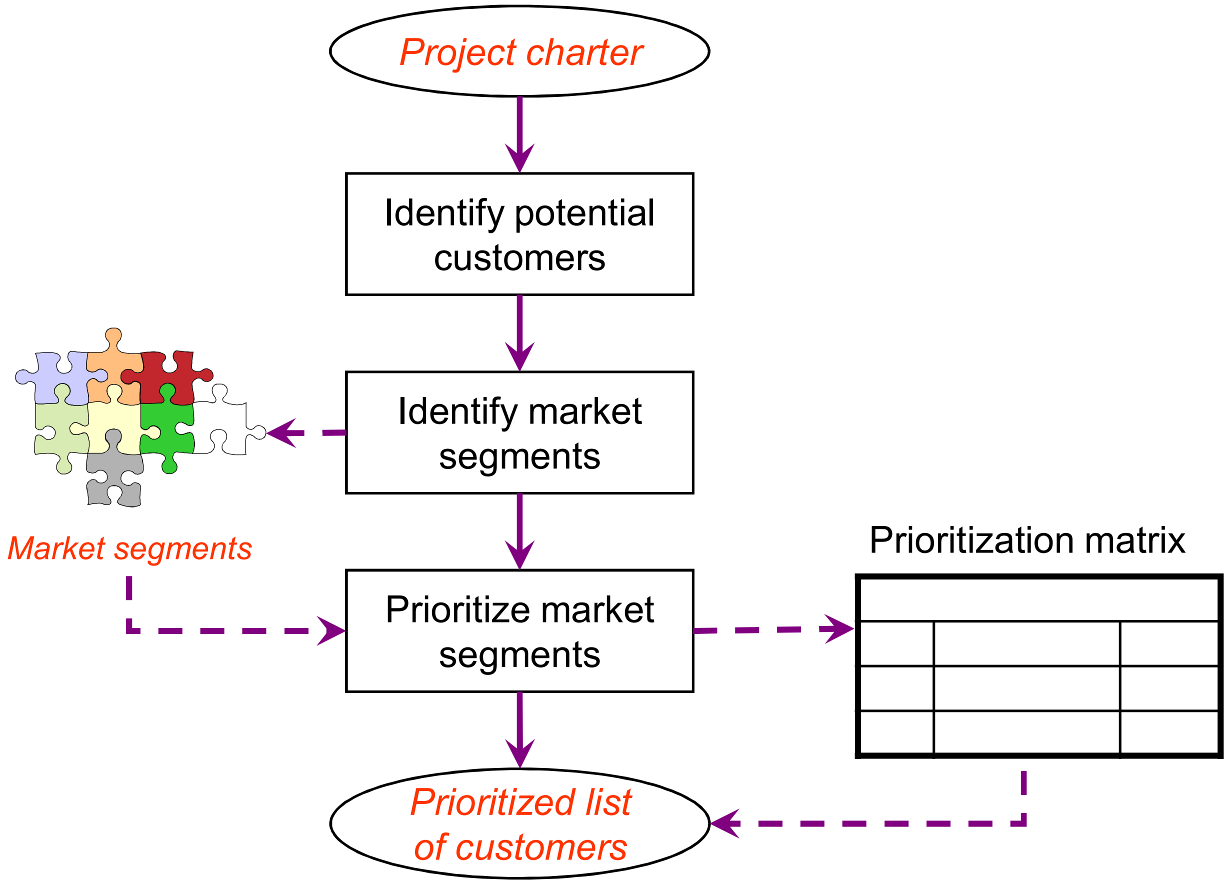
Step 1: Identify Customers and Determine What You Need to Know

1. **Identify customers and determine what you need to know**
2. Collect and analyze reactive system data; then fill gaps with proactive approaches
3. Analyze data to generate a key list of customer needs in their language
4. Translate the customer language into CTQs
5. Set specifications for CTQs

Goal

- Identify your customers
- Decide what you need to know about their needs
- Decide when and how you will get this information

Identify Customers: Process



Project Worksheet: VOC Data Collection Plan

PROJECT:

Who	What and Why
Customers and Segments	Indicate specifically what you want to know about your customers. Develop customized versions of the following questions, which you can ask during face-to-face interviews. • What's important to you? • What's a defect? • How are we doing? How do we compare with our competitors? • What do you like? What don't you like?

Sources

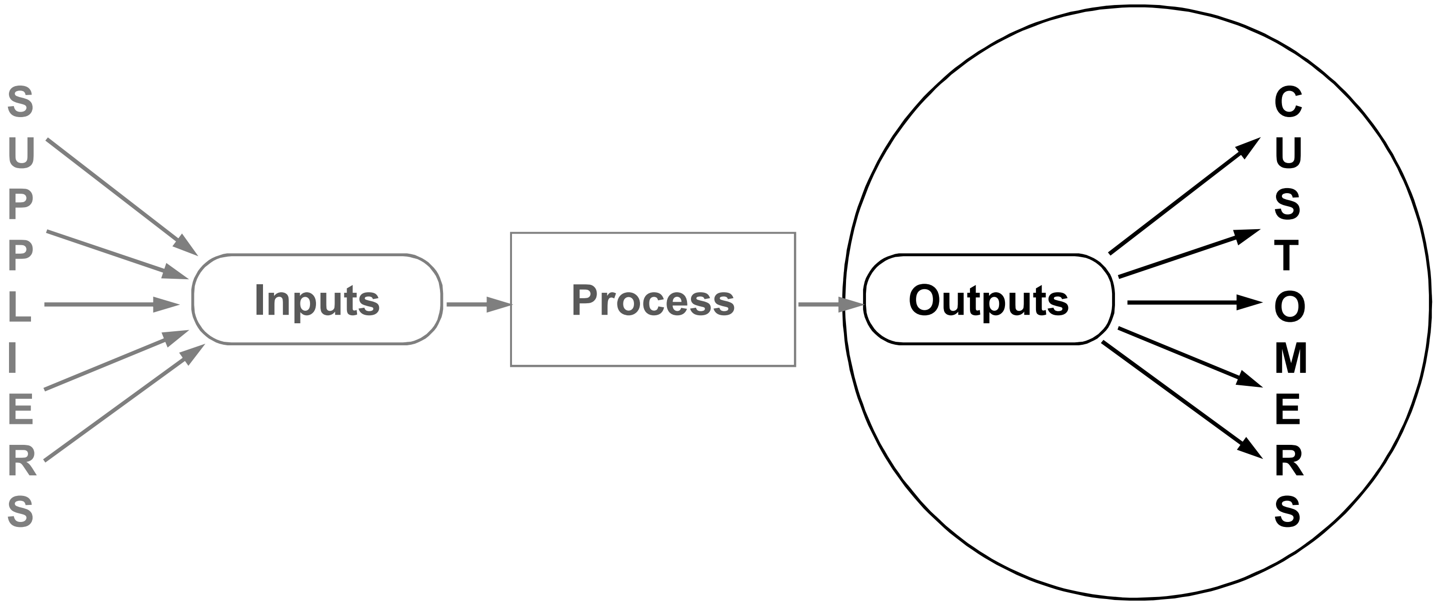
Type an **X** next to the data sources you think will be useful for this project.

REACTIVE SOURCES	PROACTIVE SOURCES
☐ Complaints	☐ Interviews
☐ Problem or service hotlines	☐ Focus groups
☐ Technical support calls	☐ Surveys
☐ Customer service calls	☐ Comment cards
☐ Claims, credits	☐ Sales visits/calls
☐ Sales reporting	☐ Direct observation
☐ Product return information	☐ Market research/monitoring
☐ Warranty claims	☐ Benchmarking
☐ Web page activity	☐ Quality scorecards
☐ Other:	☐ Other:

Summary: Which, How Many, How, and When

On a separate sheet, summarize your plans to gather and use both reactive and proactive sources. Indicate how much data you will get, how you will get it, and when. Include, for instance, the number of interviews or surveys you plan to use, which customers you will contact, when you will start and end the data collection, and so on.

Who Are Your Customers?



- What are the outputs of your process? Who are the customers of that output?
- Are there particular groups of customers whose needs are especially important to your organization?

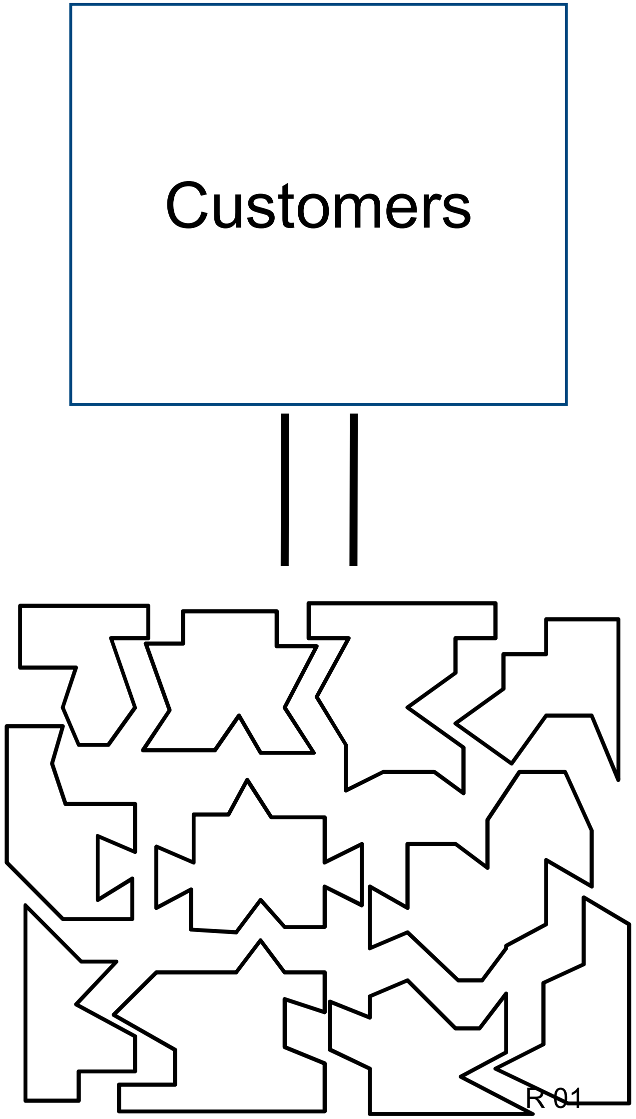
Identify Potential Customers

Identify whose interests are key and whose perspectives can add value:

- **Current customers** (buy **your** existing products)
- **Former customers** (**stopped** buying your products)
- **Competitors' customers** (buy **alternative** products)
- **Lead thinkers** and other experts
- **Technology** leaders in the industry
- **Strategic partners**
- **Internal customers**
- **Stakeholders** (internal and external)

Customer and Market Segmentation

- Often there is no single Voice of the Customer; different customers or types of customers usually have different needs and priorities
- You should include a wide variety of customers in your initial customer research efforts
- Different types of customers are often referred to as **market segments**



Common Market Segments

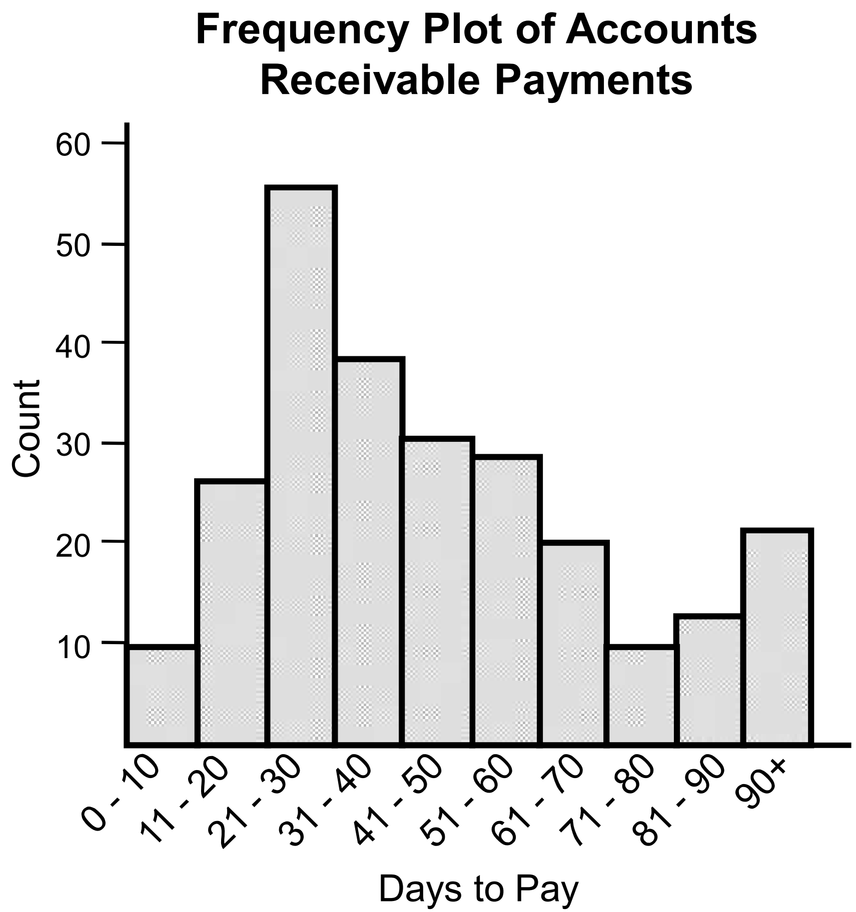
- Customer status: former customers, current customers, customers of competitors, substitute customers
- Where customers are in the “customer chain”
  - Internal user → distributor→ end user
- Type of product or service customers buy from you
- Volume of purchases: high, medium, low
- Geography
- Reason for buying
- Industry, division, or department
- Demographics, such as gender or age

Do You Have Market Segments?

- If your customers seem to have similar needs across the board, you don't necessarily need to divide them into segments
- If you suspect that different groups will have significantly different needs and that these differences will influence how you structure your process, product, or service, then it will be worthwhile to think in terms of segments

Case Study: Receivables

- A company that sells both products and associated services is trying to improve its billing process and payment of accounts receivables
- A study of how long it takes customers to pay their bills shows the average at about 48 days, but many extend to 90 days or more



Receivables VOC Plan: Who

Who

Customers and Segments

Position in organization
- Accounts payable vs. purchasing agents vs. end users

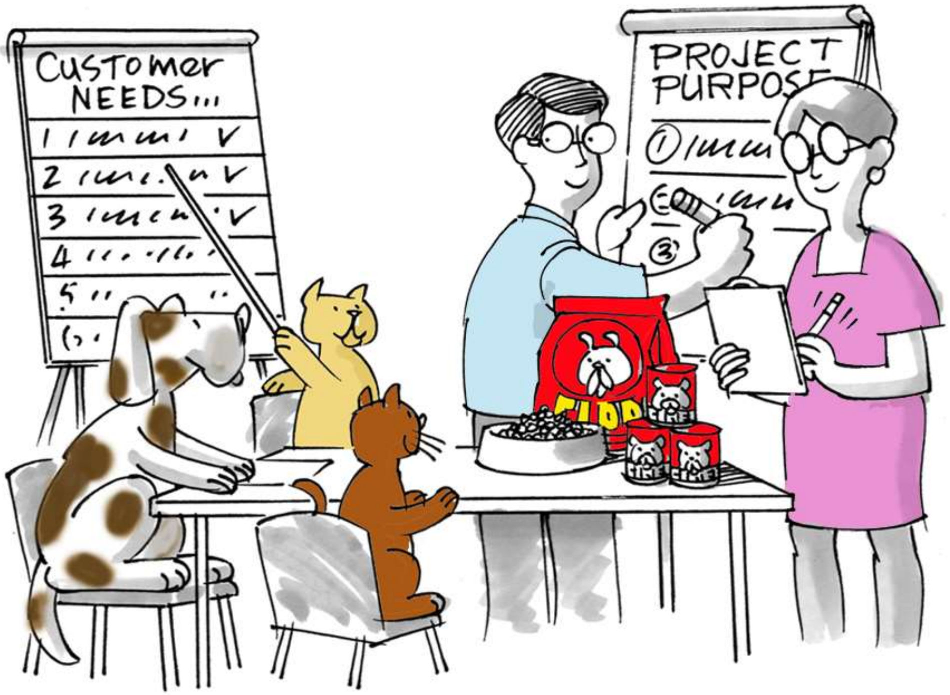
Type of business
- Government and people who work with government vs. non-government vs. foreign vs. distributors

Type of payment
- Credit card vs. purchase order vs. invoice vs. prepay by check

Payment history
- On-time vs. late
- Organizations vs. individuals

Deciding the What and Why

- Revisit your charter: what is the purpose of your project?
- How does your purpose relate to customer needs?
- What do you need to know about the needs of the customers you've identified to make sure your project purpose is on track?



Receivables VOC Plan: What and Why

What and Why

Indicate specifically what you want to know about your customers.
Develop customized versions of the following questions, which you can ask during interviews.

- What's important to you?
- What problems do you have with ___? (What's a defect?)
- How are we doing? How do we compare with our competitors?
- What do you like? What don't you like?

What are your invoice requirements?

For each requirement, follow up with: If we can't meet that requirement, what does that mean to you? (Try to determine which requirements are minor, which cause delayed payments, etc.)

How well do our processes and policies currently meet your requirements?

How do our processes and policies compare with other vendors?

What do you like about our invoicing processes and policies?

What don't you like?

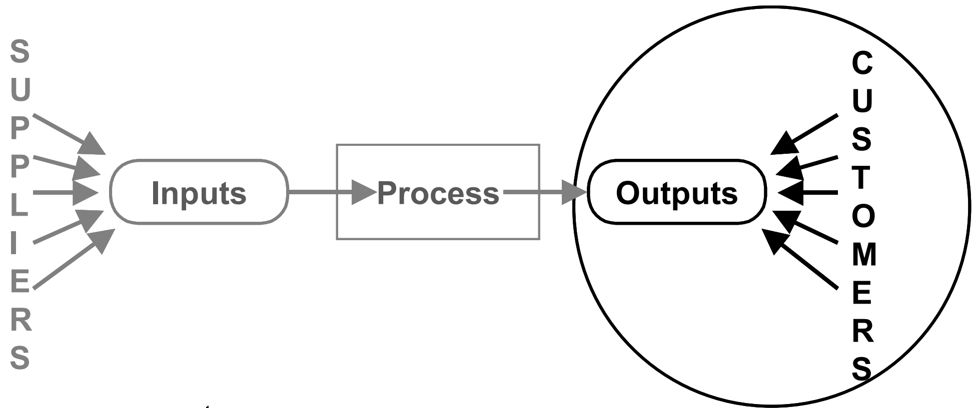
What specific changes would you like to recommend?

Your Own VOC Plan: Who, What, and Why

Instructions:

- Use the SIPOC diagram you created to begin developing your own VOC plan
- Identify the customers of the output of your process
  - Think about what customer characteristics might help you separate them into relevant segments
- Identify key questions you have about each of the customer groups
- You may want to take notes on the portion of the worksheet reprinted below and then transfer your final decisions to Project Worksheet: VOC Data Collection Plan

Time: 15 minutes



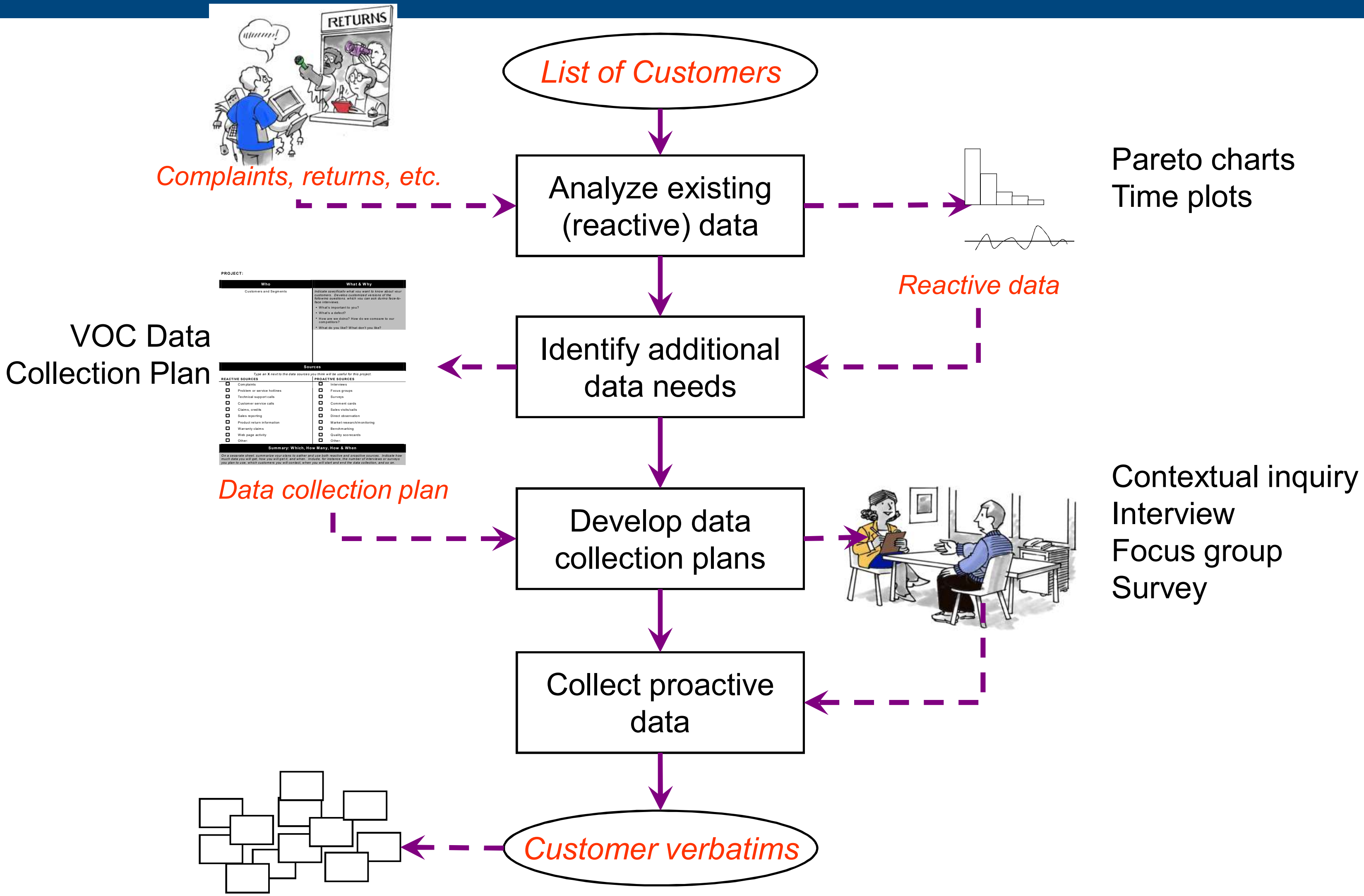
Anexas Consultancy Services

VOC Data Collection, Step 2

Step 2: Collect and Analyze Reactive and Proactive Data

1. Identify customers and determine what you need to know
2. **Collect and analyze reactive system data; then fill gaps with proactive approaches**
3. Analyze data to generate a key list of customer needs in their language
4. Translate the customer language into CTQs
5. Set specifications for CTQs

Collect Needs Data: Process



Basic VOC Systems

1. **Reactive systems**
   – Information comes to you whether or not you take action

2. **Proactive systems**
   – You need to put effort into gathering the information

Typical Reactive VOC Systems

- Customer complaints (phone or written)
- Technical support calls
- Claims, credits, contested payments
- Product return information
- Problem or service hotlines
- Customer service calls
- Sales reporting
- Warranty claims
- Webpage activity

Typical Reactive VOC Systems, cont.

Reactive systems generally gather data on:

- Current and former customers' issues or problems
- Current and former customers' unmet needs
- Current and former customers' interest in particular products or services

Proactive VOC Systems

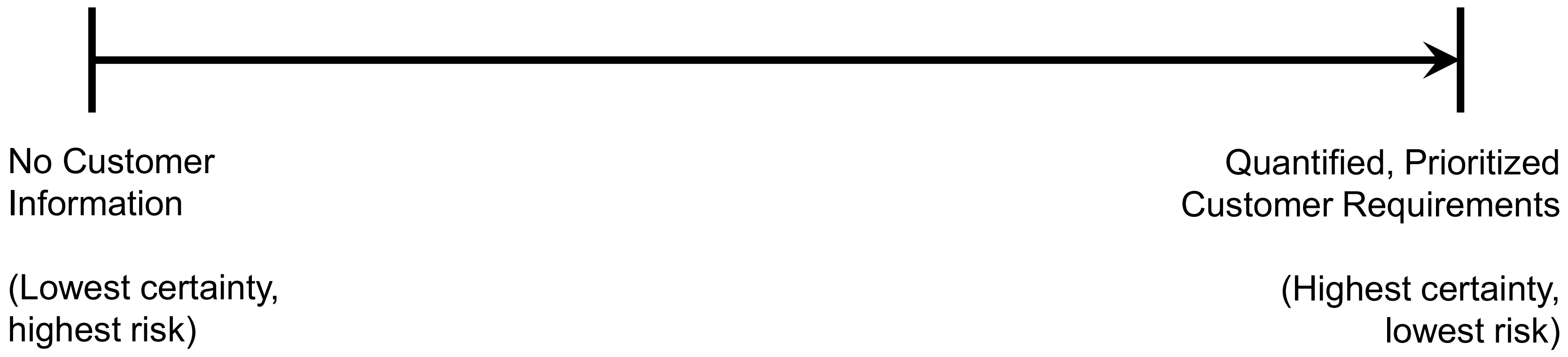
- Direct customer observation
- Interviews
- Focus groups
- Surveys
- Comment cards
- Data gathering during sales visits or calls
- Market research, market monitoring
- Benchmarking

Analyze Existing Data

1. **Collect and summarize existing data**
   - "Reactive" data will already be on hand, but will most likely need to be organized and summarized
2. **Analyze these data using appropriate tools, e.g., Pareto charts and control charts**
   - Draw preliminary conclusions from relevant existing data
3. **Determine which preliminary conclusions need to be validated with new customer research**
   - Did we draw the right conclusions from our existing data?
4. **Consider additional broad questions to understand customers' needs and extend thinking beyond existing products and services**
   - What else do we need to learn?

Identify Proactive Data Needed

- After analyzing existing data, assess how much new information is needed
- Consider how to progress from where you are to where you need to be, based on
  - Level of **certainty** you can **afford**
  - Level of **uncertainty** you can **risk**



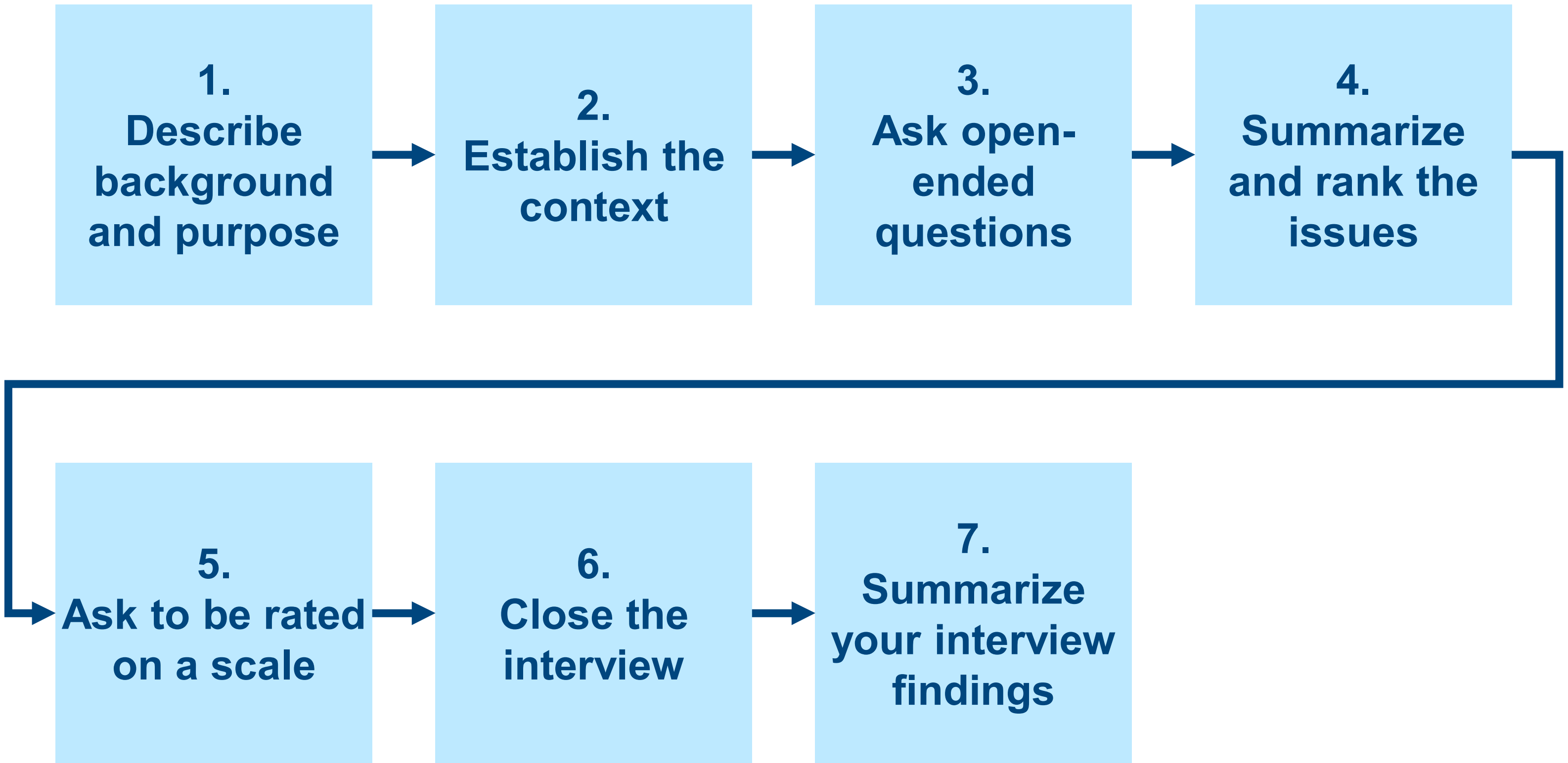
Face-to-Face Interaction

- Face-to-face interaction with customers can provide a wealth of data and knowledge that is unobtainable by other means
- A good first step in proactive data collection is **customer observation**
    1. Get them to show you, in detail, how they use your product or service (talk with them peer to peer, on-site)
    2. Ask "What are three things we could do to improve our product or service to you?" or, if time permits, conduct a lengthier interview
- Ideally, you should have face-to-face interviews prior to any other data collection or extensive phone interviews

Developing an Interview Guide

- If you are going to conduct interviews, compile questions into an interview guide
- Organize your questions
- Write a standard introduction for all interviewers to use
- Test the guide before using it with actual customers

Interview Flow



Guidelines for Conducting Interviews

- Be clear about the purpose of the interview
- Use open-ended, unbiased questions
- Ask simply worded questions
- Let the interviewee do most of the talking
- Listen actively

Sample Interview Questions

1. What is important to you about __________ ?(Name the output of your process, product, or service)
   - If the answer reveals more than one need, ask if some needs are more important than others
2. What problems do you have with our product/service? What impact does it have?
3. How are we performing in the areas you consider important?
4. What do you like about _____________?
5. What can we improve about ___________? What can we do to make your job easier?
6. What specific recommendations would you make to us?

In addition, if your customers are external to your organization, ask questions such as:

7. How do we compare relative to our competitors?
8. How easy is it to do business with us?

Open-Ended Questions

- The receivables team originally wrote, “Do our invoices meet your requirements?”—a question that asks for a yes or no answer
- The team reworded it as, “How well do our processes and policies meet your requirements? How do they not meet …?”
- If the customer cannot articulate what is important to him or her, you may want to ask about:
  - Specific products/services by name
  - Sales support—knowledge and helpfulness of sales staff
  - Responsiveness
  - Ease of doing business
  - How use of your product/service has supported the customer’s business goals

Receivables VOC Plan: Sources

Sources

Check the data sources you think will be useful for this project.

REACTIVE SOURCES

- [x] Complaints
- [ ] Problem or service hot lines
- [ ] Technical support calls
- [x] Customer service calls
- [x] Claims, credits
- [ ] Sales reporting
- [x] Product return information
- [ ] Warranty claims
- [ ] Web page activity
- [ ] Other ________________

PROACTIVE SOURCES

- [x] Interviews
- [ ] Focus groups
- [x] Surveys
- [ ] Comment cards
- [ ] Sales visits/calls
- [x] Direct observation
- [ ] Market research/monitoring
- [ ] Benchmarking
- [x] Other *Customer contact calls*

VOC Plan: Final Touches

- The last step in developing your data collection plan is to decide specifically which customers you want to interview, how many you want to interview, how you will interview them, and within what time frame the interviews should take place
- If you have a large customer base, these decisions may not be easy; ask for help from your manager, sponsor, advisor, or marketing specialist

Summary: Which, How Many, How, and When
On the back of this form or a separate sheet, summarize your plans to gather and use both reactive and proactive sources. Indicate how much data you will get, how you will get it, and when. Include, for instance, the number of interviews or surveys you plan to use, which customers you will contact, when you will start and end the data collection, and so on.

Receivables VOC Plan: Summary

Summary: Which, How Many, How, and When
On the back of this form or a separate sheet, summarize your plans to gather and use both reactive and proactive sources. Indicate how much data you will get, how you will get it, and when. Include, for instance, the number of interviews or surveys you plan to use, which customers you will contact, when you will start and end the data collection, and so on.

- Will look at five segmentation characteristics. Try to do at least 20 face-to-face interviews first, then follow up phone interviews and/or surveys for additional data. Work with statistician to identify appropriate sample size needed from base of 5,000 customer organizations.
  - Carlos and LaShawn will pull together current reactive data we already have.
  - Tina will work on the bookstore angle.
  - Maury will work with customer service on adding info to customer contact calls.
- Work to begin this Friday and extend for three weeks. Deadline is July 26.

Your Own VOC Plan: Sources and Summary

Instructions:

- Check off each of the VOC data sources you think could provide you with information relevant to your project
  - Indicate which already exist and which you may need to create
  - You may not want or need to use all the sources listed, so it's OK to leave some items unchecked
- Complete your VOC plan by jotting down your preliminary thoughts about exactly how you will collect the VOC data
- You may want to take notes on the portion of the worksheet reprinted below and then transfer your final decisions to Project Worksheet: VOC Data Collection Plan

Time: 15 minutes

Gathering the VOC Data

- Train everyone who will be gathering the VOC data
- Practice the interviews before talking with external customers
- Periodically monitor the data collection; make adjustments as necessary

Anexas Consultancy Services

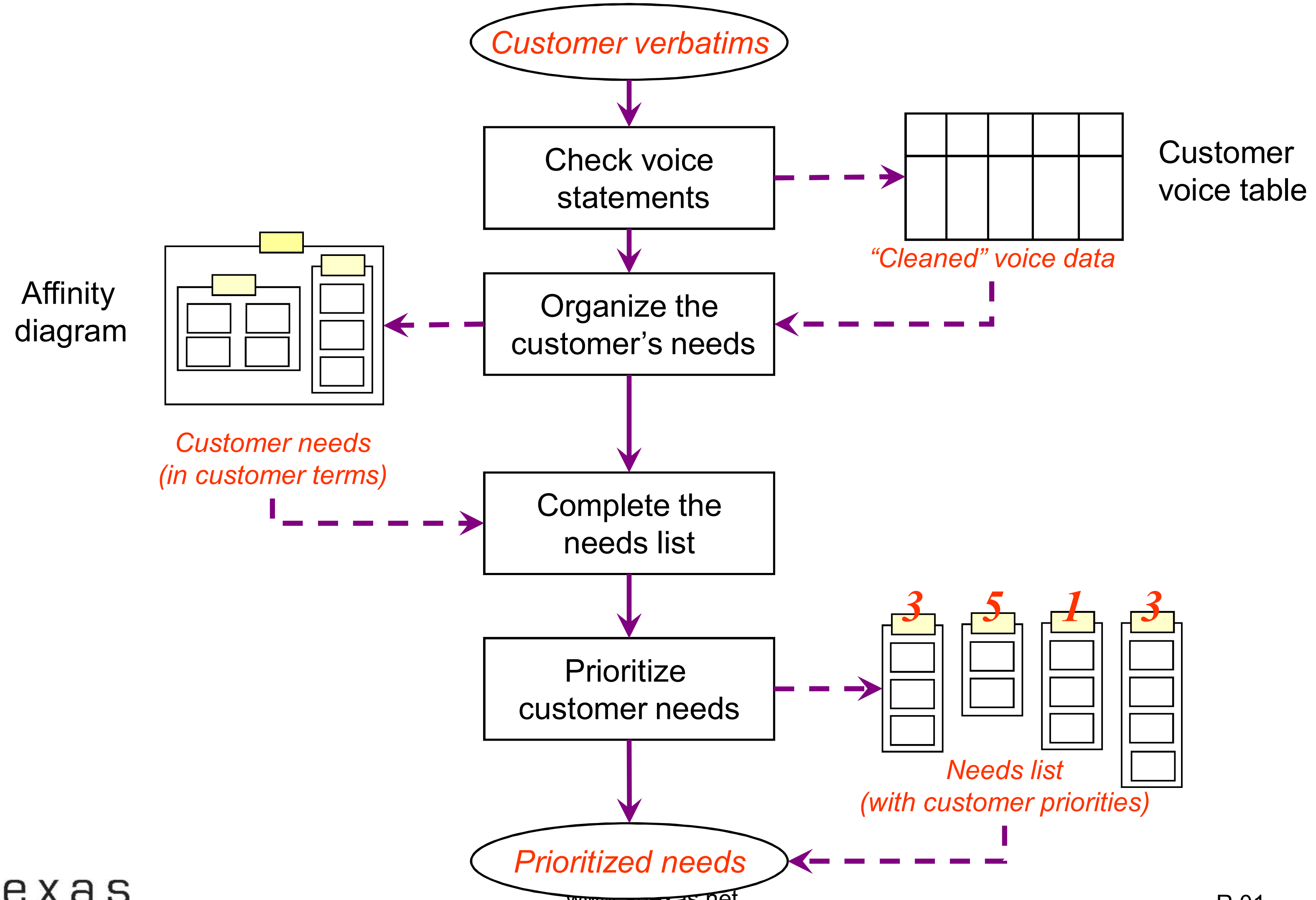
VOC Data Collection, Step 3

Step 3: Analyzing Customer Data

1.	2.	**3.**	4.	5.
Identify customers and determine what you need to know	Collect and analyze reactive system data; then fill gaps with proactive approaches	**Analyze data to generate a key list of customer needs in their language**	Translate the customer language into CTQs	Set specifications for CTQs

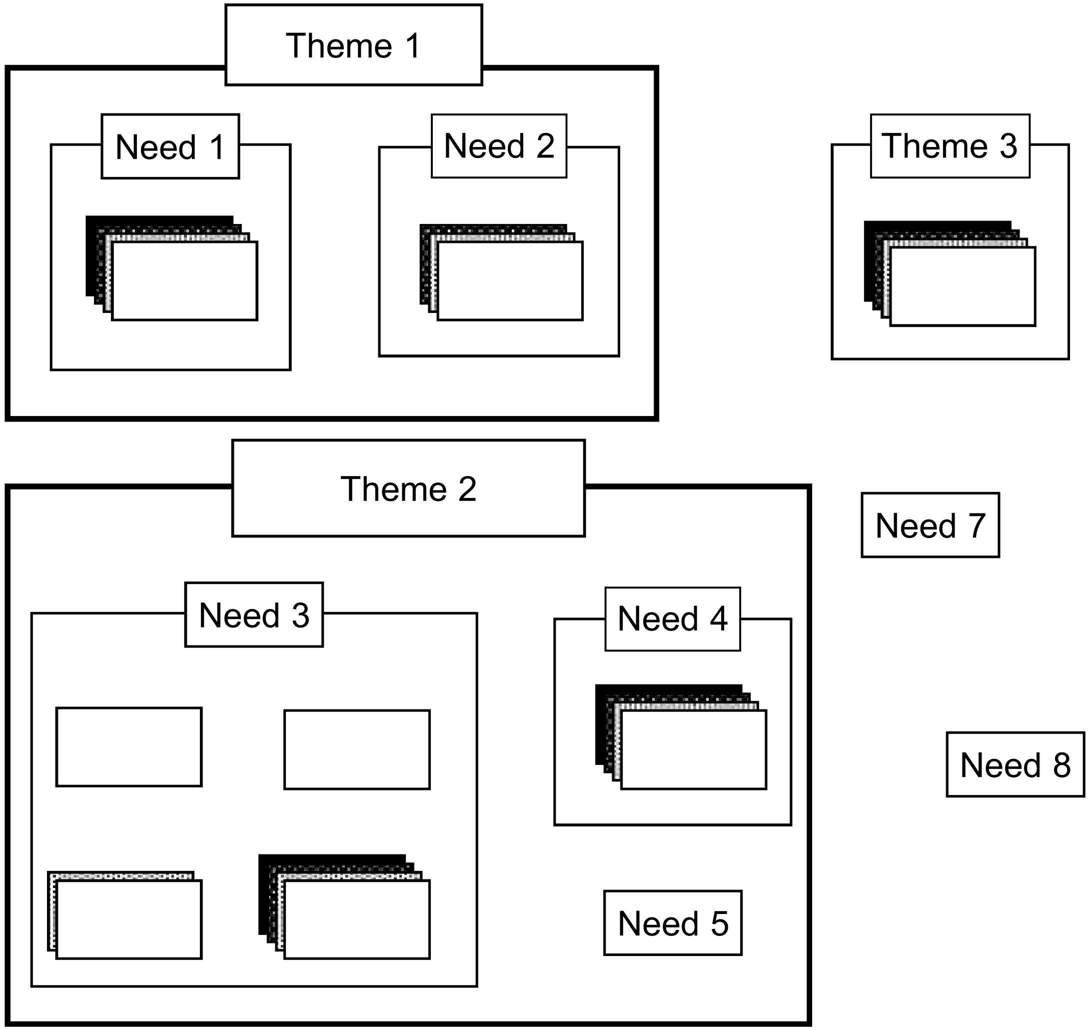
- Goal
  - Generate a list of key customer needs in their language
- Much of the data you gathered in the previous steps will be verbal data
  - It is helpful to summarize this information in a meaningful way, perhaps by using an affinity diagram (described next)

Analyze Needs Data: Process



Affinity Diagram: Definition

An affinity diagram is a tool that organizes language data into related groups



Affinity Diagram Uses

- Help grasp very large or complex issues
- Encourage breakthrough thinking
- Find patterns in mountains of data
- Gather large amounts of language data
- Organize ideas, issues, and opinions

Example: Computerized Training, cont.

A	B	C	D	E
System is easy to use	Enjoyable learning experience	System works for all types of students	Students understand skill set	Students master the skill set
System uses appropriate delivery medium	Students enjoy the experience	The system works for different entry skill levels	Students can decide when this skill will work	Students get high-quality feedback on mastery
System uses web technology	Learning isn't a hassle	The system works for varying levels of motivation	Students understand skill set	Students get enough practice
The presentation process feels familiar	Practice doesn't feel embarrassing	The system accommodates different learning styles	Students can do this	Students leave with new skills
System delivery is low cost				

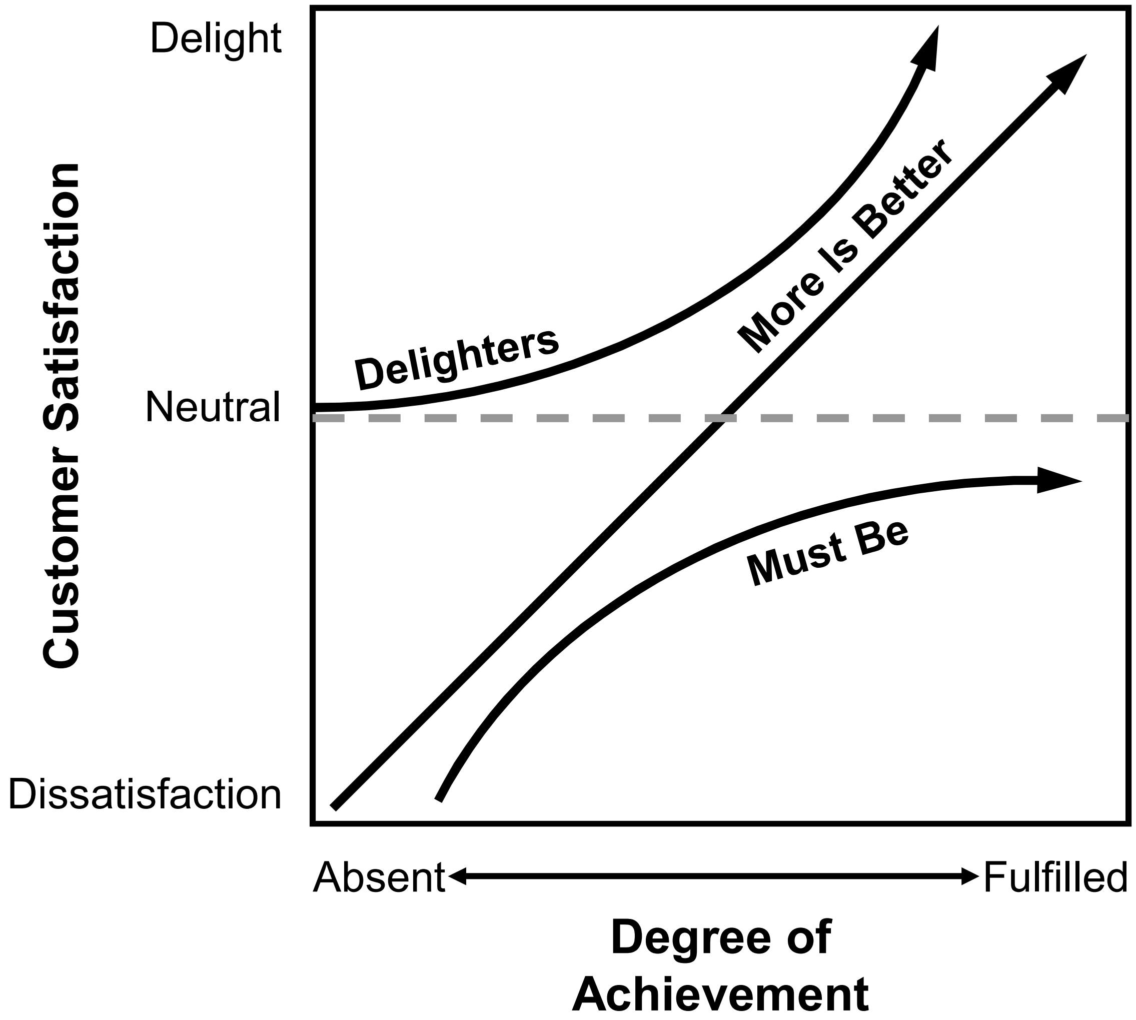
Tips for Affinity Diagrams

- **Silent Process:** Move cards without talking
  - Encourages unconventional thinking
  - Discourages semantic battles
- **Gut Reaction:** React, do not contemplate
  - If you do not like where a card is, shift it
  - Settles eventually into consensus
  - Duplicate cards that keep shifting and put in both groups
- **Avoid Pigeonholing:** Groups emerge from "the chaos of the cards"
  - Do not sort cards into predetermined categories (pigeonholes)
  - Pigeonholes force-fit everything into existing logic
  - Pigeonholes prevent breakthrough from occurring
- **Group Size:** There can be a "group" of one card, but ask…
  - Should a small group be combined with another?
  - Should a large group be broken down more precisely?

Generating Customer Need Statements

- The need statements used for an affinity diagram should be in the customer's own language if at all possible
- To get these statements, read through interview notes, survey notes, comment cards, etc., and highlight any statements you think are relevant to your project
- Transcribe the strongest of these statements to cards or self-stick notes you can use for the affinity diagram

What You Can Learn: The Kano Model



Exercise: Using the Kano Model

Objective: Practice applying the Kano classifications to actual products and services

Instructions:

- Identify customer needs related to each of the products or services listed below and divide them based on the three Kano classifications
- Do the first example together with the whole group, then work on your own or in pairs
- Be prepared to discuss your answers with the whole group

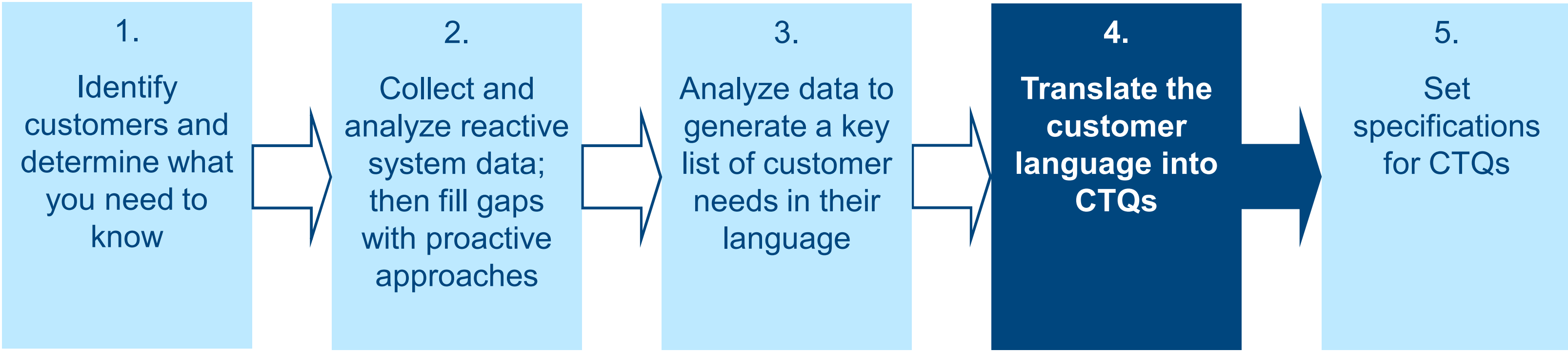
Time: 10 minutes

	Must Be	More Is Better	Delighters
Television Set			

Anexas Consultancy Services

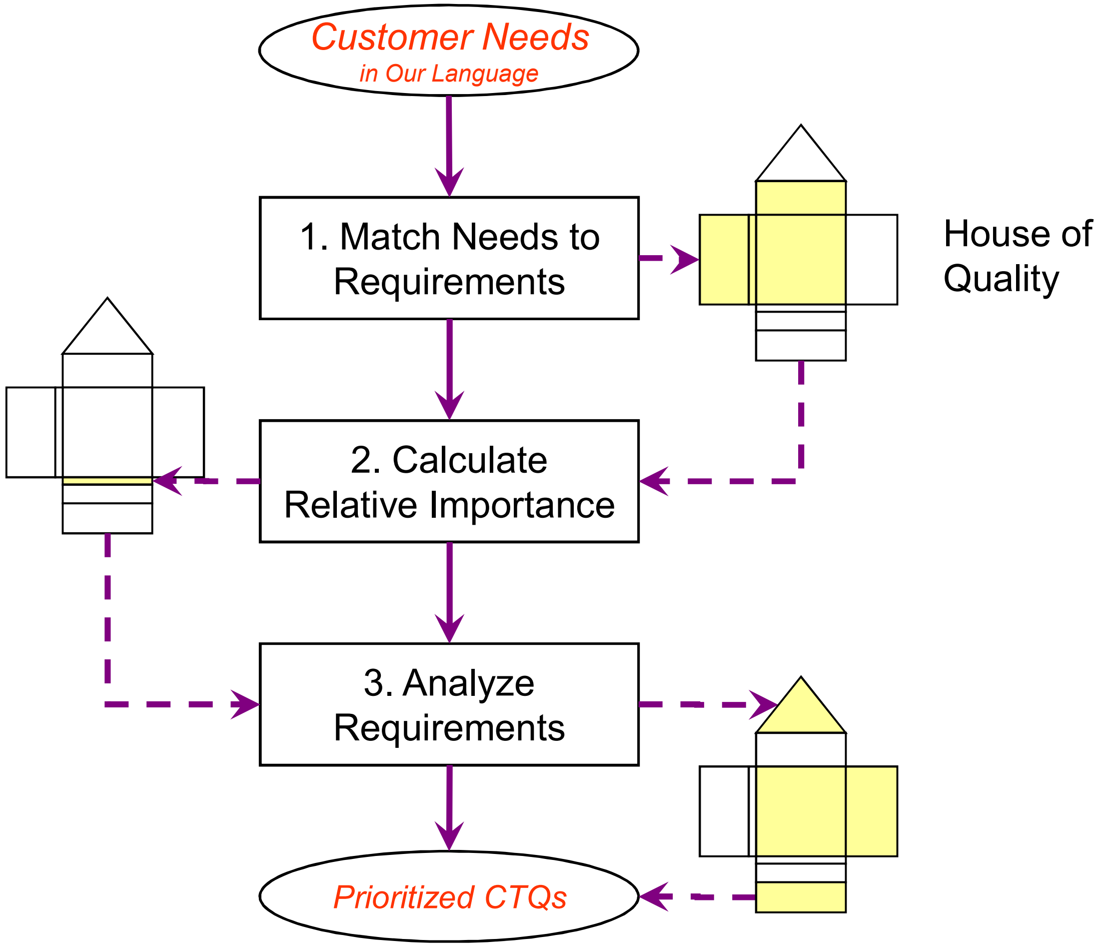
VOC Data Collection, Step 4

Step 4: Defining CTQs



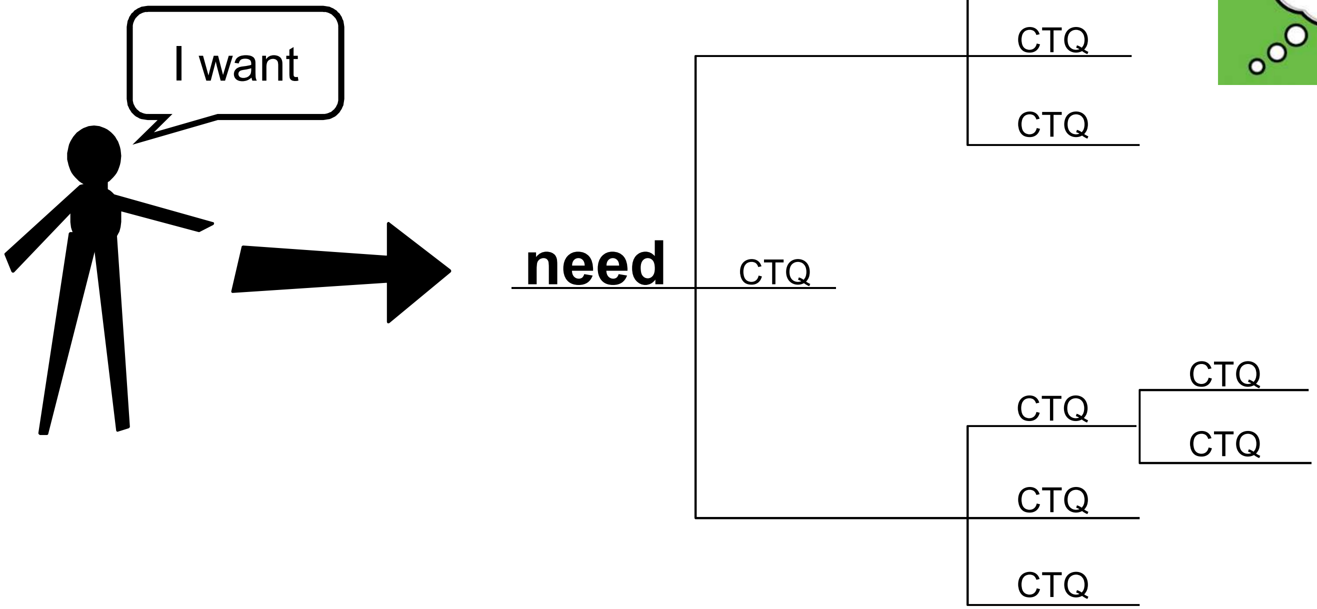
- A useful CTQ will have the following characteristics
  - It is truly critical to the customer's perception of quality
  - It can be measured
  - A specification can be set by which to determine whether or not the CTQ has been achieved
- Shown in this section are two tools for translating the VOC into CTQs:
  - CTQ tree
  - Quality function deployment (QFD)

Identify and Prioritize CTQs: Process



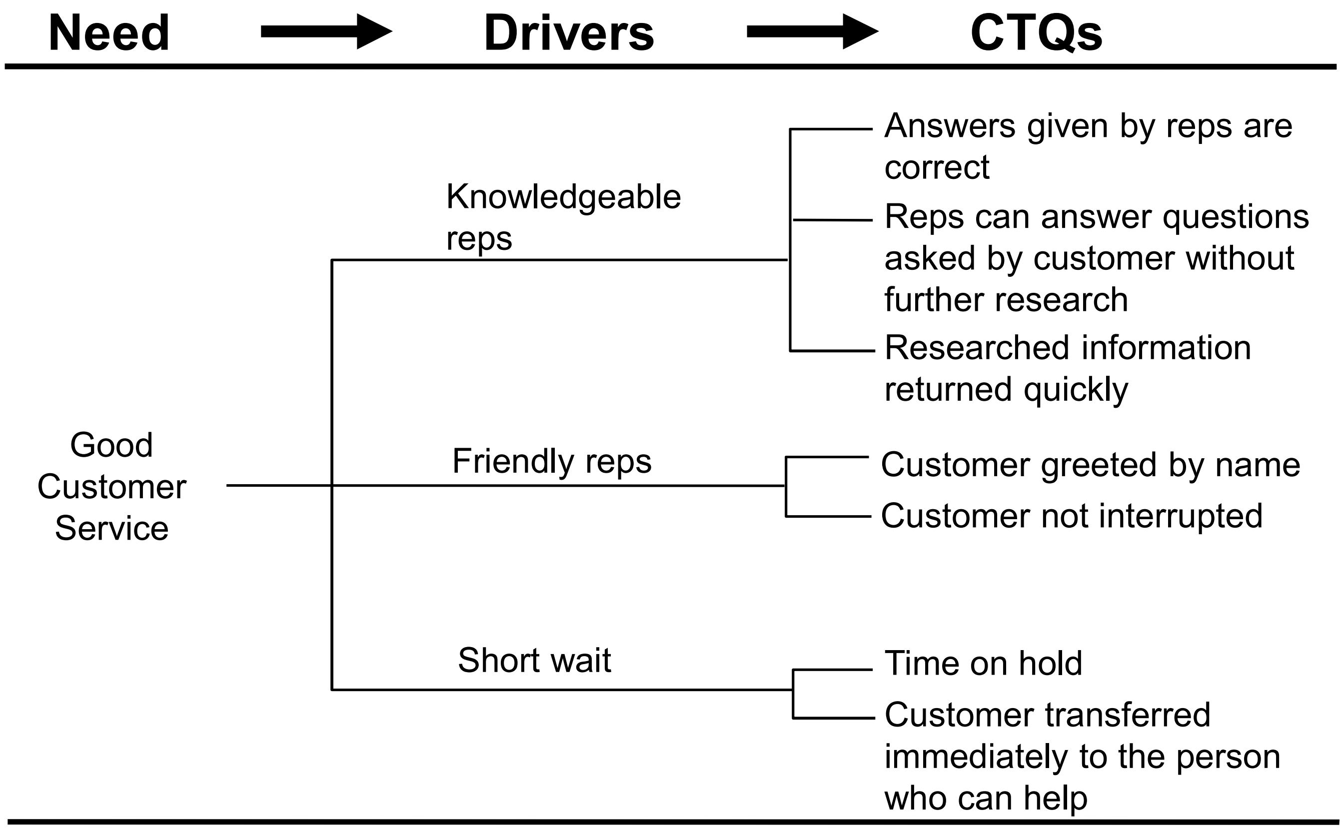
Translating VOC into CTQs

VOC **CTQ Tree**



(CTQ = Critical to Quality)

Example: CTQ Tree



General ◄- - - - - - - - - - ► **Specific**

Hard to measure ◄- - - - - - - - - - ► **Easy to measure**

Project Worksheet: Generating CTQs

Instructions:

- Use the blank tree diagram to translate a customer need from your affinity diagram into a CTQ requirement
- Be prepared to discuss your work with the whole group
- You can use the form reprinted here or the copy in the separate booklet of worksheets

Time: 15 minutes

What Is Quality Function Deployment?

- QFD (also called House of Quality) is a graphical tool summarizing information about customer requirements
- QFD is a good way to check the CTQs against customer requirements and use competitive data to help decide how to prioritize the CTQs

Anexas Consultancy Services

Quality Function Deployment (QFD)

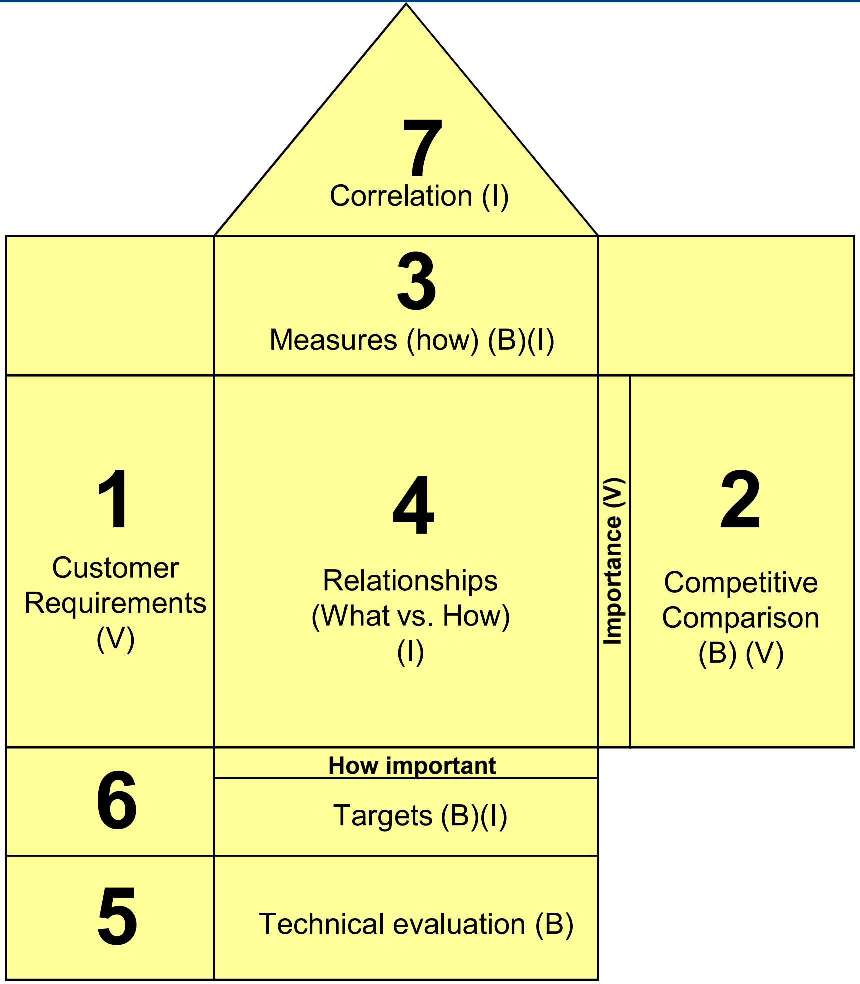
What Is Quality Function Deployment?

- QFD (also called House of Quality) is a graphical tool summarizing information about customer requirements
- QFD is a good way to check the CTQs against customer requirements and use competitive data to help decide how to prioritize the CTQs

House of Quality

- Here we break the house into seven rooms
- Just like rooms in a house, there are connections and relationships among the rooms

(V) = Comes from VOC information
(B) = Comes from benchmarking information
(I) = Comes from internal expertise

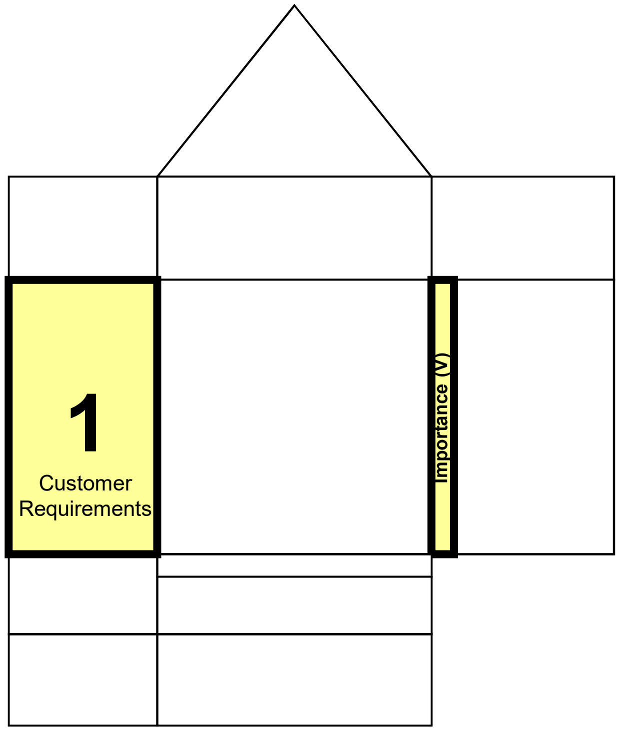


Example: QFD—Lunch Preparation

Lunch Preparation—QFD Example

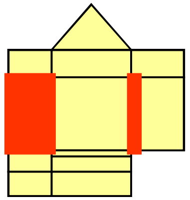
	CTQ Measures								
	Weight of Portion	% Nutrition Requirements	Met Blindfolded Jury Taste Test Rating	Ingredient Cost	Time to Prepare	Number of Ingredient Measurements	Number of Dishes Used	Solubility of Ingredients in Soap and Water	**Importance of Needs**
Fills Us Up	9	1	1						5.00
Is Nutritious	1	9		1					3.40
Tastes Good	0	0	9	1					3.30
Easy to Make				1	9	9			3.70
Easy to Clean Up							9	3	2.00
Sticks with Us	9			1					4.00
Does Not Cost Much	3			9					1.00
Does Not Make a Mess						3	9		2.30
Importance of CTQs	87	36	35	23	33	40	39	6	

A: Summarize CTQs (in QFD)
Room 1: Customer Requirements



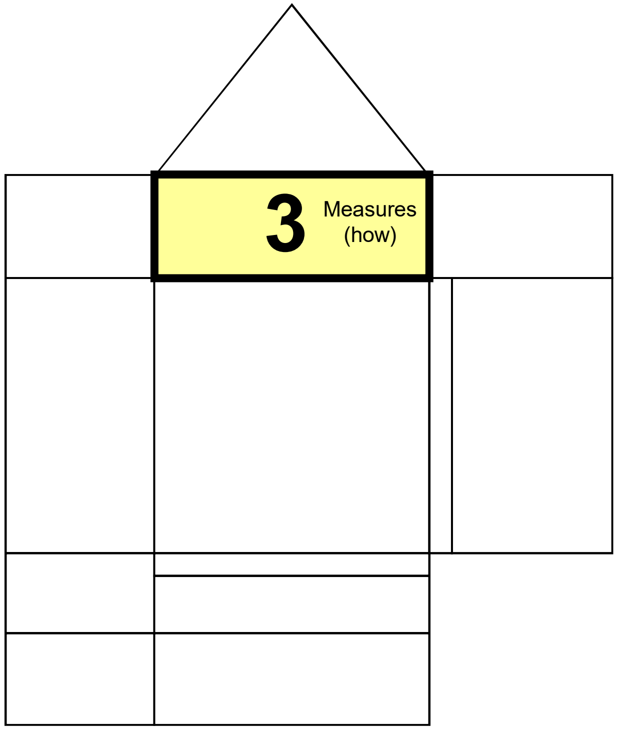
- Room 1 lists the key customer needs identified by VOC research
- The needs are defined by customers and are in customer language
- The prioritization of needs is also done by customers

Example: M&S Inc.—“Easy Order Placement”— QFD Room 1



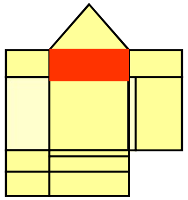
Customer Needs							Importance
I need to place orders when I want							4.30
I need to place orders from any location							3.90
I need to be able to place orders using different technologies							4.80
I want an easily understandable process							4.90
I don't want to go through many steps							4.70
I want to know immediately if an order is confirmed							4.20
I need to be able to get help if I have questions							4.00
How Important							

Room 3: Measures



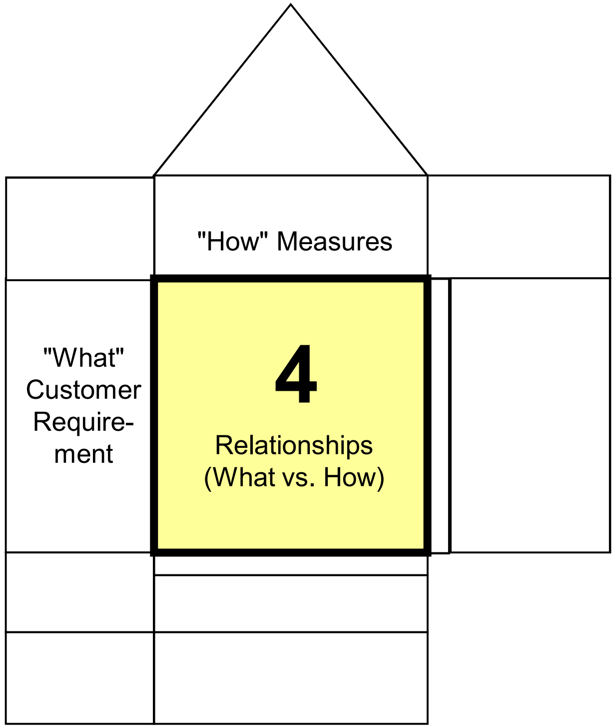
- Room 3 lists the measures developed at the end of the VOC analysis
- The ideas for measures came from:
  - The design team's work translating customer needs into CTQs (which include measures)
  - Benchmarking information on how similar characteristics are measured
  - Measures currently being used for similar designs

Example: M&S Inc.—“Easy Order Placement”—QFD Room 3



Customer Needs	% of customer-desired technologies supported	# of hours help facility is available	# of process steps	% information about completed order status accessible by customer	% historical information not requiring reentry	# of hours access is available	Importance
I need to place orders when I want							4.30
I need to place orders from any location							3.90
I need to be able to place orders using different technologies							4.80
I want an easily understandable process							4.90
I don't want to go through many steps							4.70
I want to know immediately if an order is confirmed							4.20
I need to be able to get help if I have questions							4.00
How Important							

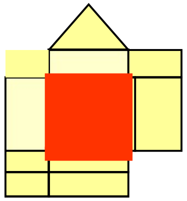
B: Prioritize CTQs (with QFD)
Room 4: Relationships



- Room 4 summarizes the relationship between potential measures and the customers' needs
- To determine the relationship, compare each measure with each need and ask:

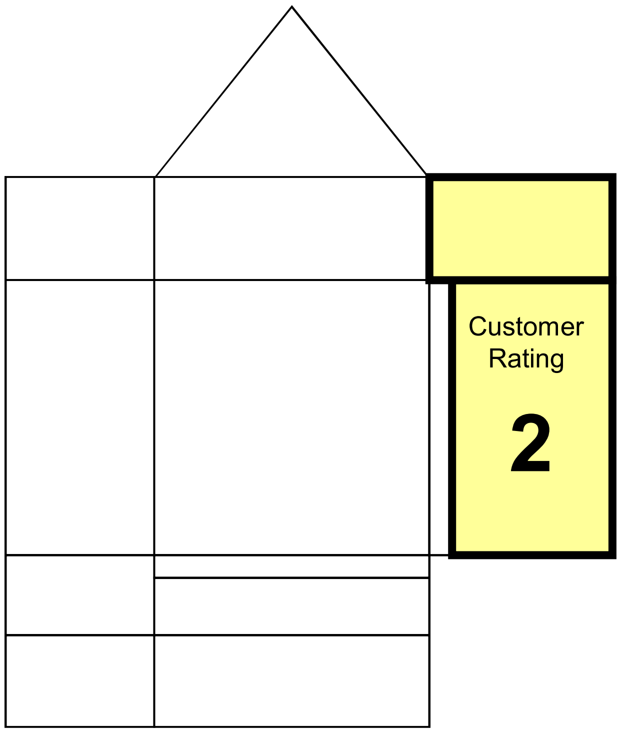
"If the design meets the target set for this measure, to what extent will the customer need be met?"

Example: M&S Inc.—"Easy Order Placement"—QFD Room 4



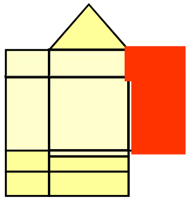
Customer Needs	% of customer-desired technologies supported	# of hours help facility is available	# of process steps	% information about completed order status accessible by customer	% historical information not requiring reentry	# of hours access is available	**Importance**
I need to place orders when I want	**3**	**3**				**9**	4.30
I need to place orders from any location	**3**						3.90
I need to be able to place orders using different technologies	**9**						4.80
I want an easily understandable process			**3**		**3**		4.90
I don't want to go through many steps			**9**		**9**		4.70
I want to know immediately if an order is confirmed				**9**			4.20
I need to be able to get help if I have questions		**9**		**3**		**3**	4.00
How Important	68	49	57	50	57	51	

Room 2: Competitive Comparison



- Room 2 graphically shows how customers perceive your organization compared with competitors with regard to meeting the customer needs listed in Room 1
- Your organization and at least two competitors are compared against customer needs
- The information used in the comparison can come from VOC research and from benchmarking studies

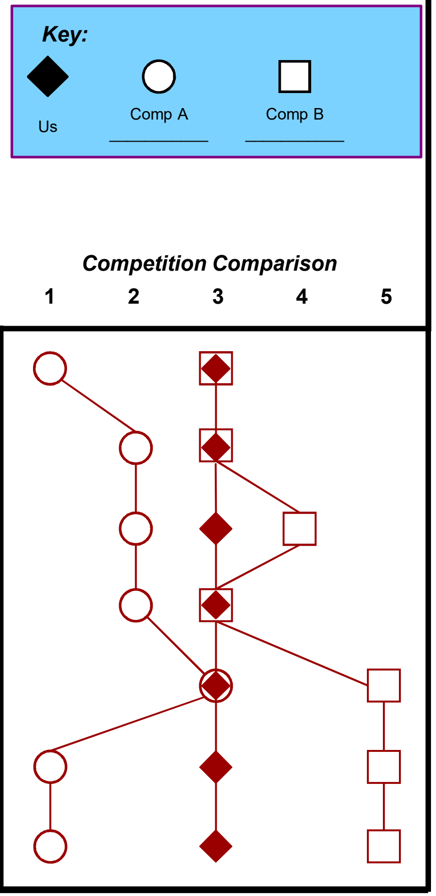
Example: M&S Inc.—"Easy Order Placement"—QFD Room 2



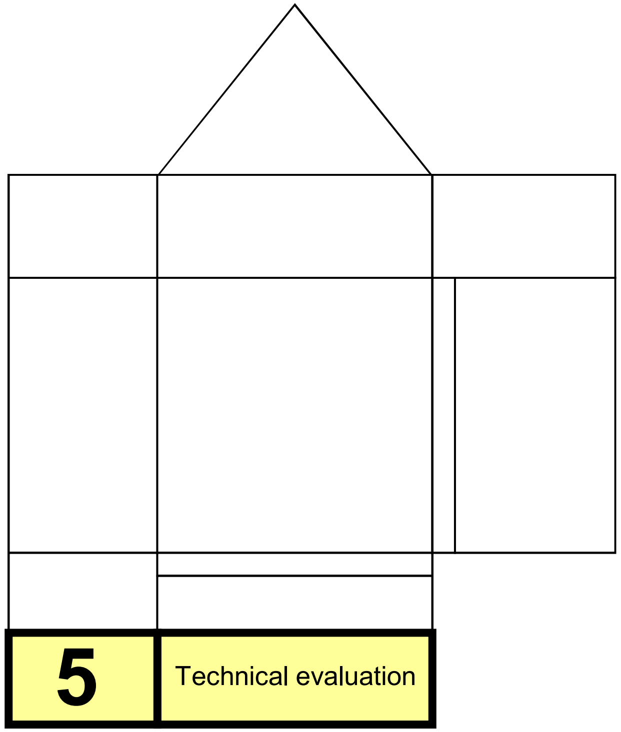
Relationship Matrix Key:

	Strong	Moderate	Weak
Weight	**9**	**3**	**1**

Customer Needs / CTQ Measures	% of customer-desired technologies supported	# of hours help facility is available	# of process steps	% information about completed order status accessible by customer	% historical information not requiring reentry	# of hours access is available	**Importance**
I need to place orders when I want	3	3				9	4.30
I need to place orders from any location	3						3.90
I need to be able to place orders using different technologies	9						4.80
I want an easily understandable process			3		3		4.90
I don't want to go through many steps			9		9		4.70
I want to know immediately if an order is confirmed				9			4.20
I need to be able to get help if I have questions		9		3		3	4.00



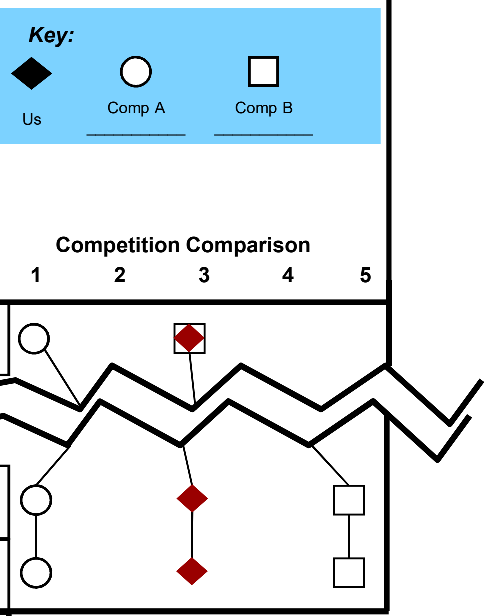
Room 5: Technical Evaluation

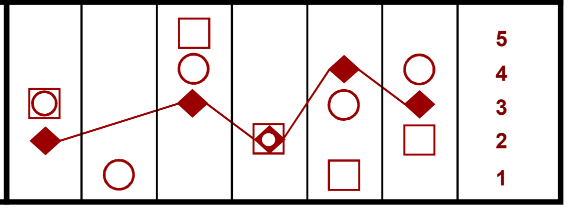


- Room 5 summarizes technical benchmarking data on how your company compares with competitors with respect to performance on key measures/design requirements

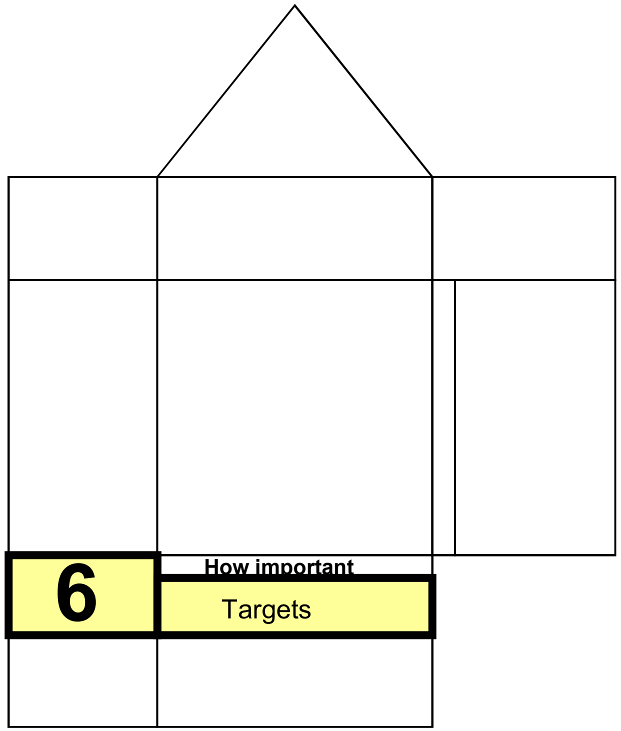
Example: M&S Inc.—"Easy Order Placement"—QFD Room 5

Customer Needs / CTQ Measures	% of customer-desired technologies supported	# of hours help facility is available	# of process steps	% information about completed order status accessible by customer	% historical information not requiring reentry	# of hours access is available	Importance
I need to place orders when I want	3	3				9	4.30
I want to know immediately if an order is confirmed				9			4.20
I need to be able to get help if I have questions		9		3		3	4.00
How Important	68	49	57	50	57	51	
Target							
Technical Evaluation							5 4 3 2 1



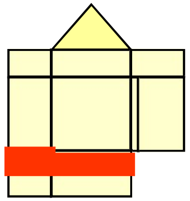


Room 6: Targets



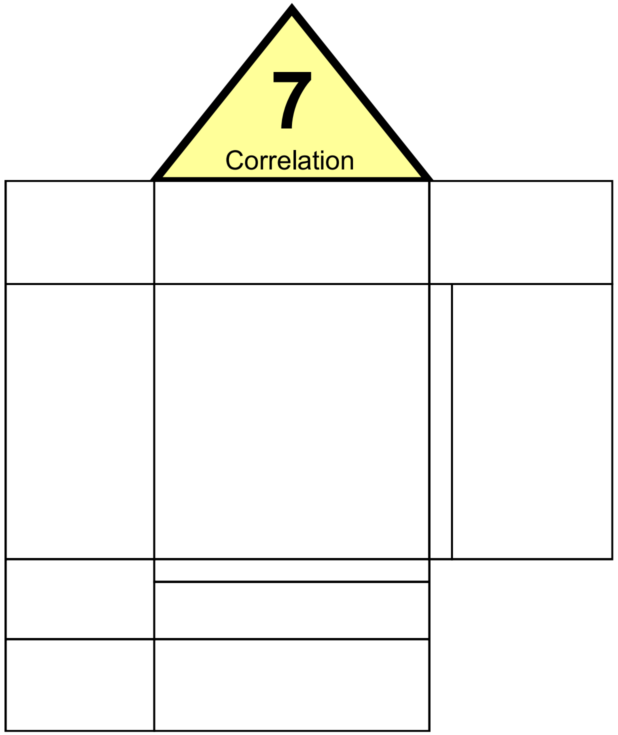
- Room 6 summarizes the targets established for the measures/ design requirements
- Targets were established in the VOC analysis where the team identified the level of performance required to meet customer needs

Example: Order Processing—QFD Room 6



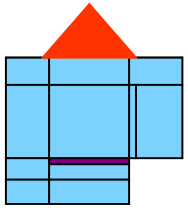
CTQ's/ Measures	% of customer-desired technologies supported	# of hours help facility is available	# of process steps	% information about completed order status accessible by customer	% historical information not requiring reentry	# of hours access is available	**Importance**
I need to place orders when I want	3	3				9	4.30
I need to place order from any location	3						3.90
I need to be able to place orders using different technologies	9						4.80
I want an easily understandable process			3		3		4.90
I don't want to go through many steps			9		9		4.70
I want to know immediately if an order is confirmed				9			4.20
I need to be able to get help if I have questions		9		3		3	4.00
How Important	68	49	57	50	57	51	
Target	**100**	**24**	**4**	**75**	**90**	**24**	

Room 7: Correlation



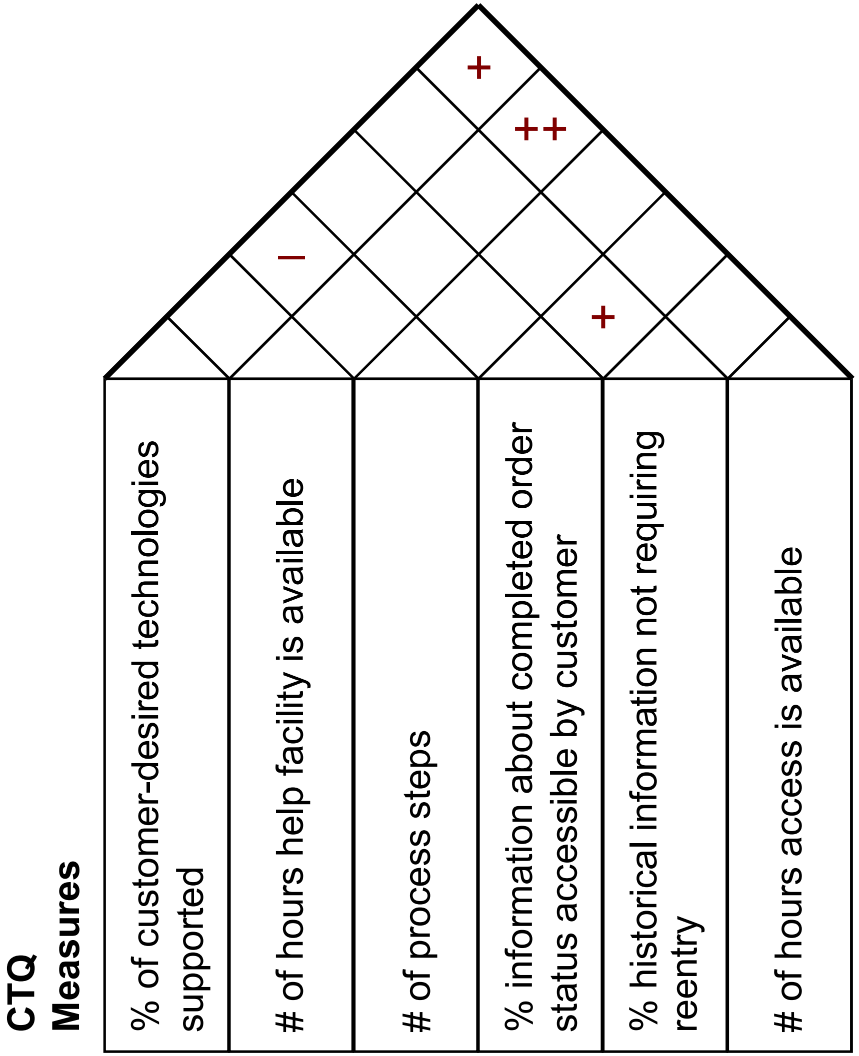
- In Room 7, relationships between measures (the "roof") are summarized
- Use symbols to represent relationships
- Evaluate the outcome
  - Positive relationships indicate synergy
  - Negative relationships may indicate conflicts
- Key question: If we design to meet CTQ1, to what extent do we satisfy CTQ2?

Example: M&S Inc.—“Easy Order Placement”—QFD Room 7

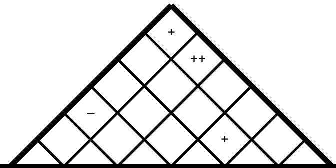


Relationship

- ++ Strong positive
- + Positive
- − Negative
- XX Strong negative

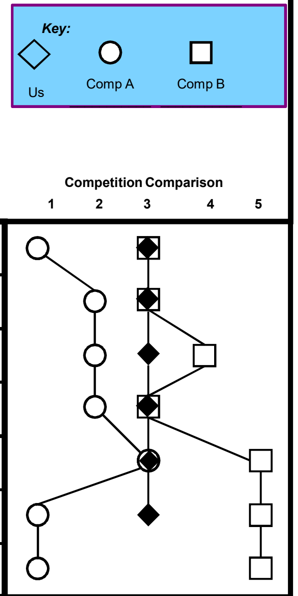


Example: M&S Inc.—"Easy Order Placement"—Completed HOQ

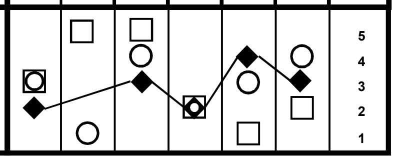


Relationship Matrix Key: Strong (Weight 9), Moderate (3), Weak (1)

Customer Needs / CTQ Measures	% of customers who desired technologies supported	# of hours help facility is available	# of process steps	% information about completed order status accessible by customer	% historical information not requiring reentry	# of hours access is available	Importance
I need to place orders when I want	3	3				9	4.30
I need to place orders from any location	3						3.90
I need to be able to place orders using different technologies	9						4.80
I want an easily understandable process			3		3		4.90
I don't want to go through many steps			9		9		4.70
I want to know immediately if an order is confirmed				9			4.20
I need to be able to get help if I have questions		9		3		3	4.00
How Important	68	49	57	50	57	51	
Target	100	24	4	75	90	24	



Technical Evaluation

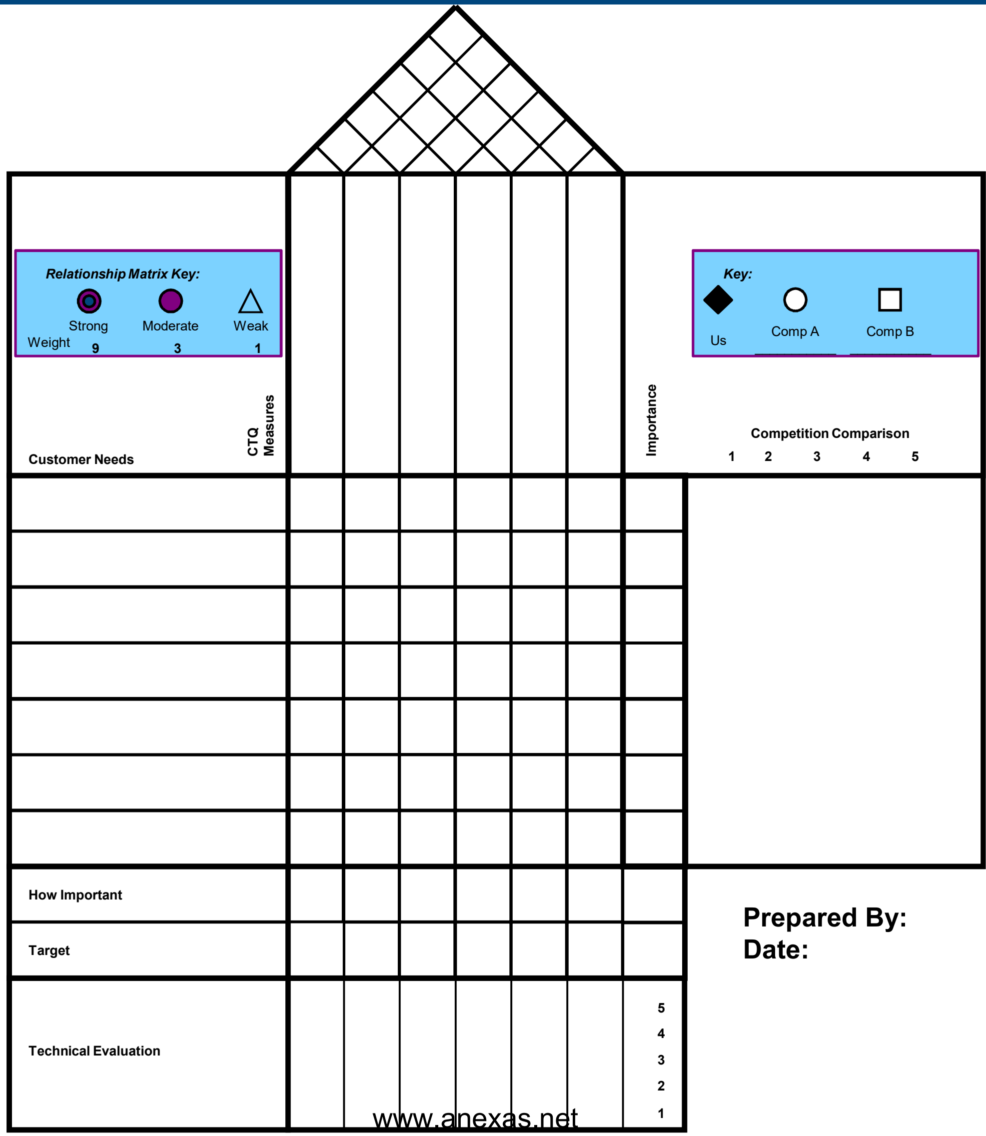


Example: M&S Inc.—"Easy Order Placement"—QFD Output

Order placement: first-level need

CTQ Measures	Importance	Target	Upper Spec Limit	Lower Spec Limit
% of customer-desired technologies supported	68	100	N/A	75
# of hours help facility is available	49	24	N/A	21
# of process steps	57	4	6	2
% information about completed order status accessible by customer	50	75	N/A	60
% historical information not requiring reentry	57	90	N/A	75
# of hours access is available	51	24	N/A	21

QFD Template



Prepared By:
Date:

Selecting CTQs to Focus On

- Which will have the greatest positive impact on the customer?
- Which are within your scope or process area of focus?
- Which of the Kano Must Be characteristics are not addressed?

Anexas Consultancy Services

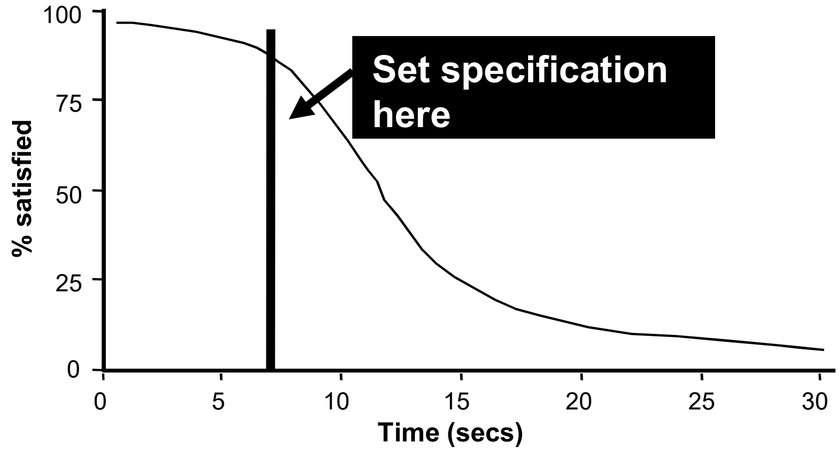
VOC Data Collection, Step 5

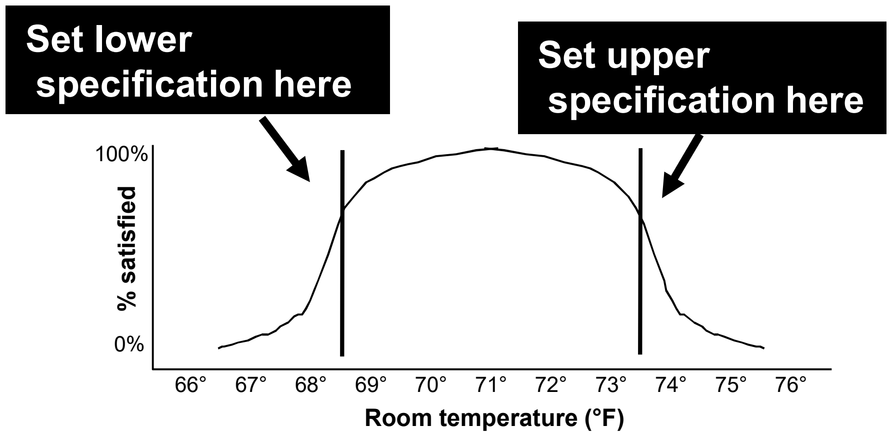
Step 5: Setting Specifications

1. Identify customers and determine what you need to know
2. Collect and analyze reactive system data; then fill gaps with proactive approaches
3. Analyze data to generate a key list of customer needs in their language
4. Translate the customer language into CTQs
5. **Set specifications for CTQs**

Specifications for CTQs

- In manufacturing, specification limits often come from technical or mechanical requirements
- Otherwise, base specification limits on data about customer needs
- Set specifications at the places where customer satisfaction starts to fall off appreciably





Exercise: Setting Specifications

Objective: Practice establishing specification limits that relate to customer requirements

Instructions:

- The sample CTQ tree shown earlier is reprinted below
- Select at least one CTQ for each driver and use the space on the next page to indicate how you would go about setting specifications limits for it
- Be prepared to discuss your answers with the whole group

Time: 10 minutes

Exercise: Worksheet

CTQ	Potential Specification Method
Answers are correct	
Reps can answer question	
Information returned quickly	
Customer greeted by name	
Customer not interrupted	
Time on hold	
Transfers immediate	

Summary: The Five-Step VOC Data Collection Process

1. Identify customers and determine what you need to know
2. Collect and analyze reactive system data; then fill gaps with proactive approaches
3. Analyze data to generate a key list of customer needs in their language
4. Translate the customer language into CTQs
5. Set specifications for CTQs

By following this process, we can help ensure that we have understood the current situation from the customer's perspective

Revisiting Your Charter

- Do you still think customers would consider the project a high priority?
  - If not, can you modify your focus to make it more relevant to customer needs?
  - If you can't answer the question, what additional information can you collect to determine how the customer might perceive your project?
- Do you have enough data to justify working on this project?
  - If not, can you get timely information so you can keep your project moving forward?
  - Do you need to modify your timeline to include some customer research up front? Whose approval would you need to make that adjustment?

Anexas Consultancy Services

DEFINE: Define the Project

Review

You Were Here

DEFINE Phase Deliverables

- Product or process linked to strategic business requirements
- Clear problem and goal statements, and business benefits
- High-level financial benefits approved by finance analyst
- High-level process map of major process steps (SIPOC)
- Customer critical to quality (CTQ) requirements
- Linkage of customer requirements to process outputs

DEFINE Phase Deliverables, cont.

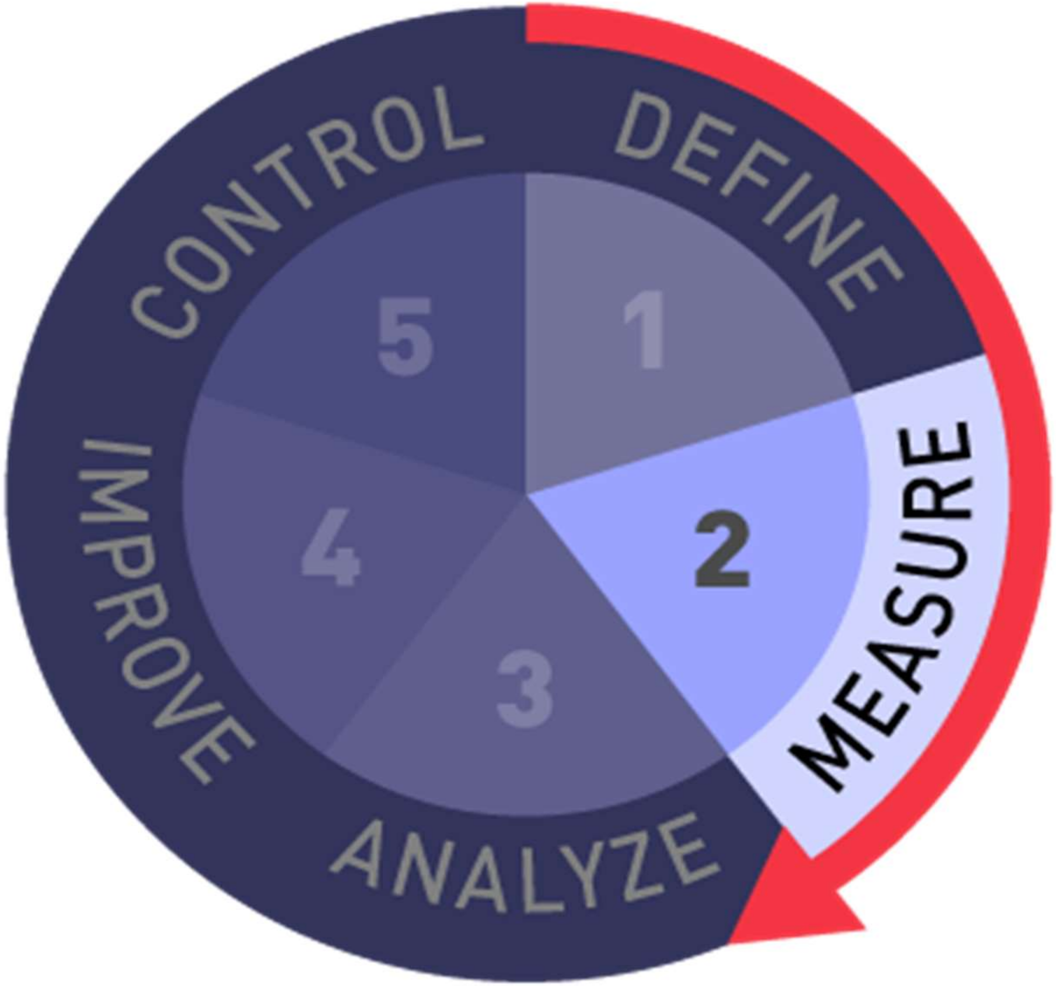
- Project plan with milestones and deliverables
- Stakeholder identification and analysis
- Completed and signed-off project charter
- DEFINE section of storyboard completed
- DEFINE phase discussed and agreed on with sponsor and coach
- DEFINE deliverables completed and phase approved

Anexas Consultancy Services

MEASURE: Measure the Current Situation

Overview

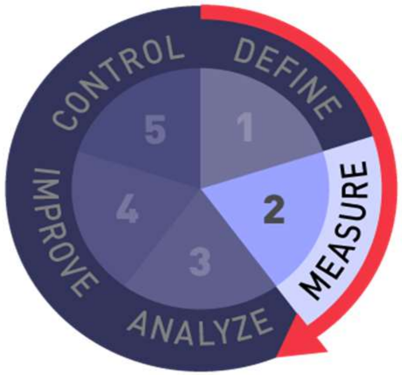
You Are Here — MEASURE



MEASURE: Measure the Current Situation

Goal

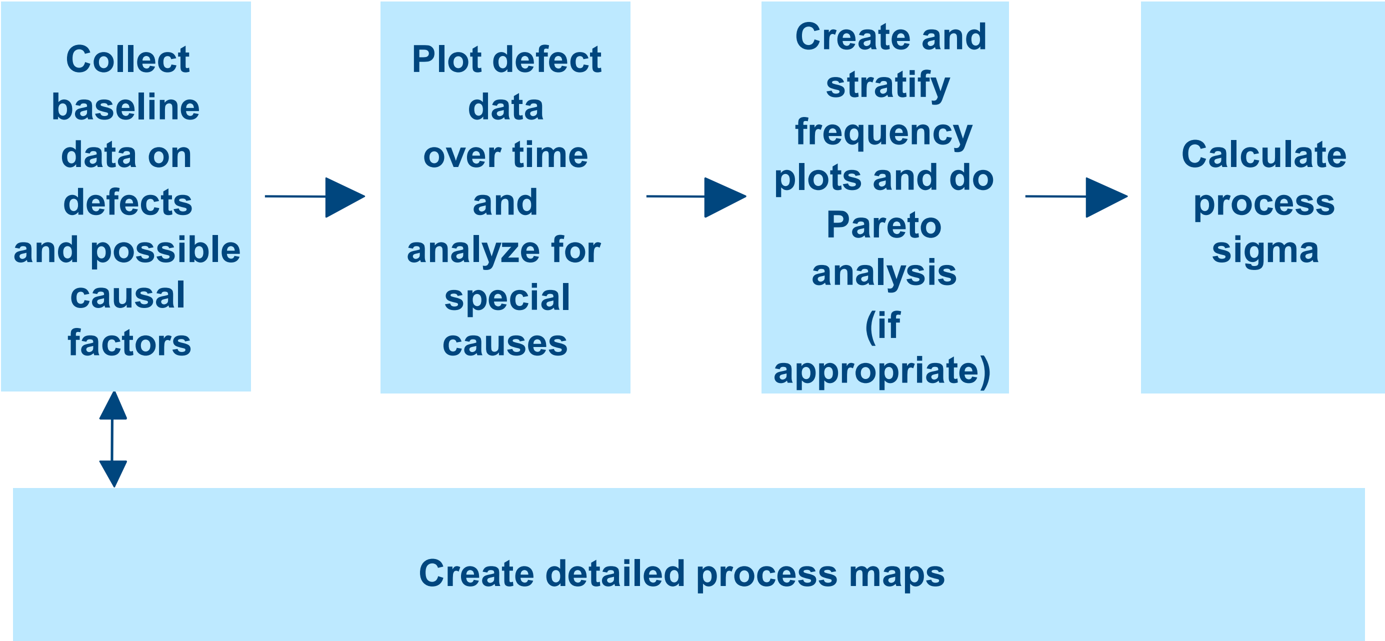
- Focus the improvement effort by gathering information on the current situation



Output

- Data that pinpoints problem location or occurrence
- Baseline data on how well the process meets customer needs (to determine current process sigma)
- Understanding of how current process operates
- A more focused problem statement

Approach to MEASURE



- Data methods and process mapping often occur in parallel in the MEASURE step
- Mapping the process may give insight into what data to collect and where
- Collecting and plotting the data may show which process areas need to be mapped in more detail

Preview of MEASURE Modules

- A factual understanding of MEASURE means your knowledge is based on data—which means you have to know what data to collect, what to do with them, and how to interpret the patterns or clues you uncover
- The modules we'll cover will help you:
  - Understand the various types of data and how to collect appropriate data (Data Collection)
  - Identify patterns related to variation over time (Data Analysis I: Identifying Patterns over Time)

Preview of MEASURE Modules, cont.

- The modules we'll cover will help you: (cont.)
  - Identify other kinds of patterns in data (Data Analysis II: Looking for Patterns Not Related to Time)
  - Define your baseline process sigma level (Determining Process Sigma)*
  - Identify waste in the way the process is organized (Process Analysis)

Anexas Consultancy Services

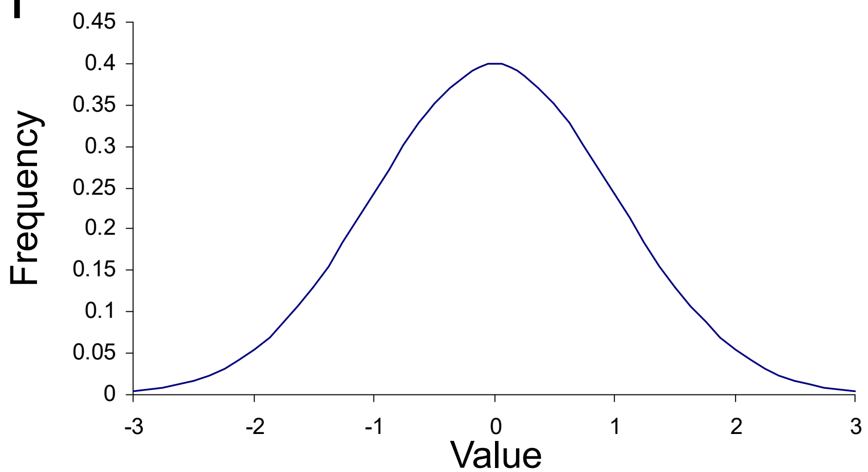
Basic Statistics Theory

Anexas Consultancy Services

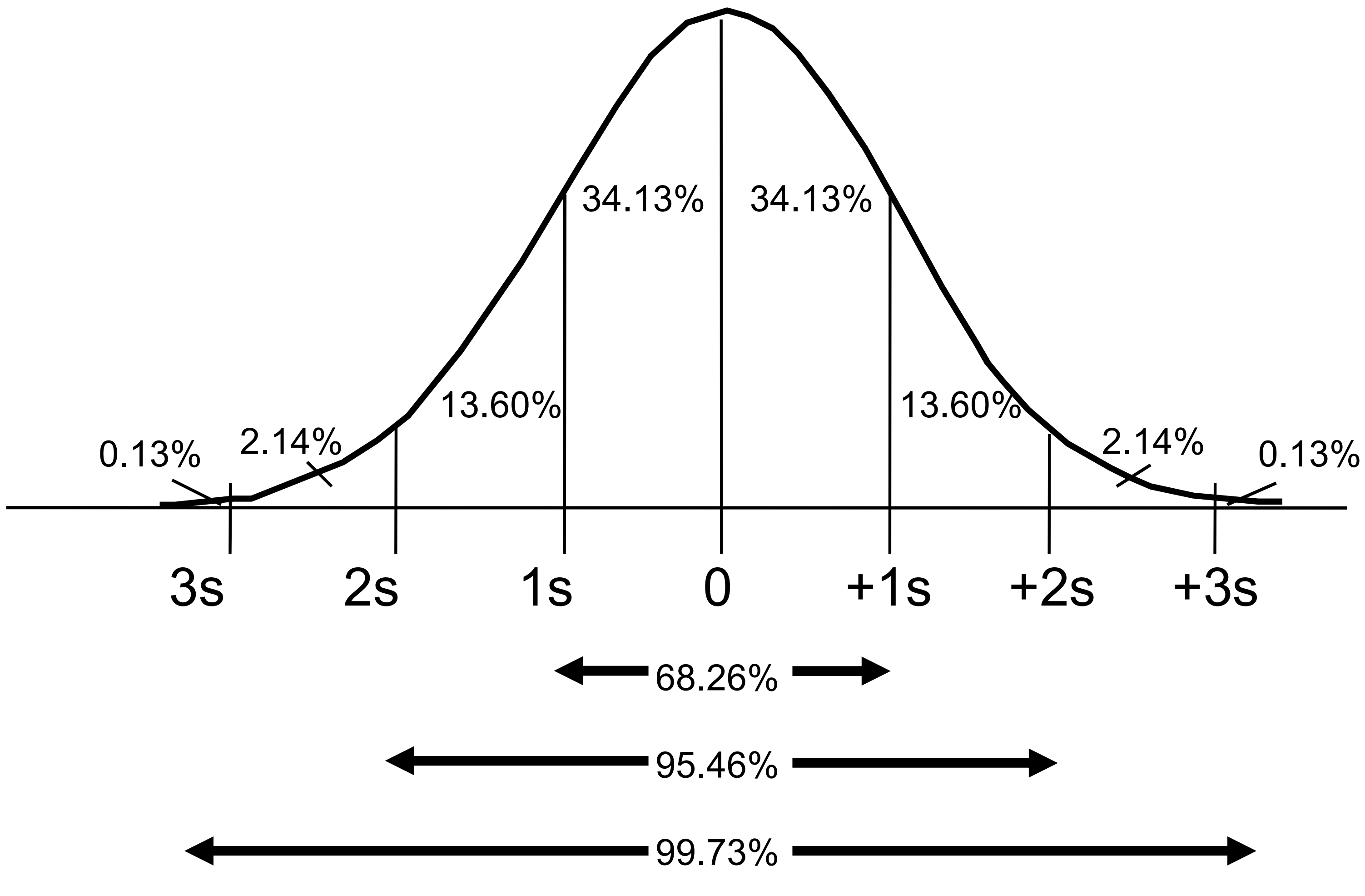
The Normal Distribution

Data and Statistics

- Data is the way we measure process performance
- Two main types of data
  - Continuous—measured
    - Example: Temperature
  - Discrete—categorized and counted
    - Example: Acceptable yes or no
- Continuous data are often treated as if they represented a sample from a distribution
- As shown, distribution is represented by a curve that shows all the possible values of the data and their relative frequency



Normal Distribution



Equations for Mean and Standard Deviation

Sample Mean

$$\overline{X} = \frac{\sum_{i=1}^{n} X_i}{n}$$

Sample Standard Deviation $s = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \overline{X})^2}{n-1}}$

Calculating Mean and Standard Deviation

1. List the data (order doesn't matter)

3. Subtract the mean from each individual data value

4. Square the differences between the values and the mean

5. Sum the square of the differences

6. Divide the sum from Step 5 by (n-1)—the number of data values minus 1

7. Take the square root of the answer from Step 6

2. Sum all values, then divide by the number of values to determine the mean

	X	$(X - \overline{X})$	$(X_i - \overline{X})^2$
1			
2			
3			
4			
5			
6			
7			
8			
9			
•			
•			
•			
•			
•			
n			
Sum			
Mean			
S2			
S			

Anexas Consultancy Services

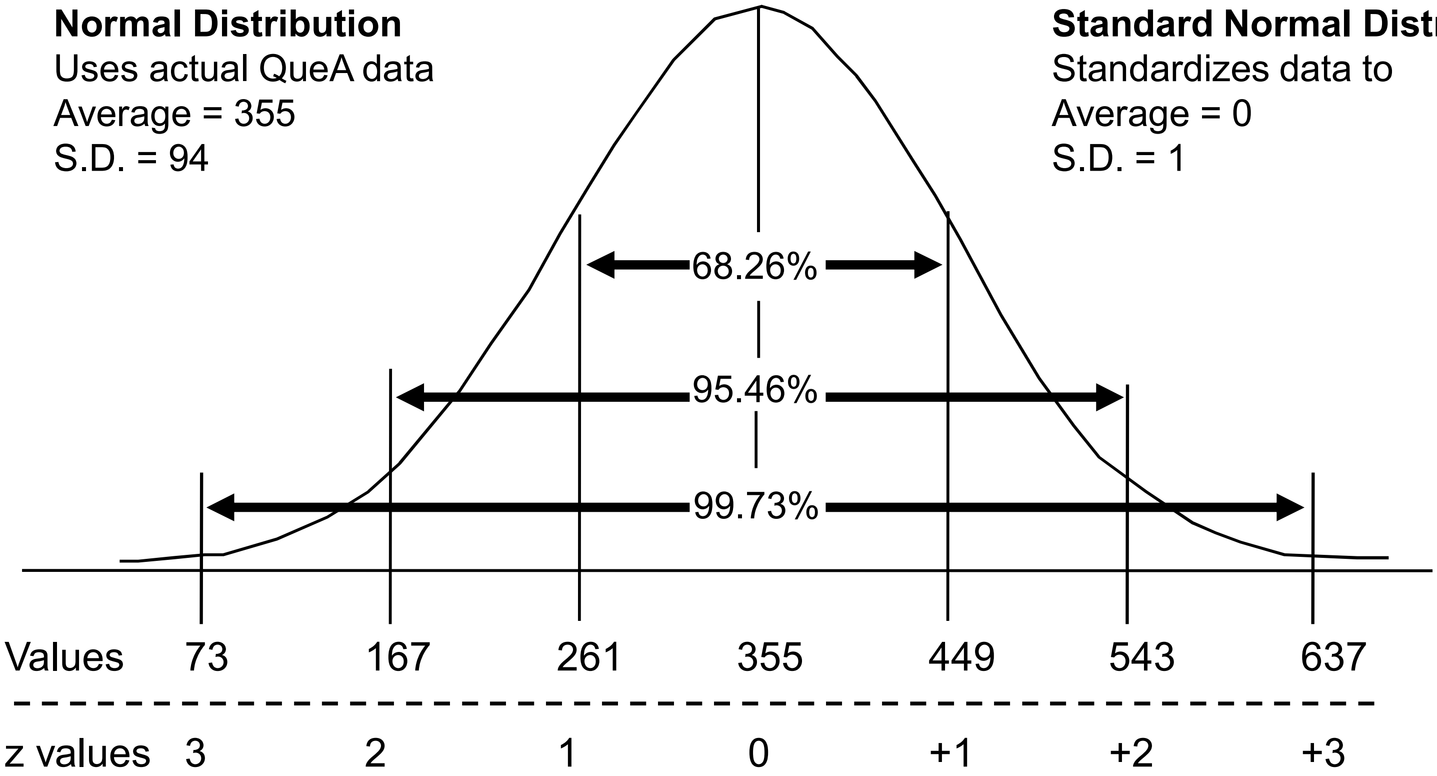
Areas Under Normal Curves

Normal Curve Probabilities

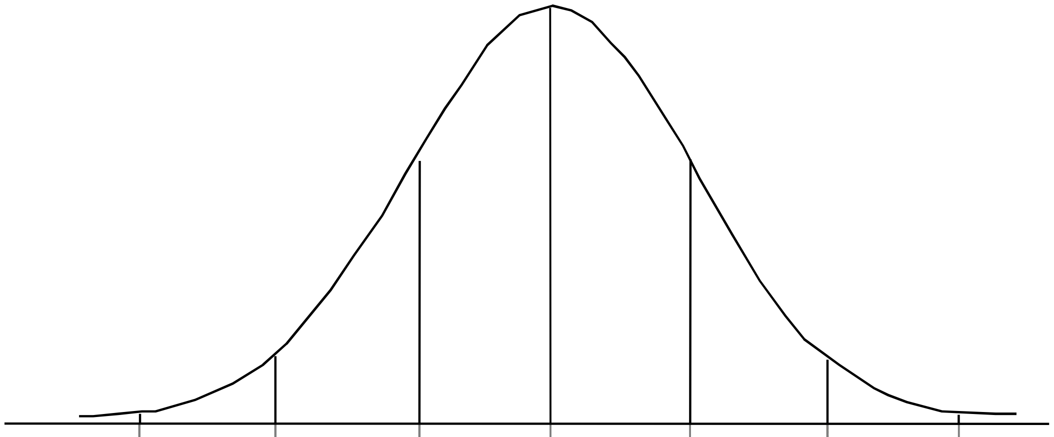
What's the probability that a caller will wait less than 600 seconds?

Normal Distribution
Uses actual QueA data
Average = 355
S.D. = 94

Standard Normal Distribution
Standardizes data to
Average = 0
S.D. = 1



Converting to Standard Normal



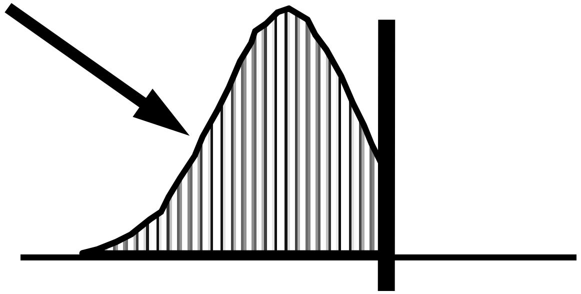
Standard Normal Mean = 0 s = 1	3	2	1	0	+1	+2	+3
Actual Data Mean = 355 s = 94	73	167	261	355	449	543	637
Mean = $\bar{X}$ s=s	**$\bar{X}$–3s**	**$\bar{X}$ 2**	**$\bar{X}$ s**	**$\bar{X}$**	**$\bar{X}$ + s**	**$\bar{X}$ + 2s**	**$\bar{X}$ + 3s**

Calculate the z-value for a limit of 25

$$Z = \frac{USL - \bar{X}}{s} = \frac{600 - 355}{94} = \mathbf{2.61}$$

600

Z Table



Z Decimal

Z Whole Number	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
4	0.000032	0.000021	0.000013	0.000009	0.000005	0.000003	0.000002	0.000001	0.000001	0.000000
3	0.001350	0.000968	0.000687	0.000483	0.000337	0.000233	0.000159	0.000108	0.000072	0.000048
2	0.022750	0.017864	0.013903	0.010724	0.008198	0.006210	0.004661	0.003467	0.002555	0.001866
1	0.158655	0.135666	0.115070	0.096801	0.080757	0.066807	0.054799	0.044565	0.035930	0.028716
0	0.500000	0.460172	0.420740	0.382089	0.344578	0.308538	0.274253	0.241964	0.211855	0.184060
0	0.500000	0.539828	0.579260	0.617911	0.655422	0.691462	0.725747	0.758036	0.788145	0.815940
1	0.841345	0.864334	0.884930	0.903199	0.919243	0.933193	0.945201	0.955435	0.964070	0.971284
2	0.977250	0.982136	0.986097	0.989276	0.991802	0.993790	0.995339	0.996533	0.997445	0.998134
3	0.998650	0.999032	0.999313	0.999517	0.999663	0.999767	0.999841	0.999892	0.999928	0.999952
4	0.999968	0.999979	0.999987	0.999991	0.999995	0.999997	0.999998	0.999999	0.999999	1.000000

Discussion: Is Something Fishy?

- You manage the shipping department for a manufacturer of medical devices
- You get a charge for $642 for expedited parts that you think usually comes in closer to $500
- You obtain 250 recent charges for that same item to make comparisons
- You want to know if there is something fishy about this charge or if it is within the usual range for that item
- How can you use the data to answer the question?
  –
  –

Discussion Answers: Is Something Fishy?

Option 1: Create a control chart of the data

- Use a control chart of claims amounts to see if the fishy charge is outside the limits

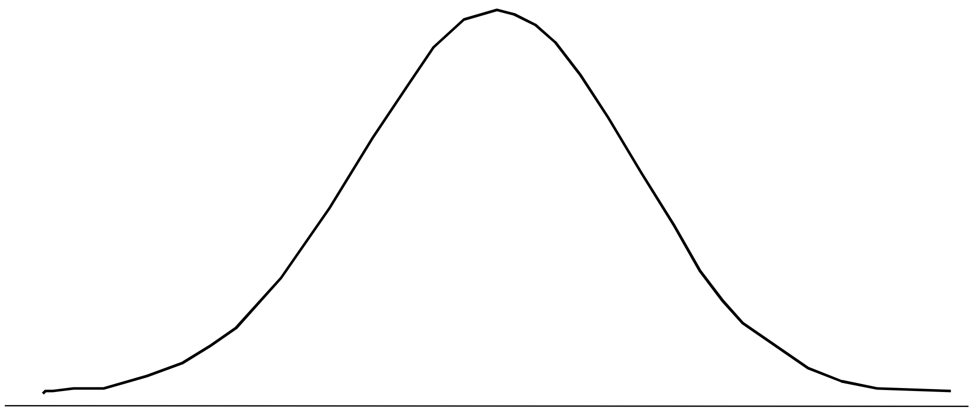
Option 2: Apply Normal theory

- Use Normal theory, a body of statistics built around the properties of the Normal distribution
- See where the fishy value falls in the distribution of these data

Recap: The Normal Curve

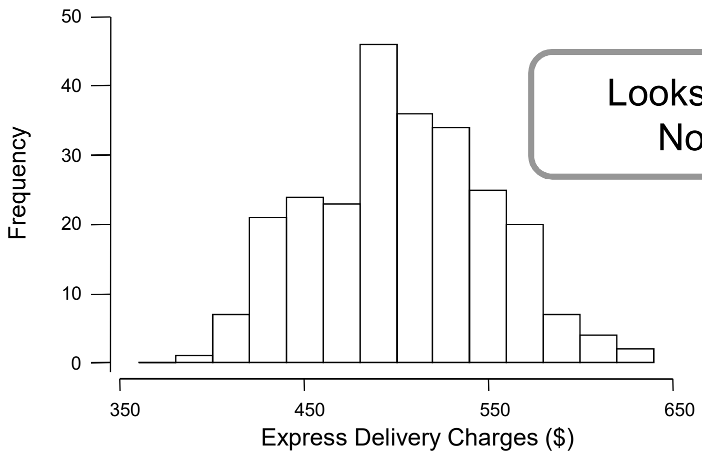
Definition

- A probability distribution in which the most frequently occurring value is in the middle and other probabilities tail off symmetrically in both directions
  - This shape is sometimes called a **bell shaped curve**



Overview: Using Normal Theory to Answer "Fishy" Questions

1. Make a histogram to see if (continuous) data are Normal



Looks roughly Normal.

2. Get the mean and standard deviation of data

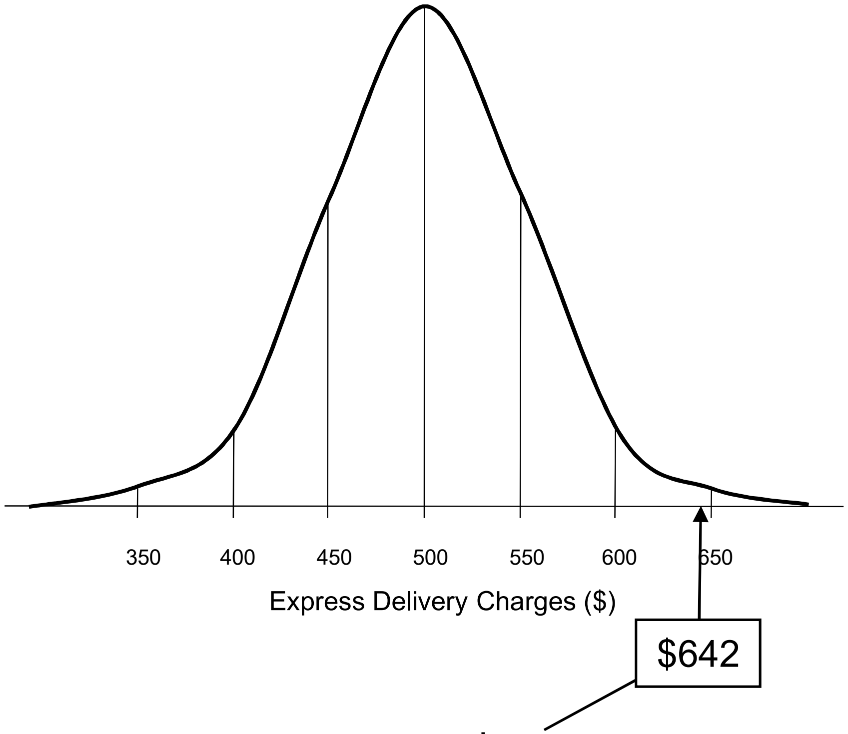
$$\overline{X} = \frac{\sum X}{n} = \$500$$

$$S = \sqrt{\frac{\sum (X - \overline{X})^2}{n-1}} = \$50$$

A standard deviation is the typical amount an observation varies from the mean.

Overview: Using Normal Theory to Answer "Fishy" Questions, cont.

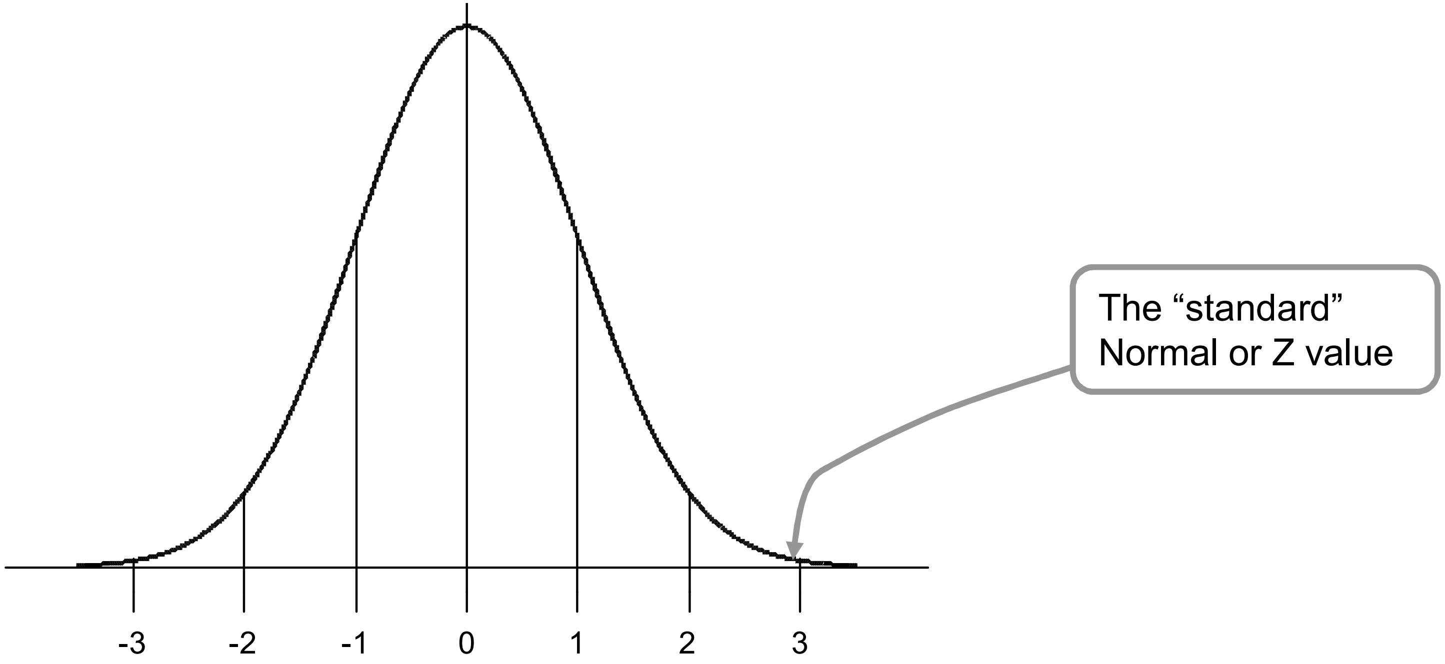
3. Draw Normal curve for data



4. Compare the value of interest ($642) with the Normal curve

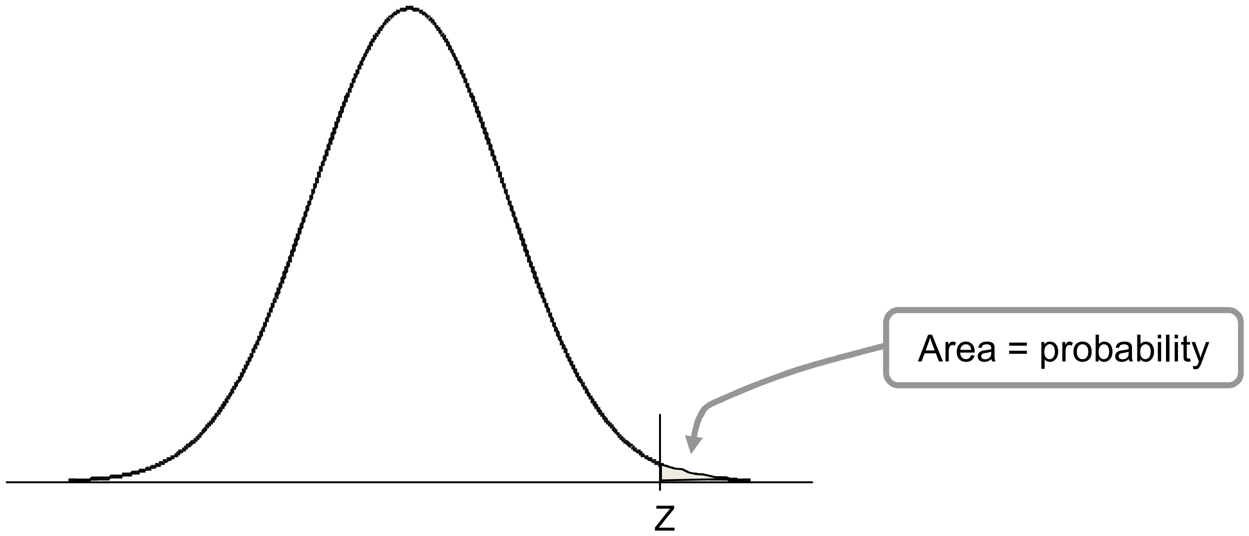
Overview: Using Normal Theory to Answer "Fishy" Questions, cont.

5. How many standard deviations away from the mean is the value of interest?



Overview: Using Normal Theory to Answer "Fishy" Questions, cont.

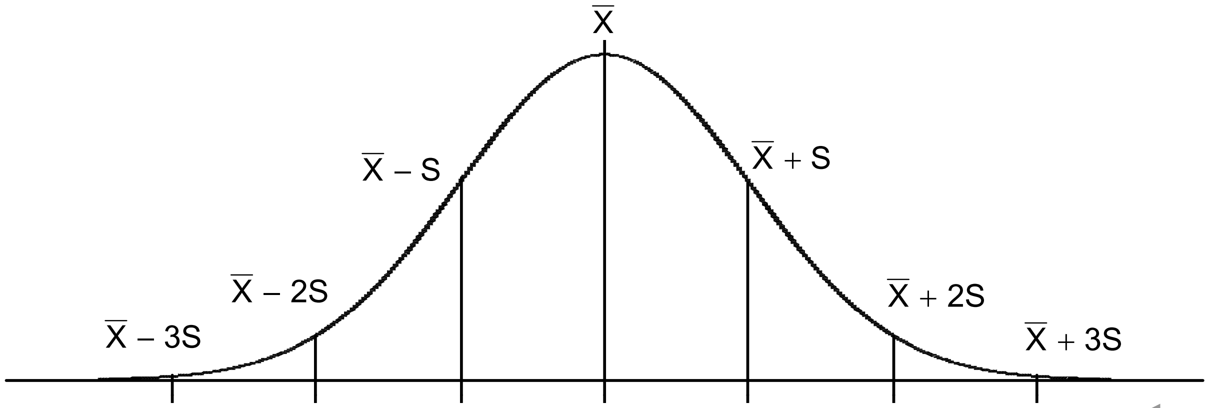
6. Look up the probability of a claim being that value or higher in the Normal table of z values



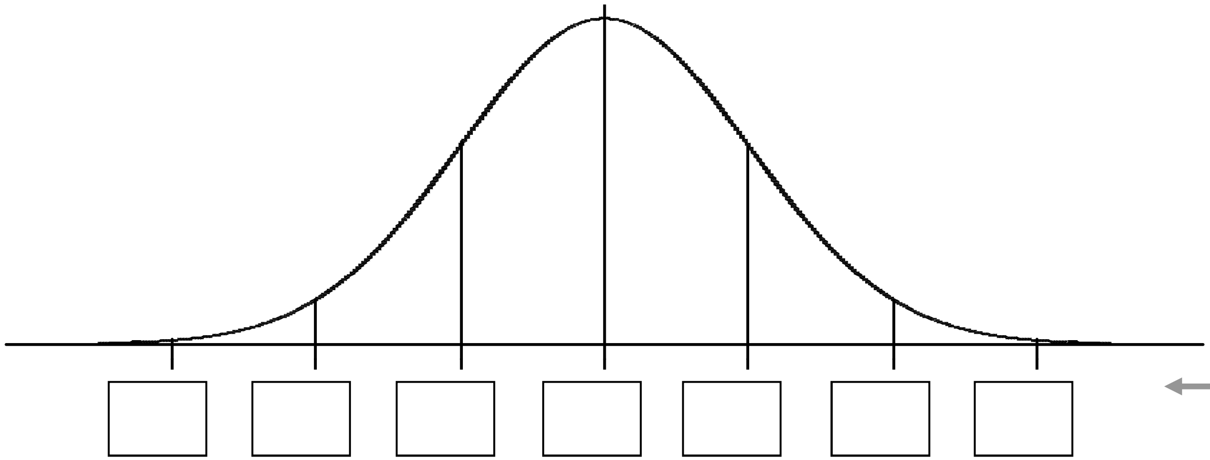
7. If probability is low, something is probably fishy

"Low" usually means < 0.05

Drawing Normal Curves



Normal data; "any" scale

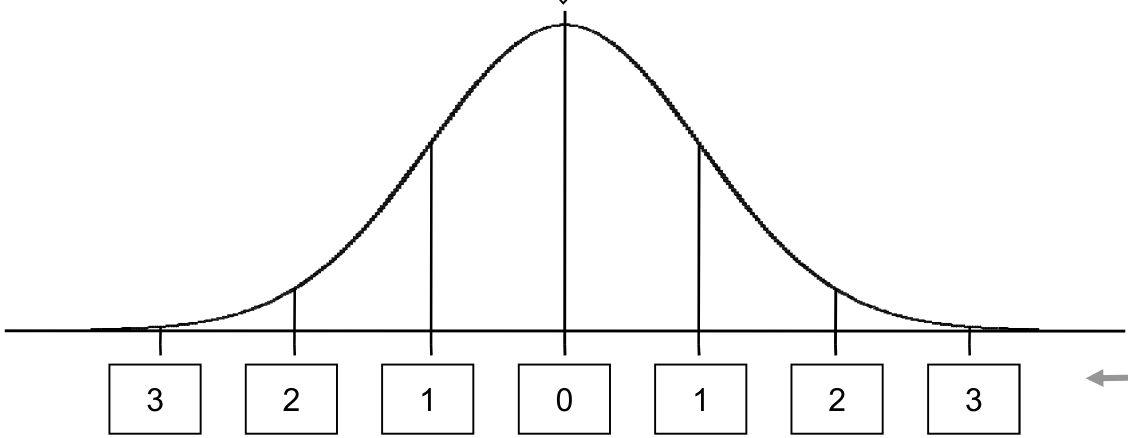


Fill in the blanks for data with
$\bar{X} = 500$
$s = 50$

Drawing Normal Curves, cont.

$$Z = \frac{(X - \overline{X})}{S}$$

X = value of interest



Standard Normal
(or z values)
$\overline{X} = 0$
$s = 1$

Z value: Same as a "Standard" Normal Value

Z value

How many standard deviations is the value of interest away from the mean?

$$Z = \frac{(\text{value-of-interest}) - \overline{X}}{S}$$

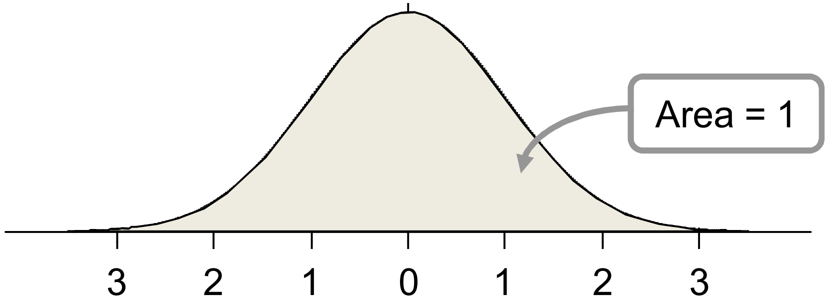
Claims example

How many standard deviations is \$642 away from \$500? (Or "What is the Z value for 642?")

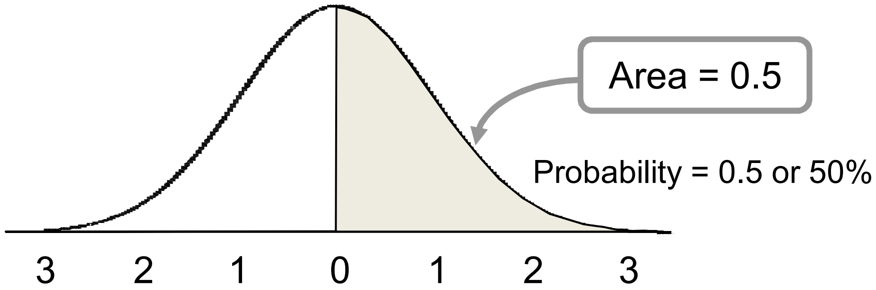
$$Z = \frac{642 - 500}{50} = \frac{142}{50} = 2.84$$

Probabilities of z values

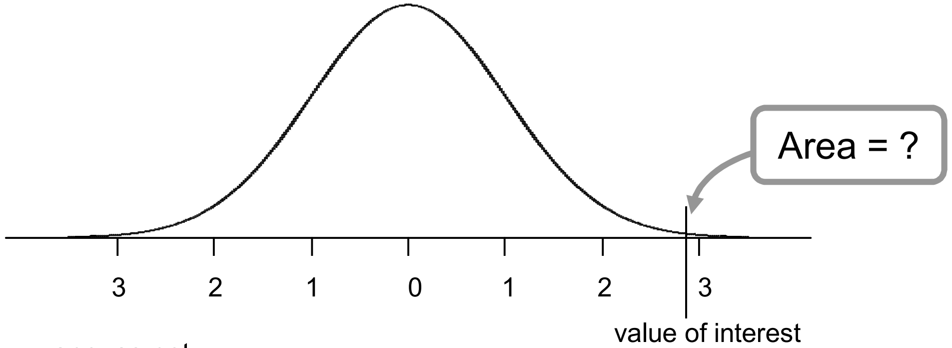
- Area under the standard Normal curve = probability



- What is the probability a Z value will be ≥ zero?



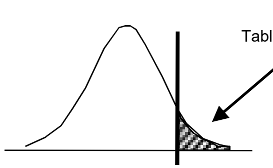
- What is the probability a Z value will be ≥ 2.84?



Normal Tables: Looking up Probabilities

Two types of tables

1. Reports area ≥ (to the right of) the value of interest



Standard Normal Table

Z	Area	Z	Area	Z	Area	Z	Area	Z	Area	Z	Area	Z	Area	Z	Area	Z	Area
0.00	0.500000	0.60	0.274253	1.20	0.115070	1.80	0.035930	2.40	0.008198	3.00	0.001350	3.60	0.000159	4.20	0.000013	4.80	0.000001
0.01	0.496011	0.61	0.270931	1.21	0.113139	1.81	0.035148	2.41	0.007976	3.01	0.001306	3.61	0.000153	4.21	0.000013	4.81	0.000001
0.02	0.492022	0.62	0.267629	1.22	0.111232	1.82	0.034380	2.42	0.007760	3.02	0.001264	3.62	0.000147	4.22	0.000012	4.82	0.000001
0.03	0.488034	0.63	0.264347	1.23	0.109349	1.83	0.033625	2.43	0.007549	3.03	0.001223	3.63	0.000142	4.23	0.000012	4.83	0.000001
0.04	0.484047	0.64	0.261086	1.24	0.107488	1.84	0.032884	2.44	0.007344	3.04	0.001183	3.64	0.000136	4.24	0.000011	4.84	0.000001
0.05	0.480061	0.65	0.257846	1.25	0.105650	1.85	0.032157	2.45	0.007143	3.05	0.001144	3.65	0.000131	4.25	0.000011	4.85	0.000001
0.06	0.476078	0.66	0.254627	1.26	0.103835	1.86	0.031443	2.46	0.006947	3.06	0.001107	3.66	0.000126	4.26	0.000010	4.86	0.000001
0.07	0.472097	0.67	0.251429	1.27	0.102042	1.87	0.030742	2.47	0.006756	3.07	0.001070	3.67	0.000121	4.27	0.000010	4.87	0.000001
0.08	0.468119	0.68	0.248252	1.28	0.100273	1.88	0.030054	2.48	0.006569	3.08	0.001035	3.68	0.000117	4.28	0.000009	4.88	0.000001
0.09	0.464144	0.69	0.245097	1.29	0.098525	1.89	0.029379	2.49	0.006387	3.09	0.001001	3.69	0.000112	4.29	0.000009	4.89	0.000001
0.10	0.460172	0.70	0.241964	1.30	0.096800	1.90	0.028717	2.50	0.006210	3.10	0.000968	3.70	0.000108	4.30	0.000009	4.90	0.000000
0.11	0.456205	0.71	0.238852	1.31	0.095098	1.91	0.028067	2.51	0.006037	3.11	0.000935	3.71	0.000104	4.31	0.000008	4.91	0.000000
0.12	0.452242	0.72	0.235763	1.32	0.093418	1.92	0.027429	2.52	0.005868	3.12	0.000904	3.72	0.000100	4.32	0.000008	4.92	0.000000
0.13	0.448283	0.73	0.232695	1.33	0.091759	1.93	0.026803	2.53	0.005703	3.13	0.000874	3.73	0.000096	4.33	0.000007	4.93	0.000000
0.14	0.444330	0.74	0.229650	1.34	0.090123	1.94	0.026190	2.54	0.005543	3.14	0.000845	3.74	0.000092	4.34	0.000007	4.94	0.000000
0.15	0.440382	0.75	0.226627	1.35	0.088508	1.95	0.025588	2.55	0.005386	3.15	0.000816	3.75	0.000088	4.35	0.000007	4.95	0.000000

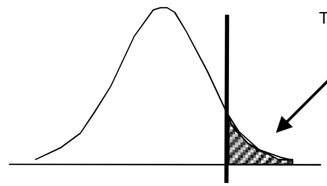
A larger version of this table is on the next page.

Standard Normal Table

Standard Normal Table

Z	Area	Z	Area	Z	Area	Z	Area	Z	Area	Z	Area	Z	Area	Z	Area	Z	Area
0.00	0.500000	0.60	0.274253	1.20	0.115070	1.80	0.035930	2.40	0.008198	3.00	0.001350	3.60	0.000159	4.20	0.000013	4.80	0.000001
0.01	0.496011	0.61	0.270931	1.21	0.113139	1.81	0.035148	2.41	0.007976	3.01	0.001306	3.61	0.000153	4.21	0.000013	4.81	0.000001
0.02	0.492022	0.62	0.267629	1.22	0.111232	1.82	0.034380	2.42	0.007760	3.02	0.001264	3.62	0.000147	4.22	0.000012	4.82	0.000001
0.03	0.488034	0.63	0.264347	1.23	0.109349	1.83	0.033625	2.43	0.007549	3.03	0.001223	3.63	0.000142	4.23	0.000012	4.83	0.000001
0.04	0.484047	0.64	0.261086	1.24	0.107488	1.84	0.032884	2.44	0.007344	3.04	0.001183	3.64	0.000136	4.24	0.000011	4.84	0.000001
0.05	0.480061	0.65	0.257846	1.25	0.105650	1.85	0.032157	2.45	0.007143	3.05	0.001144	3.65	0.000131	4.25	0.000011	4.85	0.000001
0.06	0.476078	0.66	0.254627	1.26	0.103835	1.86	0.031443	2.46	0.006947	3.06	0.001107	3.66	0.000126	4.26	0.000010	4.86	0.000001
0.07	0.472097	0.67	0.251429	1.27	0.102042	1.87	0.030742	2.47	0.006756	3.07	0.001070	3.67	0.000121	4.27	0.000010	4.87	0.000001
0.08	0.468119	0.68	0.248252	1.28	0.100273	1.88	0.030054	2.48	0.006569	3.08	0.001035	3.68	0.000117	4.28	0.000009	4.88	0.000001
0.09	0.464144	0.69	0.245097	1.29	0.098525	1.89	0.029379	2.49	0.006387	3.09	0.001001	3.69	0.000112	4.29	0.000009	4.89	0.000001
0.10	0.460172	0.70	0.241964	1.30	0.096800	1.90	0.028717	2.50	0.006210	3.10	0.000968	3.70	0.000108	4.30	0.000009	4.90	0.000000
0.11	0.456205	0.71	0.238852	1.31	0.095098	1.91	0.028067	2.51	0.006037	3.11	0.000935	3.71	0.000104	4.31	0.000008	4.91	0.000000
0.12	0.452242	0.72	0.235763	1.32	0.093418	1.92	0.027429	2.52	0.005868	3.12	0.000904	3.72	0.000100	4.32	0.000008	4.92	0.000000
0.13	0.448283	0.73	0.232695	1.33	0.091759	1.93	0.026803	2.53	0.005703	3.13	0.000874	3.73	0.000096	4.33	0.000007	4.93	0.000000
0.14	0.444330	0.74	0.229650	1.34	0.090123	1.94	0.026190	2.54	0.005543	3.14	0.000845	3.74	0.000092	4.34	0.000007	4.94	0.000000
0.15	0.440382	0.75	0.226627	1.35	0.088508	1.95	0.025588	2.55	0.005386	3.15	0.000816	3.75	0.000088	4.35	0.000007	4.95	0.000000
0.16	0.436441	0.76	0.223627	1.36	0.086915	1.96	0.024998	2.56	0.005234	3.16	0.000789	3.76	0.000085	4.36	0.000007		
0.17	0.432505	0.77	0.220650	1.37	0.085343	1.97	0.024419	2.57	0.005085	3.17	0.000762	3.77	0.000082	4.37	0.000006		
0.18	0.428576	0.78	0.217695	1.38	0.083793	1.98	0.023852	2.58	0.004940	3.18	0.000736	3.78	0.000078	4.38	0.000006		
0.19	0.424655	0.79	0.214764	1.39	0.082264	1.99	0.023295	2.59	0.004799	3.19	0.000711	3.79	0.000075	4.39	0.000006		
0.20	0.420740	0.80	0.211855	1.40	0.080757	2.00	0.022750	2.60	0.004661	3.20	0.000687	3.80	0.000072	4.40	0.000005		
0.21	0.416834	0.81	0.208970	1.41	0.079270	2.01	0.022216	2.61	0.004527	3.21	0.000664	3.81	0.000069	4.41	0.000005		
0.22	0.412936	0.82	0.206108	1.42	0.077804	2.02	0.021692	2.62	0.004396	3.22	0.000641	3.82	0.000067	4.42	0.000005		
0.23	0.409046	0.83	0.203269	1.43	0.076359	2.03	0.021178	2.63	0.004269	3.23	0.000619	3.83	0.000064	4.43	0.000005		
0.24	0.405165	0.84	0.200454	1.44	0.074934	2.04	0.020675	2.64	0.004145	3.24	0.000598	3.84	0.000062	4.44	0.000004		
0.25	0.401294	0.85	0.197663	1.45	0.073529	2.05	0.020182	2.65	0.004025	3.25	0.000577	3.85	0.000059	4.45	0.000004		
0.26	0.397432	0.86	0.194895	1.46	0.072145	2.06	0.019699	2.66	0.003907	3.26	0.000557	3.86	0.000057	4.46	0.000004		
0.27	0.393580	0.87	0.192150	1.47	0.070781	2.07	0.019226	2.67	0.003793	3.27	0.000538	3.87	0.000054	4.47	0.000004		
0.28	0.389739	0.88	0.189430	1.48	0.069437	2.08	0.018763	2.68	0.003681	3.28	0.000519	3.88	0.000052	4.48	0.000004		
0.29	0.385908	0.89	0.186733	1.49	0.068112	2.09	0.018309	2.69	0.003573	3.29	0.000501	3.89	0.000050	4.49	0.000004		
0.30	0.382089	0.90	0.184060	1.50	0.066807	2.10	0.017864	2.70	0.003467	3.30	0.000483	3.90	0.000048	4.50	0.000003		
0.31	0.378280	0.91	0.181411	1.51	0.065522	2.11	0.017429	2.71	0.003364	3.31	0.000466	3.91	0.000046	4.51	0.000003		
0.32	0.374484	0.92	0.178786	1.52	0.064255	2.12	0.017003	2.72	0.003264	3.32	0.000450	3.92	0.000044	4.52	0.000003		
0.33	0.370700	0.93	0.176186	1.53	0.063008	2.13	0.016586	2.73	0.003167	3.33	0.000434	3.93	0.000042	4.53	0.000003		
0.34	0.366928	0.94	0.173609	1.54	0.061780	2.14	0.016177	2.74	0.003072	3.34	0.000419	3.94	0.000041	4.54	0.000003		
0.35	0.363169	0.95	0.171056	1.55	0.060571	2.15	0.015778	2.75	0.002980	3.35	0.000404	3.95	0.000039	4.55	0.000003		
0.36	0.359424	0.96	0.168528	1.56	0.059380	2.16	0.015386	2.76	0.002890	3.36	0.000390	3.96	0.000037	4.56	0.000003		
0.37	0.355691	0.97	0.166023	1.57	0.058208	2.17	0.015003	2.77	0.002803	3.37	0.000376	3.97	0.000036	4.57	0.000002		
0.38	0.351973	0.98	0.163543	1.58	0.057053	2.18	0.014629	2.78	0.002718	3.38	0.000362	3.98	0.000034	4.58	0.000002		
0.39	0.348268	0.99	0.161087	1.59	0.055917	2.19	0.014262	2.79	0.002635	3.39	0.000349	3.99	0.000033	4.59	0.000002		
0.40	0.344578	1.00	0.158655	1.60	0.054799	2.20	0.013903	2.80	0.002555	3.40	0.000337	4.00	0.000032	4.60	0.000002		
0.41	0.340903	1.01	0.156248	1.61	0.053699	2.21	0.013553	2.81	0.002477	3.41	0.000325	4.01	0.000030	4.61	0.000002		
0.42	0.337243	1.02	0.153864	1.62	0.052616	2.22	0.013209	2.82	0.002401	3.42	0.000313	4.02	0.000029	4.62	0.000002		
0.43	0.333598	1.03	0.151505	1.63	0.051551	2.23	0.012874	2.83	0.002327	3.43	0.000302	4.03	0.000028	4.63	0.000002		
0.44	0.329969	1.04	0.149170	1.64	0.050503	2.24	0.012545	2.84	0.002256	3.44	0.000291	4.04	0.000027	4.64	0.000002		
0.45	0.326355	1.05	0.146859	1.65	0.049471	2.25	0.012224	2.85	0.002186	3.45	0.000280	4.05	0.000026	4.65	0.000002		
0.46	0.322758	1.06	0.144572	1.66	0.048457	2.26	0.011911	2.86	0.002118	3.46	0.000270	4.06	0.000025	4.66	0.000002		
0.47	0.319178	1.07	0.142310	1.67	0.047460	2.27	0.011604	2.87	0.002052	3.47	0.000260	4.07	0.000024	4.67	0.000002		
0.48	0.315614	1.08	0.140071	1.68	0.046479	2.28	0.011304	2.88	0.001988	3.48	0.000251	4.08	0.000023	4.68	0.000001		
0.49	0.312067	1.09	0.137857	1.69	0.045514	2.29	0.011011	2.89	0.001926	3.49	0.000242	4.09	0.000022	4.69	0.000001		
0.50	0.308538	1.10	0.135666	1.70	0.044565	2.30	0.010724	2.90	0.001866	3.50	0.000233	4.10	0.000021	4.70	0.000001		
0.51	0.305026	1.11	0.133500	1.71	0.043633	2.31	0.010444	2.91	0.001807	3.51	0.000224	4.11	0.000020	4.71	0.000001		
0.52	0.301532	1.12	0.131357	1.72	0.042716	2.32	0.010170	2.92	0.001750	3.52	0.000216	4.12	0.000019	4.72	0.000001		
0.53	0.298056	1.13	0.129238	1.73	0.041815	2.33	0.009903	2.93	0.001695	3.53	0.000208	4.13	0.000018	4.73	0.000001		
0.54	0.294599	1.14	0.127143	1.74	0.040930	2.34	0.009642	2.94	0.001641	3.54	0.000200	4.14	0.000017	4.74	0.000001		
0.55	0.291160	1.15	0.125072	1.75	0.040059	2.35	0.009387	2.95	0.001589	3.55	0.000193	4.15	0.000017	4.75	0.000001		
0.56	0.287740	1.16	0.123024	1.76	0.039204	2.36	0.009137	2.96	0.001538	3.56	0.000185	4.16	0.000016	4.76	0.000001		
0.57	0.284339	1.17	0.121000	1.77	0.038364	2.37	0.008894	2.97	0.001489	3.57	0.000178	4.17	0.000015	4.77	0.000001		
0.58	0.280957	1.18	0.119000	1.78	0.037538	2.38	0.008656	2.98	0.001441	3.58	0.000172	4.18	0.000015	4.78	0.000001		
0.59	0.277595	1.19	0.117023	1.79	0.036727	2.39	0.008424	2.99	0.001395	3.59	0.000165	4.19	0.000014	4.79	0.000001		

Z



Tabled Area

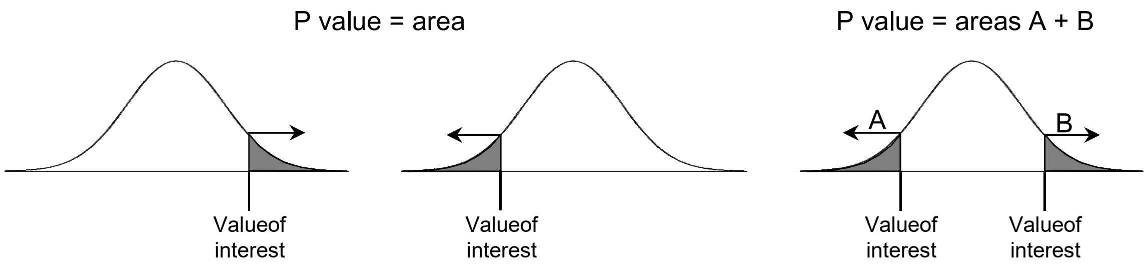
Anexas Consultancy Services

Looking
Up Probabilities

P values Are Probabilities for Values of Interest

P value =

- Tail area
- Area under curve beyond value of interest
- Probability of being at the value of interest or beyond



- A small P value (0 to 0.05) means:
  - The probability is small that the value of interest did, indeed, come from that distribution; it is likely to have come from some other distribution
  - Something's fishy!

P values Are Probabilities for Values of Interest, cont.

Claims example

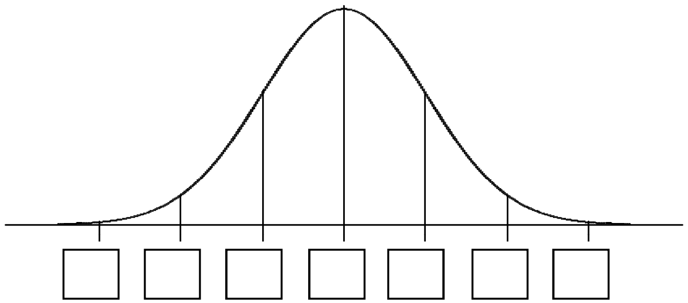
- Charge of interest = $642
- Z value = 2.84
- P value = 0.0023 (very small)

Conclusion

- The likelihood is small that the charge of $642 came from the same distribution as the other charges
- Something's probably fishy; investigate the charge further

Exercise: Using Normal Theory and P values

- You receive another charge of $970 for a different item
- Find its P value given that 250 recent charges of the same type are roughly Normal with an average of $800 and a standard deviation of $200
  - Are the data Normal (and continuous)?
  - Get mean and standard deviation of the data
  - Label the Normal curve for these data



  - Mark on the curve where the value of interest falls in the distribution

Exercise: Using Normal Theory and P values, cont.

- How many standard deviations is the value of interest from the mean? (What is the Z value?)

$$Z = \frac{(\text{value-of-interest}) - \overline{X}}{S} = \boxed{}$$

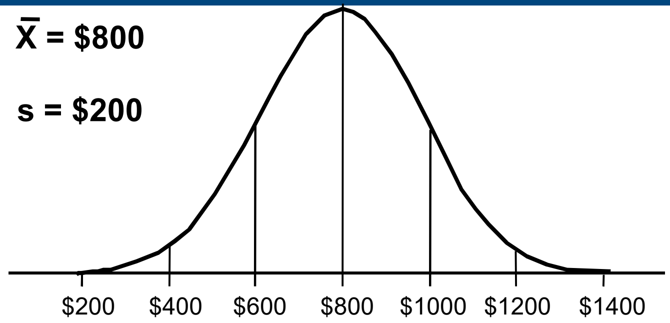
- Look up the probability of the claim being that Z value or beyond in the Standard Normal table

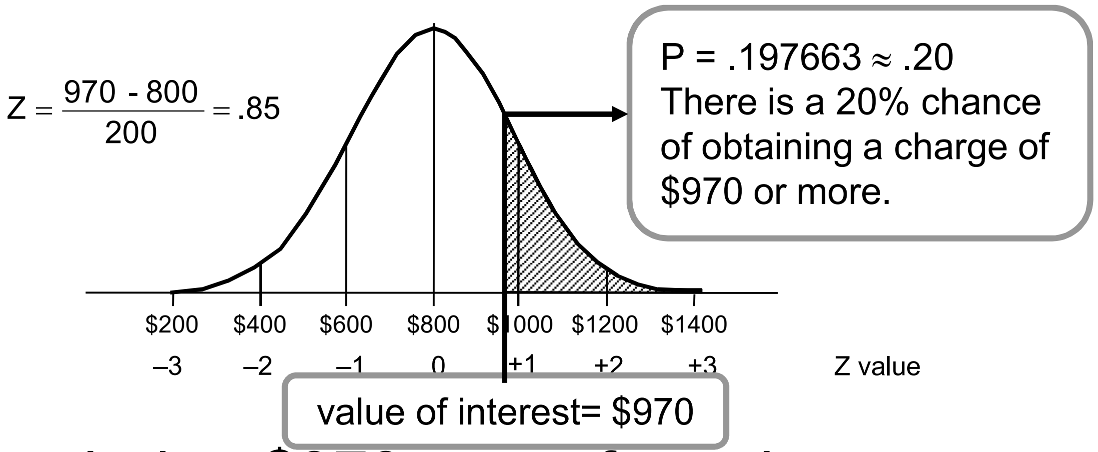
  P value =

- P value means:

  Will you investigate the claim or not?

Answer: Using Normal Theory and P values





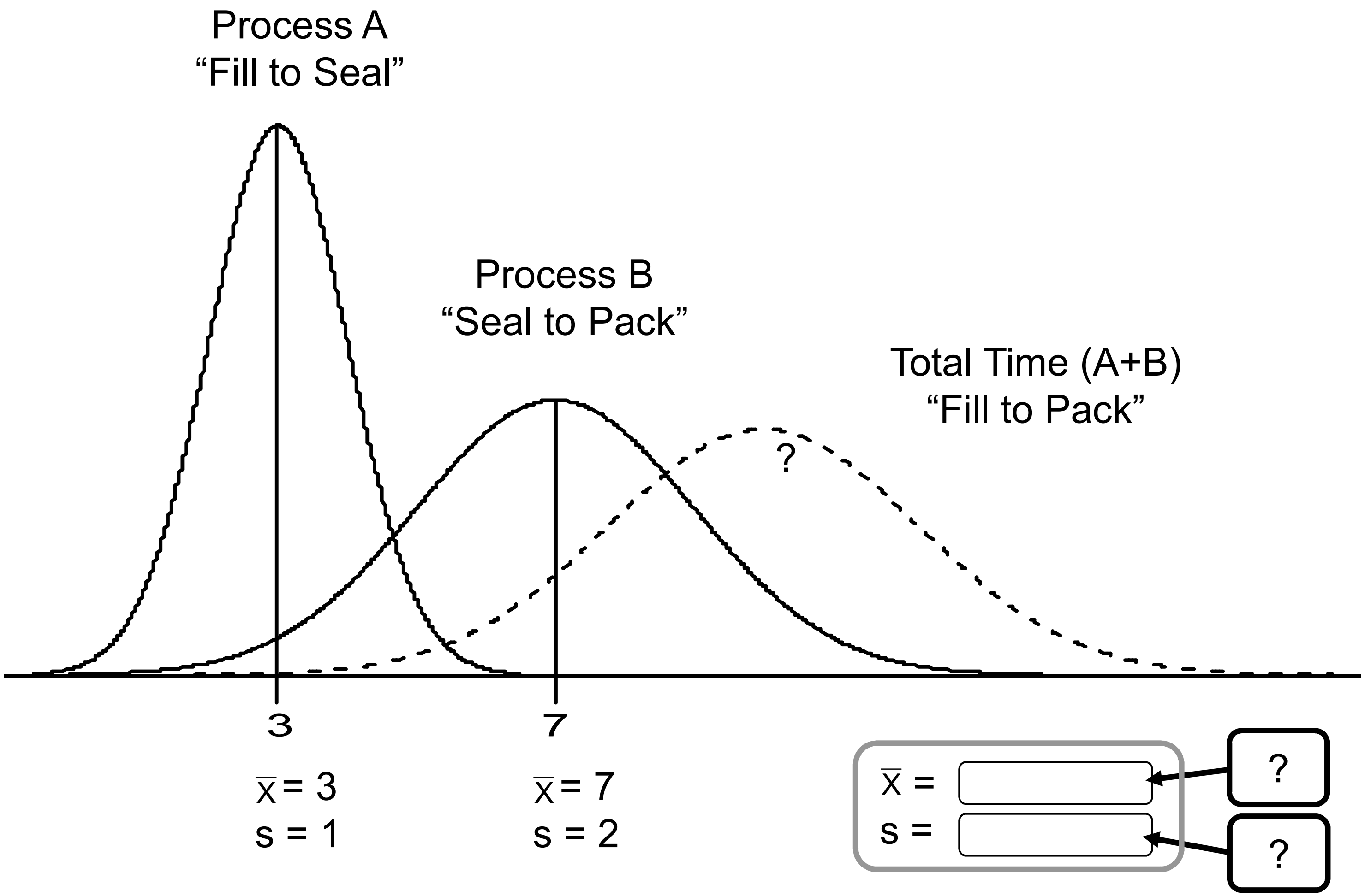
Conclusion

- It is likely enough that $970 came from the same distribution as the other charges
- Do not investigate; pay the charge

Anexas Consultancy Services

Combining Distributions

Part 1: Adding Distributions



How to Add Normal Distributions

Means are additive

$$\bar{X}_{A+B} = \bar{X}_A + \bar{X}_B$$
$$= 3 + 7$$
$$= 10$$

Are standard deviations additive?

$$S_{A+B} \overset{?}{=} S_A + S_B$$

NO! Incorrect

- When you add two variables, the variation increases, but by how much?
- The combined distribution will be wider than either curve alone

Variances Are Additive; Standard Deviations Are Not

- A standard deviation is the typical amount an observation varies from the mean
- Standard deviations are derived from a statistical term called **variance**

$$\text{St. Dev.} = \sqrt{\text{Variance}}$$

- Variances are additive, but standard deviations are not
- To combine two standard deviations, square each to get the variances, add the variances, and then take a square root of the combined variance

Variances Are Additive; Standard Deviations Are Not, cont.

Process Time Example

To add distributions:

- Add means to get new mean
- Add variances and then take square root to get standard deviation of combined distribution

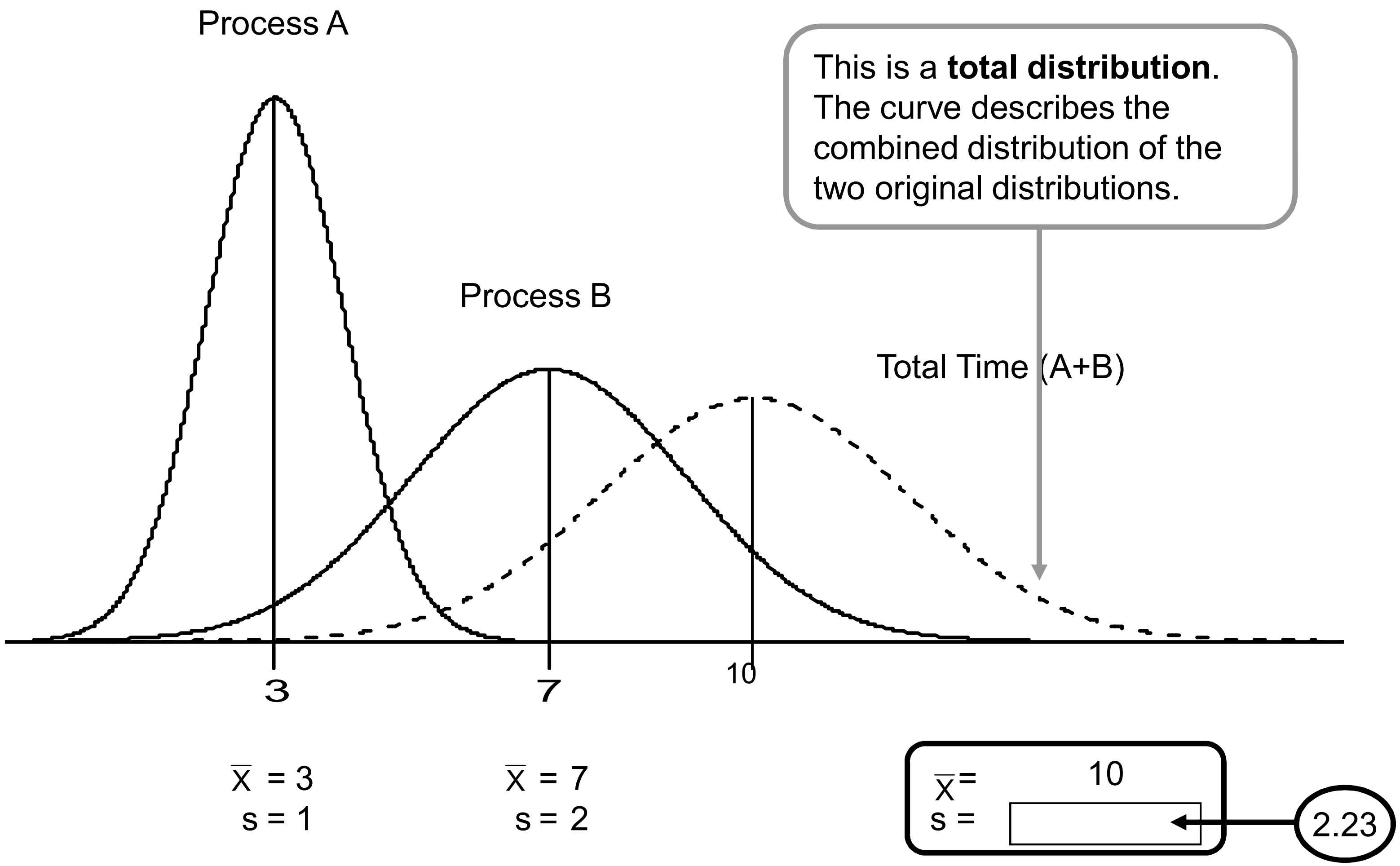
$$S_{A+B} = \sqrt{S_A^2 + S_B^2} = \sqrt{(1)^2 + (2)^2} = \sqrt{5} = 2.23$$

Correct; add variances and then take square root.

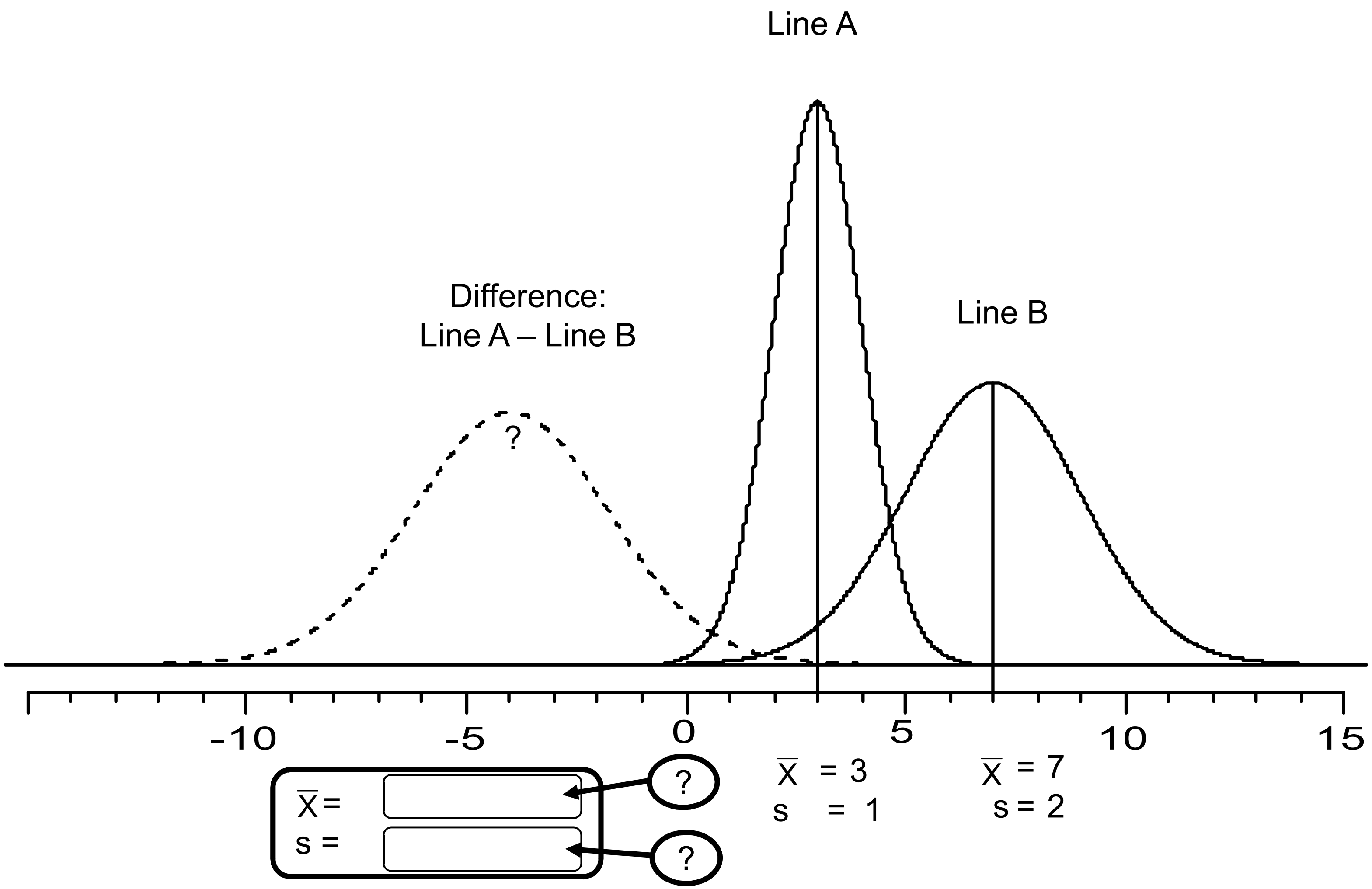
$$\neq 1 + 2 = 3$$

Incorrect; do not add standard deviation

Variances Are Additive; Standard Deviations Are Not, cont.



Part 2: Subtracting Distributions



How to Subtract Normal Distributions

For differences, subtract means, but add variances

- It may seem counterintuitive at first, but any time you combine distributions, variation always increases
- So even when you subtract means, you add variances

Mean

$$\bar{X}_{A+B} = \bar{X}_A + \bar{X}_B$$

Variance

$$S^2_{A-B} = S^2_A + S^2_B$$

Standard Deviation

$$S_{A-B} = \sqrt{S^2_A + S^2_B}$$

Example: Subtracting Distributions

Process Time Example

$$\overline{X}_{A-B} = \overline{X}_A - \overline{X}_B = 3 - 7 = -4$$

It's negative because the process time for Line A is on average 4 minutes shorter than the process time for Line B.

$$S_{A-B} = \sqrt{s_A^2 + s_B^2} = \sqrt{(1)^2 + (2)^2} = \sqrt{5} = 2.23$$

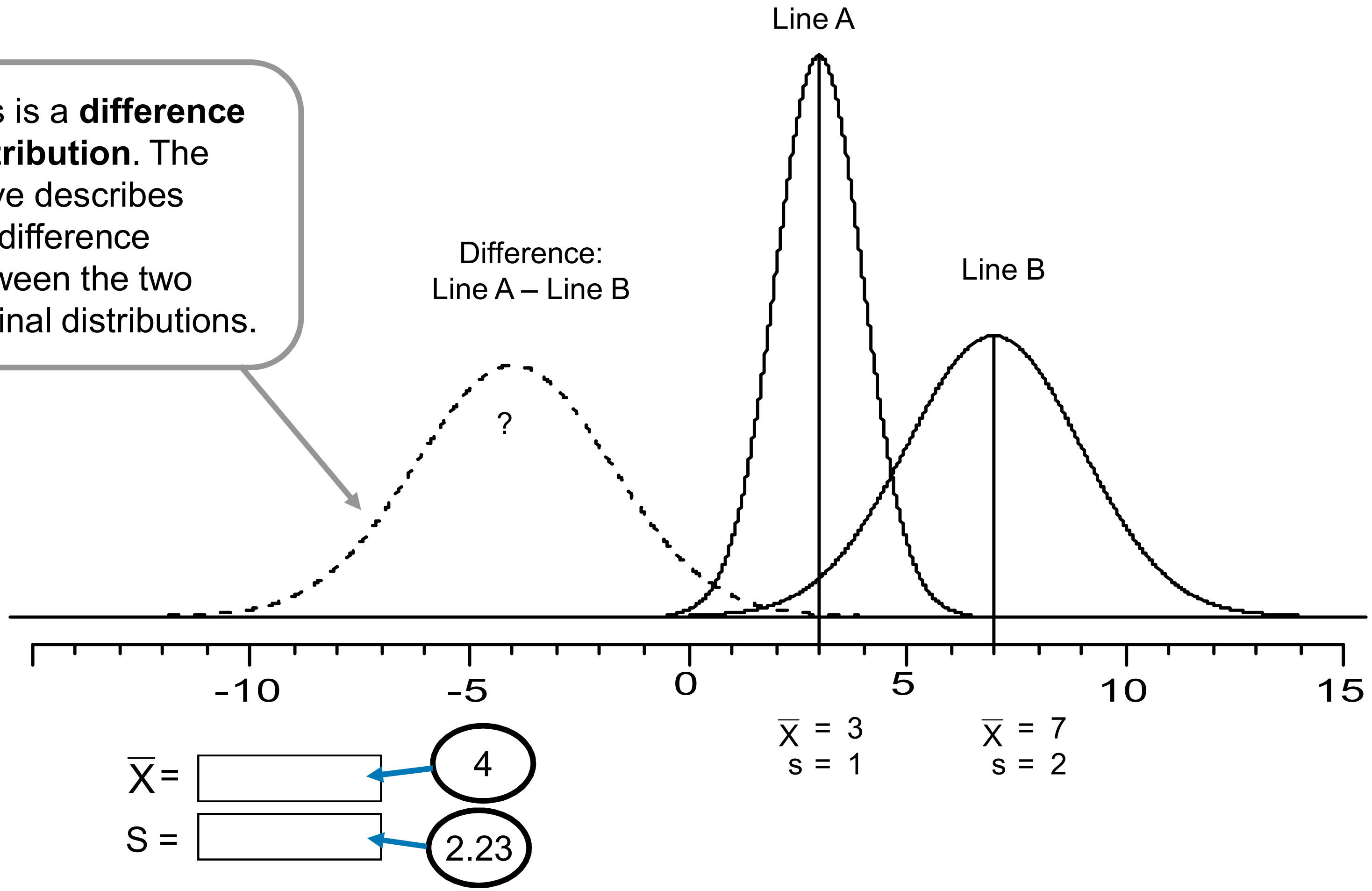
Correct

$$\neq 1 - 2 = -1$$

Incorrect

Example: Subtracting Distributions, cont.

This is a **difference distribution**. The curve describes the difference between the two original distributions.



Additivity of Variances

1. **Adding distributions to get a total**

$$\bar{X}_{A+B} = \bar{X}_A + \bar{X}_B$$

$$S^2_{A+B} = S^2_A + S^2_B$$

$$S_{A+B} = \sqrt{S^2_A + S^2_B}$$

2. **Subtracting distributions to get a difference**

$$\bar{X}_{A+B} = \bar{X}_A + \bar{X}_B$$

$$S^2_{A-B} = S^2_A + S^2_B$$

$$S_{A-B} = \sqrt{S^2_A + S^2_B}$$

Same

When adding or subtracting distributions, the procedure is the same for getting a standard deviation

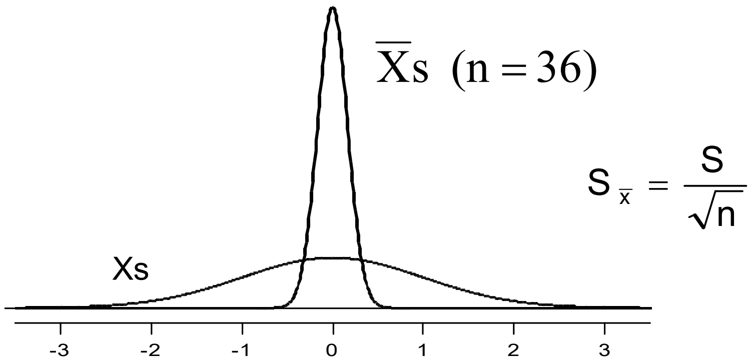
- Add variances
- Take a square root

Anexas Consultancy Services

Central Limit Theorem and Confidence Intervals

The Central Limit Theorem, Part 1

- The Central Limit Theorem is an important statistical concept that applies to a large number of statistical tools within the Six Sigma Body of Knowledge
- Understanding it is indispensable to interpreting results of various statistical tools (e.g., regression analysis or hypothesis testing)
- We will use Minitab to generate "random" data to illustrate how the Central Limit Theorem works
- Part 1 of the Central Limit Theorem says the standard deviation of averages is less than the standard deviation of individual observations by a factor of $\frac{1}{\sqrt{n}}$



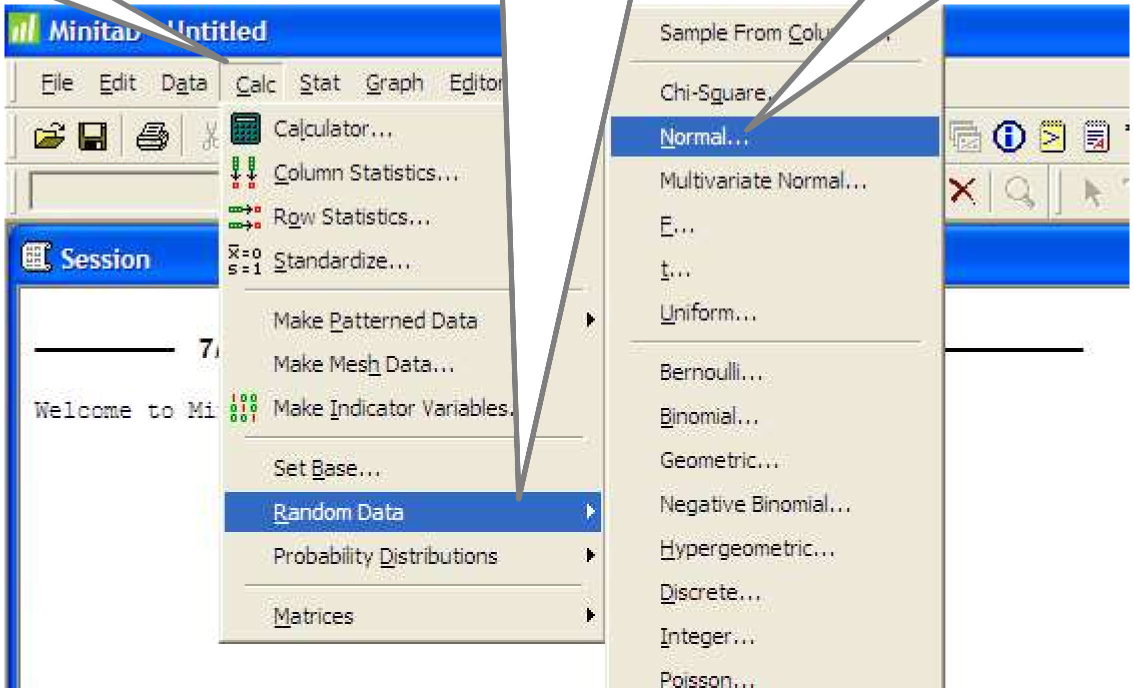
The Central Limit Theorem, Part 1

- Open a blank Minitab worksheet

1. Click on Calc

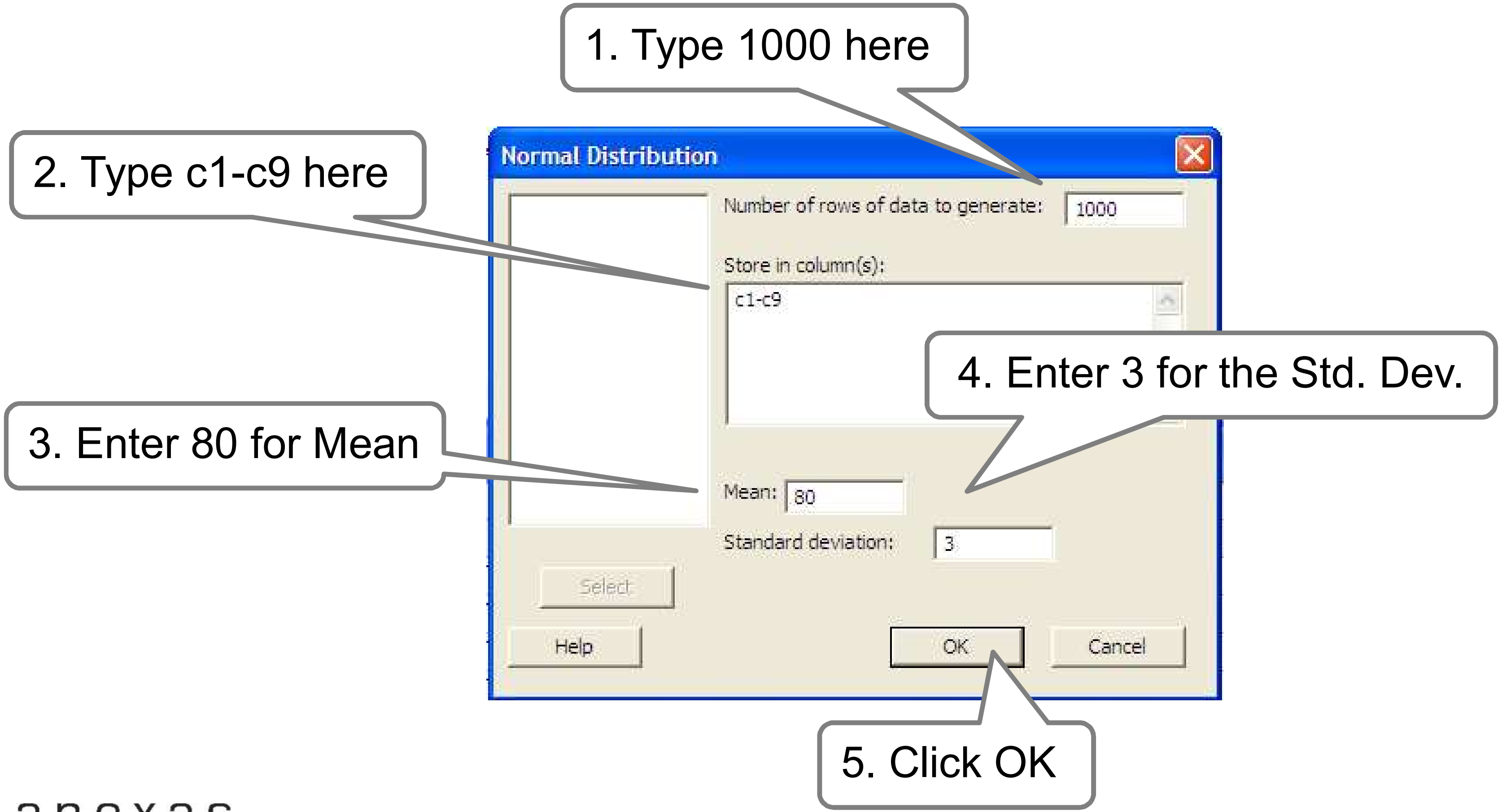
2. Select Random Data

3. Select Normal



The Central Limit Theorem, Part 1, cont.

- Have Minitab generate random normal data as shown below:



The Central Limit Theorem, Part 1, cont.

Output: your numbers will be different

Worksheet 1 ***

↓	C1	C2	C3	C4	C5	C6	C7	C8	C9
1	83.6550	79.5600	78.4506	82.2106	75.9103	76.6537	79.4996	74.8787	78.4519
2	79.8536	79.8202	77.4575	87.0574	75.8258	81.7003	83.0624	78.5713	81.1571
3	84.9487	87.0001	74.2243	78.3876	78.7760	76.1865	84.8863	78.4661	81.9700
4	81.1384	78.7630	80.6872	86.3217	79.0401	80.3601	83.0348	84.7032	79.0495
5	79.4711	79.5336	79.8951	83.2326	82.3533	83.3356	78.7162	87.2212	72.8625

Next: Type X1…X9 as shown

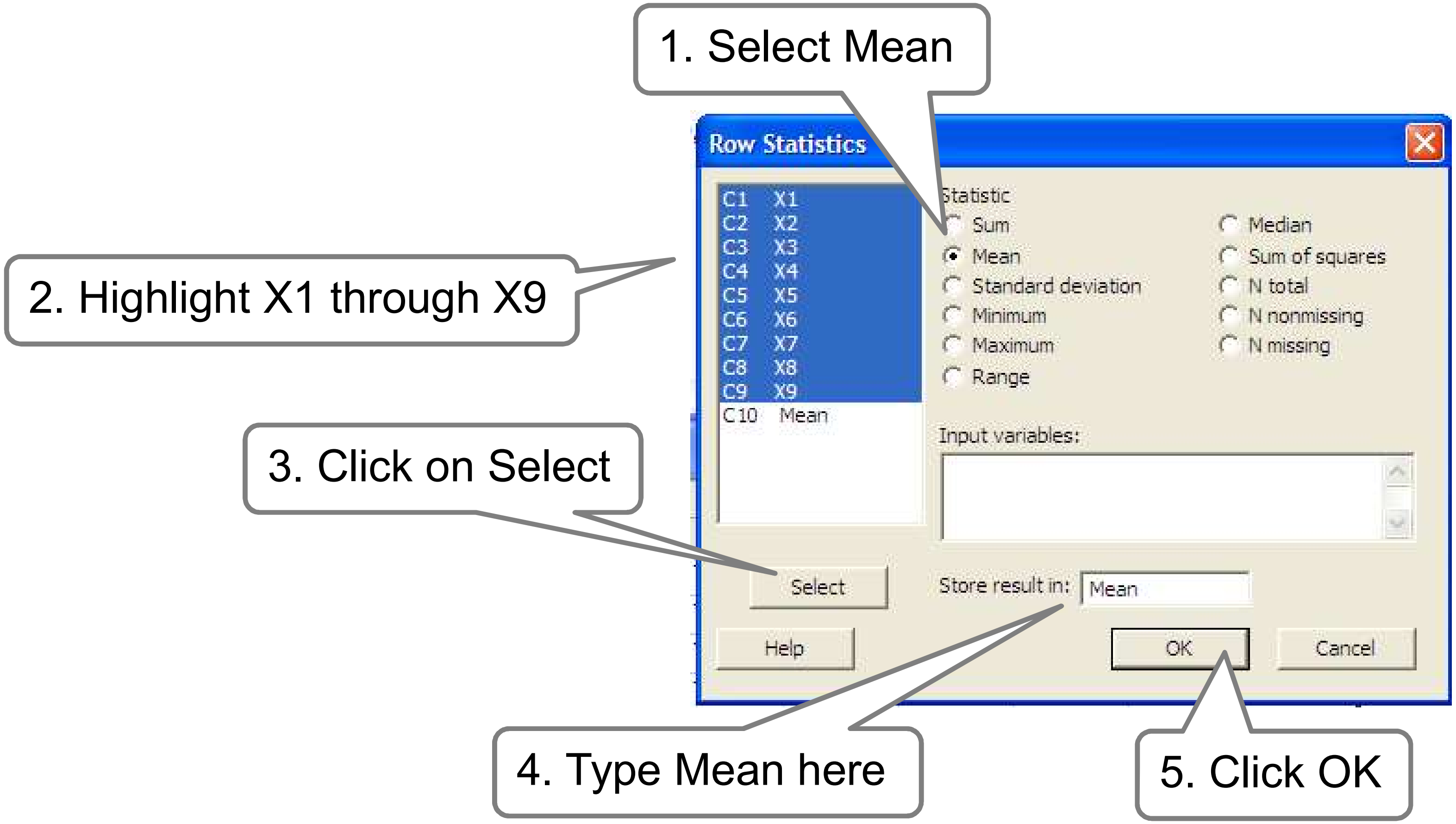
Type Mean as C10's name

Worksheet 1 ***

↓	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
	X1	X2	X3	X4	X5	X6	X7	X8	X9	Mean
1	83.6550	79.5600	78.4506	82.2106	75.9103	76.6537	79.4996	74.8787	78.4519	
2	79.8536	79.8202	77.4575	87.0574	75.8258	81.7003	83.0624	78.5713	81.1571	
3	84.9487	87.0001	74.2243	78.3876	78.7760	76.1865	84.8863	78.4661	81.9700	
4	81.1384	78.7630	80.6872	86.3217	79.0401	80.3601	83.0348	84.7032	79.0495	
5	79.4711	79.5336	79.8951	83.2326	82.3533	83.3356	78.7162	87.2212	72.8625	

The Central Limit Theorem, Part 1, cont.

- From the main menu, click on Calc > Row Statistics



The Central Limit Theorem, Part 1, cont.

Output: your numbers will be different

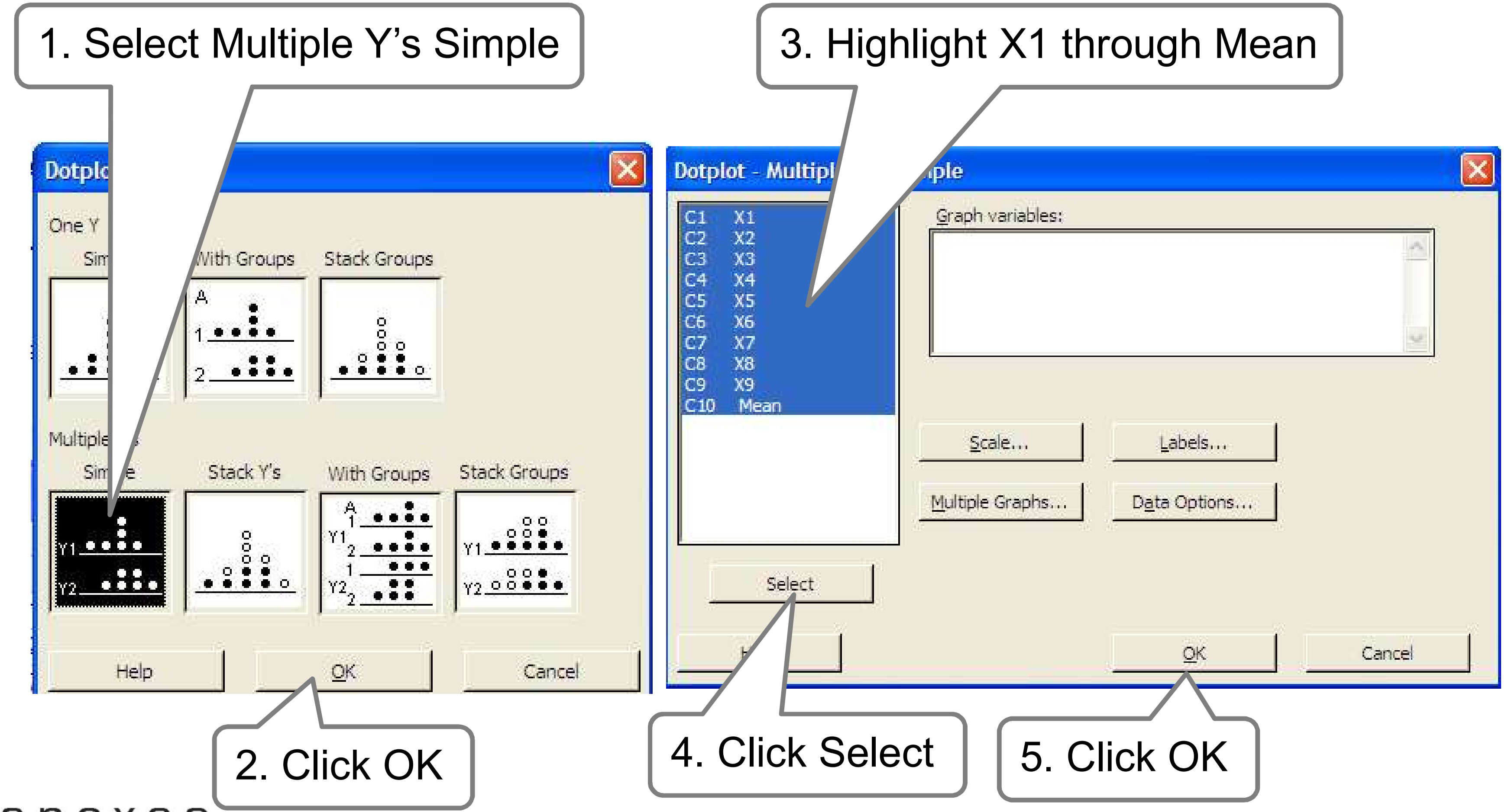
Worksheet 1 ***

↓	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
	X1	X2	X3	X4	X5	X6	X7	X8	X9	Mean
1	83.6550	79.5600	78.4506	82.2106	75.9103	76.6537	79.4996	74.8787	78.4519	78.8078
2	79.8536	79.8202	77.4575	87.0574	75.8258	81.7003	83.0624	78.5713	81.1571	80.5006
3	84.9487	87.0001	74.2243	78.3876	78.7760	76.1865	84.8863	78.4661	81.9700	80.5384
4	81.1384	78.7630	80.6872	86.3217	79.0401	80.3601	83.0348	84.7032	79.0495	81.4553
5	79.4711	79.5336	79.8951	83.2326	82.3533	83.3356	78.7162	87.2212	72.8625	80.7357
6	81.5827	81.9029	83.6519	77.9239	81.5689	76.1915	78.4964	81.9043	81.7659	80.5543
7	82.8922	81.9180	77.7750	78.2163	75.8942	77.3754	78.7867	74.3572	77.2389	78.2727
8	80.1942	79.0787	79.5300	74.8835	80.9407	79.3496	76.6232	72.2527	80.5293	78.1535
9	77.5850	78.1653	79.4201	81.8047	82.4503	83.8673	76.5159	77.9000	78.6011	79.5900
10	73.6482	81.4310	78.5088	76.5771	72.6084	80.5710	81.4985	78.5333	76.9386	77.8128

- **Next**: Compare the distribution of the X's with the distribution of the Mean

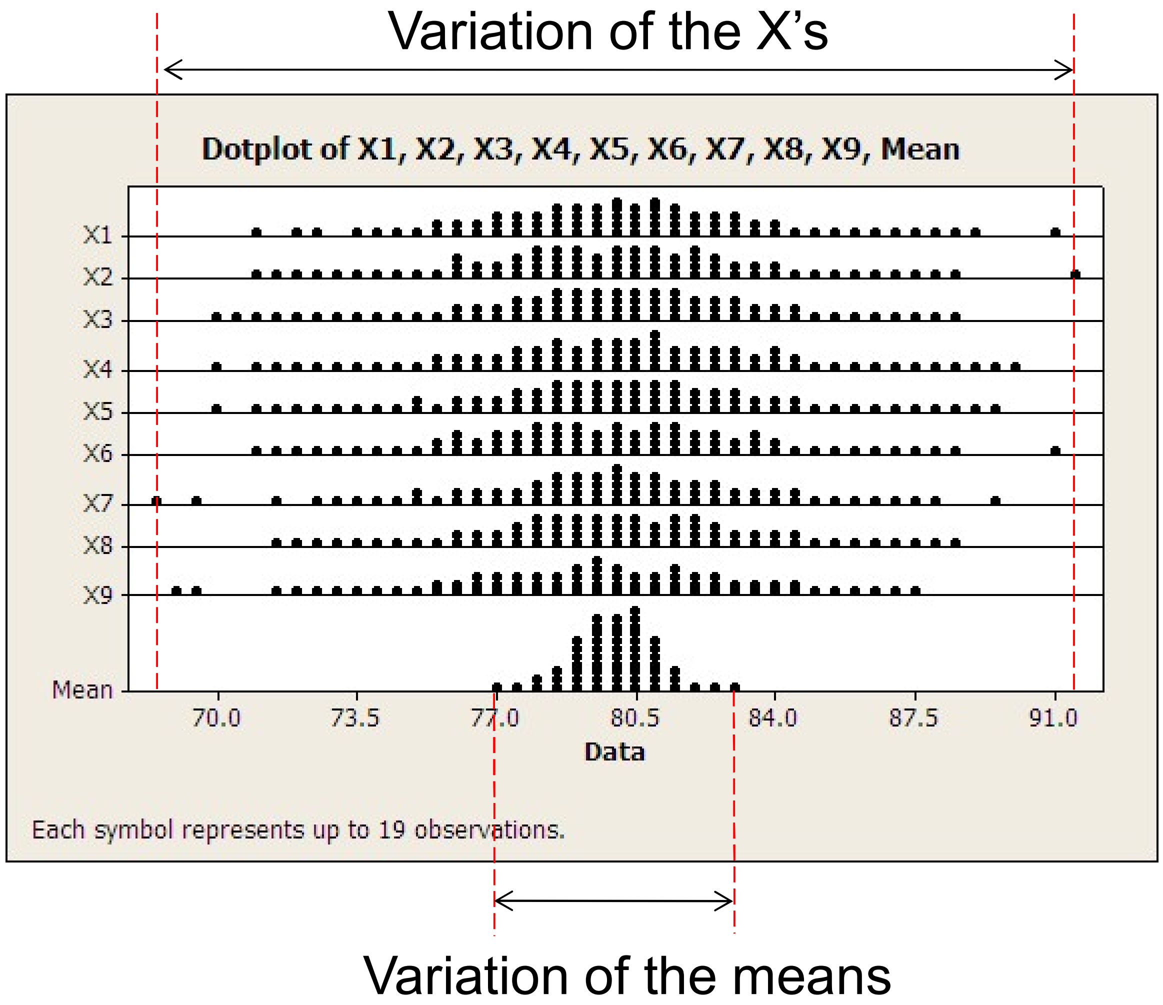
The Central Limit Theorem, Part 1, cont.

- From the main menu, click on Graph > Dotplot…



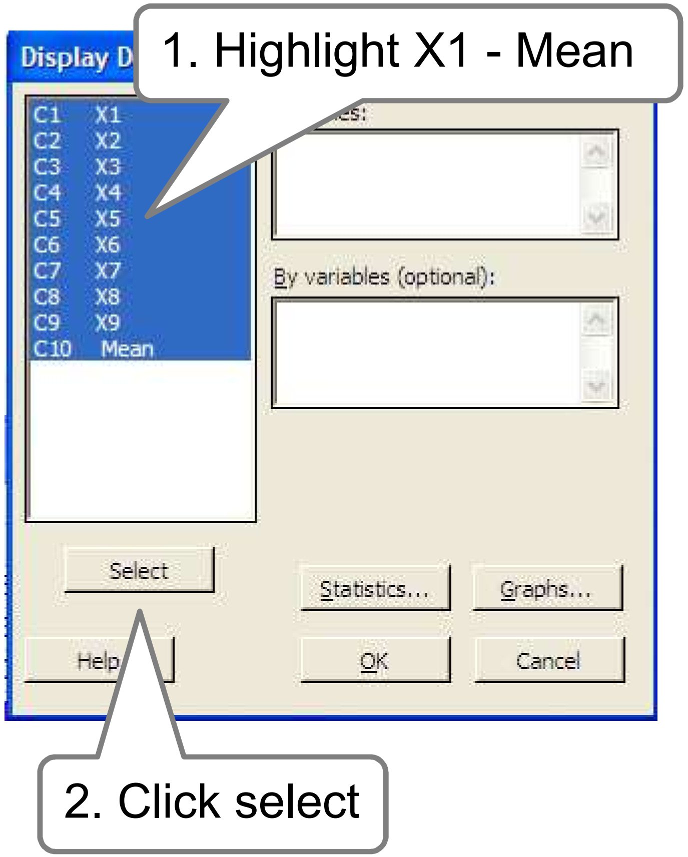
The Central Limit Theorem, Part 1, cont.

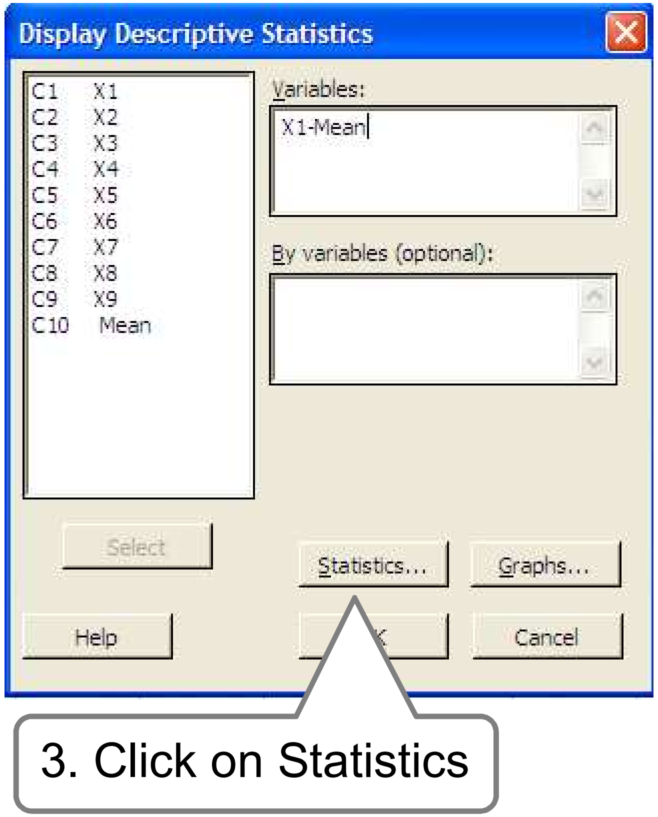
- The dot plot shows that the variation of the means is less than the variation of the X's
- **By how much?**



The Central Limit Theorem, Part 1, cont.

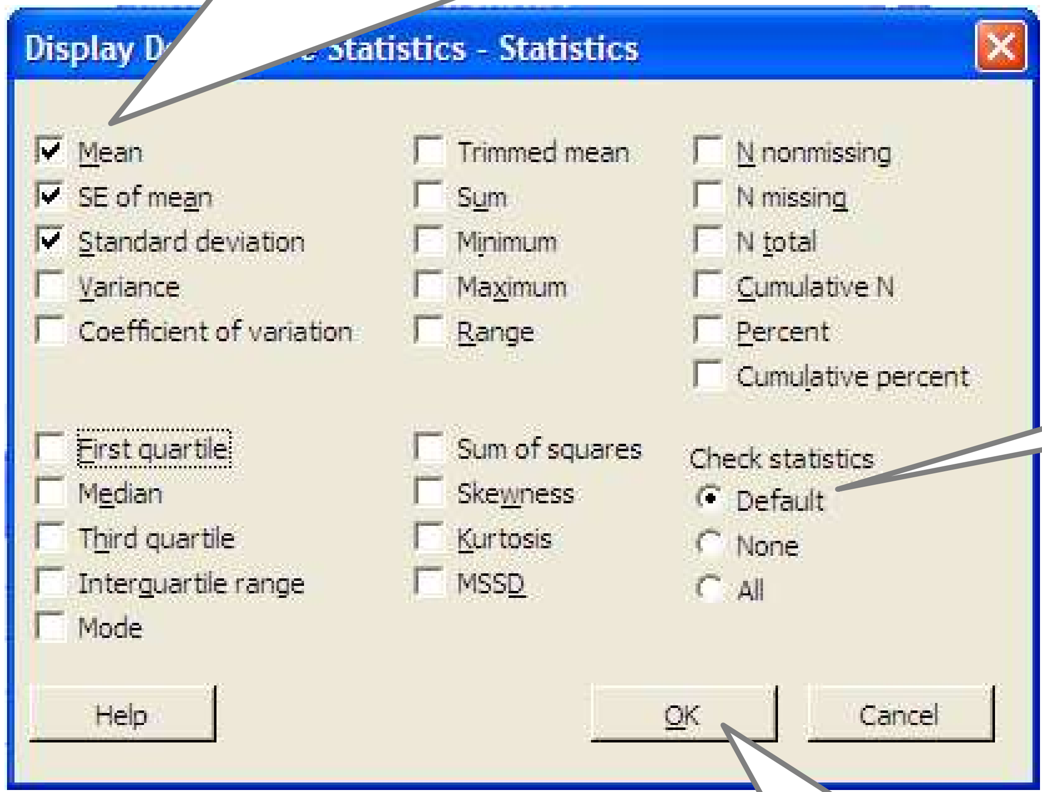
- Click on Stat > Basic Statistics > Display Descriptive Statistics…





The Central Limit Theorem, Part 1, cont.

1. Select only the first 3 statistics. Unselect all others



2. Select default

3. Click OK

The Central Limit Theorem, Part 1, cont.

We will explain SE Mean later

Variable	Mean	SE Mean	StDev
X1	80.006	0.0929	2.937
X2	79.775	0.0962	3.043
X3	80.181	0.0962	3.042
X4	80.140	0.0968	3.062
X5	79.998	0.0952	3.011
X6	79.912	0.0957	3.027
X7	79.987	0.0939	2.970
X8	80.059	0.0927	2.930
X9	79.860	0.0959	3.031
Mean	79.991	0.0308	0.974

The formula

$$\text{Std. Dev. Means} = \frac{\text{Std. Dev Xs}}{\sqrt{n}}$$

⇨ Std. Dev. Xs ≈ 3.0

⇨ Std. Dev. Means ≈ 1.0

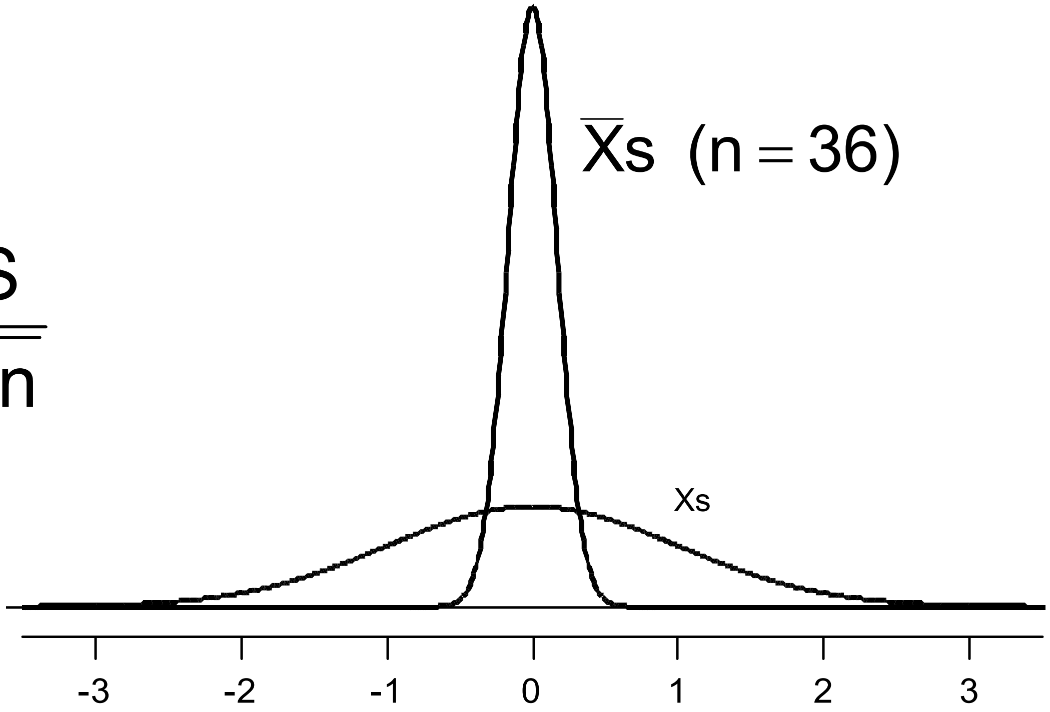
The formula holds

$$\text{Std. Dev. Means} = 3.0 / \sqrt{9} = 1$$

The Central Limit Theorem, Part 1: Conclusion

- The standard deviation of averages is less than the standard deviation of individual observations by a factor of $\frac{1}{\sqrt{n}}$

$$S_{\bar{x}} = \frac{S}{\sqrt{n}}$$



The “Standard Error” of the Mean

SE Mean = Standard Deviation of the Mean

Variable	Mean	SE Mean	StDev
X1	80.006	0.0929	2.937
X2	79.775	0.0962	3.043
X3	80.181	0.0962	3.042
X4	80.140	0.0968	3.062
X5	79.998	0.0952	3.011
X6	79.912	0.0957	3.027
X7	79.987	0.0939	2.970
X8	80.059	0.0927	2.930
X9	79.860	0.0959	3.031
Mean	79.991	0.0308	0.974

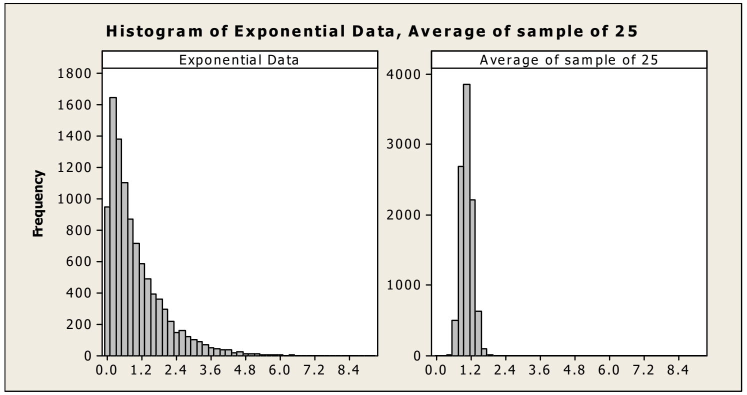
$$\text{Std. Dev. Means} = \frac{\text{Std. Dev X's}}{\sqrt{n}}$$

Std. Dev. X1 = 2.937

$$\text{SE Mean X1} = \frac{2.937}{\sqrt{1000}} = 0.0929$$

The Central Limit Theorem, Part 2

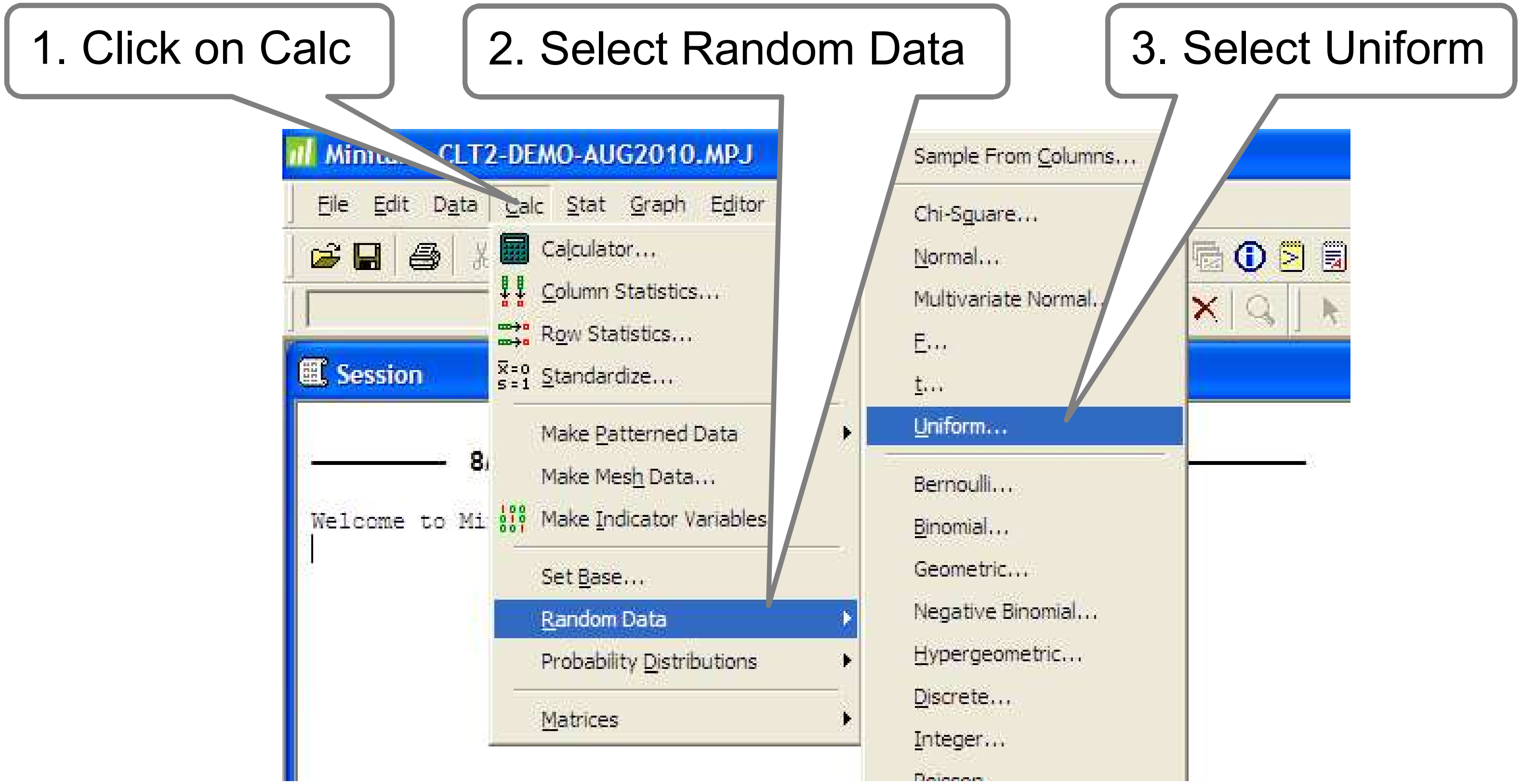
- Part 2 of the Central Limit Theorem states that the averages of independent random data tend to a normal distribution even if the raw data themselves are not normally distributed
- The important role of the normal distribution in statistical theory derives, in large part, from this remarkable property
- Here's a graphical example below. Again, we will use Minitab to illustrate how Part 2 works:



- On the left is a histogram of 10,000 pieces of exponential data
- On the right is the average of 10,000 samples of size 25 taken from the distribution on the left
- The averages are normal even though the values being averaged are far from normal

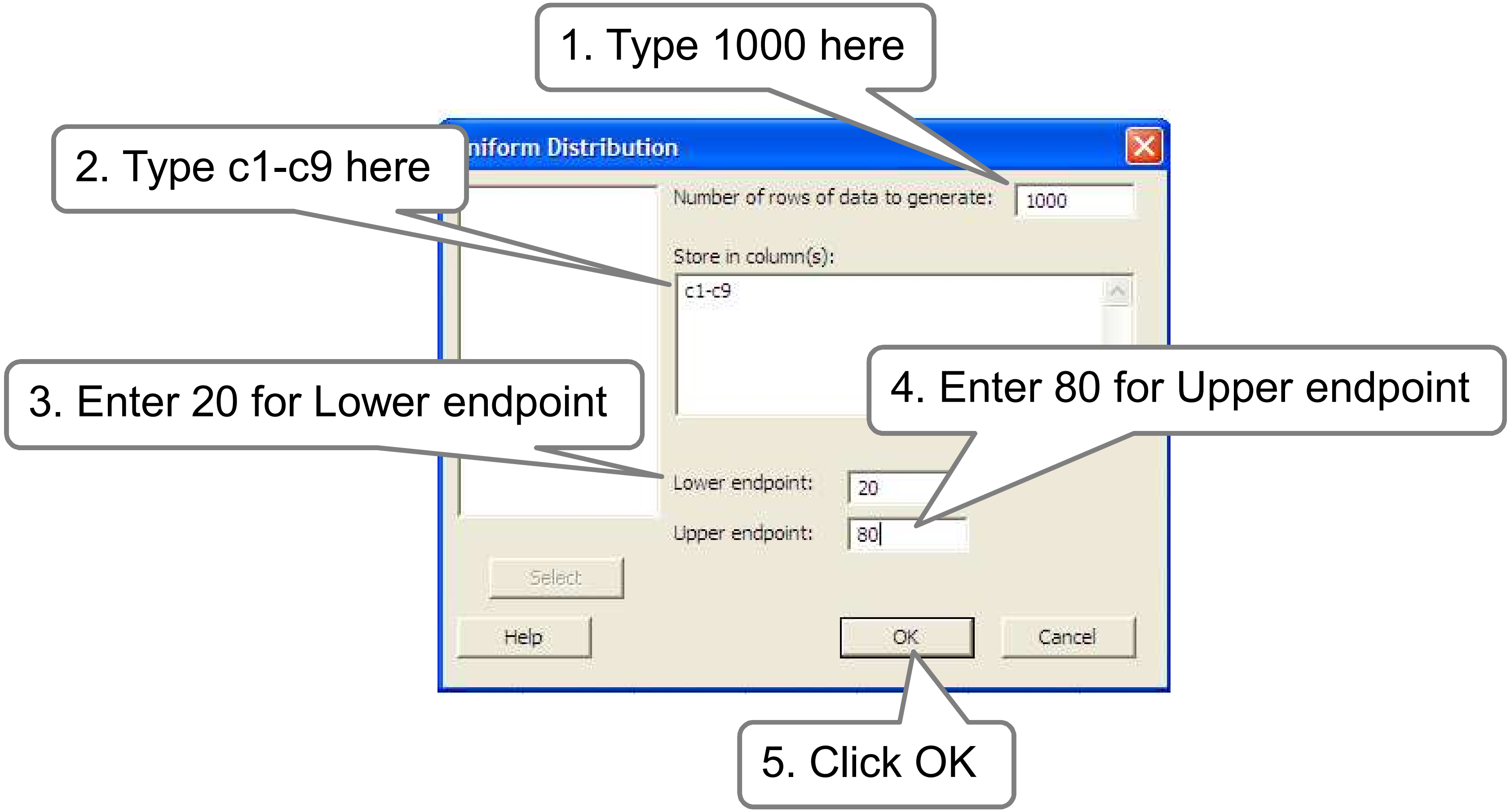
The Central Limit Theorem, Part 2

- Open a blank Minitab worksheet



The Central Limit Theorem, Part 2, cont.

- Have Minitab generate random normal data as shown below:



The Central Limit Theorem, Part 2, cont.

Output: your numbers will be different

Worksheet 1 ***

↓	C1	C2	C3	C4	C5	C6	C7	C8	C9
1	25.1980	55.9567	55.2737	78.1289	54.9771	45.0978	51.2510	28.0212	77.8197
2	68.9381	66.6212	29.1924	44.3467	47.7908	40.9916	73.9495	70.4063	31.2044
3	32.2529	56.7699	41.1999	31.1444	47.1724	45.3103	65.2176	37.1441	60.9313
4	36.4569	46.5723	39.7521	55.9497	66.7198	61.6150	53.0317	64.9298	35.4842
5	49.6973	43.3836	54.2835	61.6928	79.3652	25.5048	75.4674	66.3605	30.0810

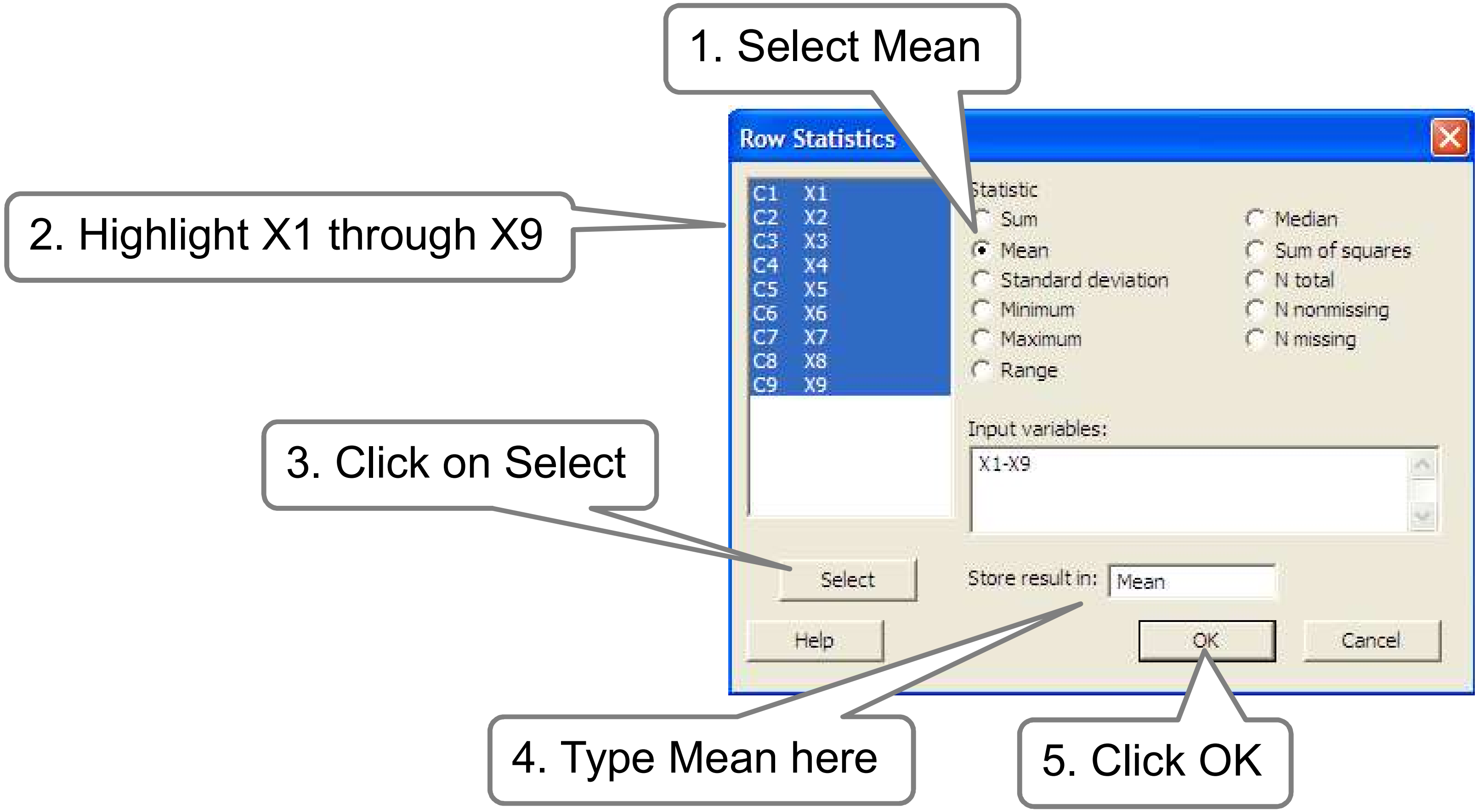
Next: Type X1…X9 as shown ⇨ Type Mean as C10's name

Worksheet 1 ***

↓	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
	X1	X2	X3	X4	X5	X6	X7	X8	X9	Mean
1	25.1980	55.9567	55.2737	78.1289	54.9771	45.0978	51.2510	28.0212	77.8197	
2	68.9381	66.6212	29.1924	44.3467	47.7908	40.9916	73.9495	70.4063	31.2044	
3	32.2529	56.7699	41.1999	31.1444	47.1724	45.3103	65.2176	37.1441	60.9313	
4	36.4569	46.5723	39.7521	55.9497	66.7198	61.6150	53.0317	64.9298	35.4842	
5	49.6973	43.3836	54.2835	61.6928	79.3652	25.5048	75.4674	66.3605	30.0810	

The Central Limit Theorem, Part 2, cont.

- From the main menu, click on Calc > Row Statistics



The Central Limit Theorem, Part 2, cont.

Output: your numbers will be different

Worksheet 1 ***

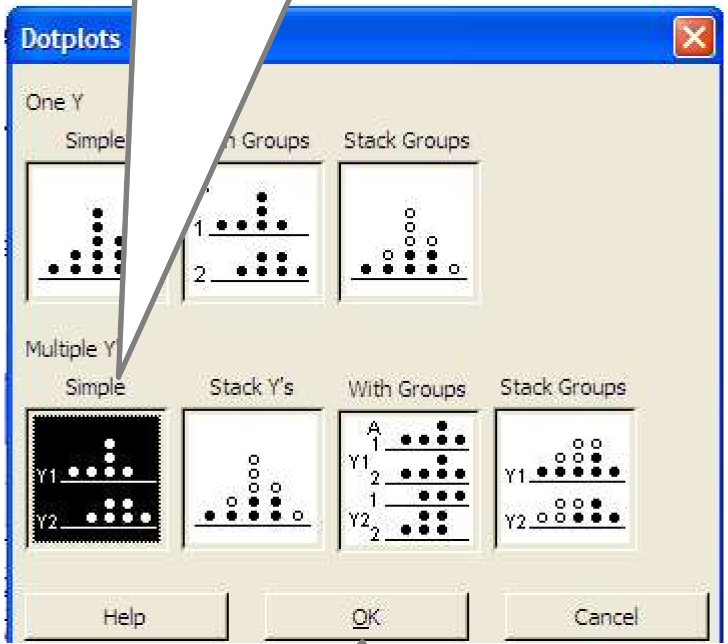
↓	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
	X1	X2	X3	X4	X5	X6	X7	X8	X9	Mean
1	25.1980	55.9567	55.2737	78.1289	54.9771	45.0978	51.2510	28.0212	77.8197	52.4138
2	68.9381	66.6212	29.1924	44.3467	47.7908	40.9916	73.9495	70.4063	31.2044	52.6046
3	32.2529	56.7699	41.1999	31.1444	47.1724	45.3103	65.2176	37.1441	60.9313	46.3492
4	36.4569	46.5723	39.7521	55.9497	66.7198	61.6150	53.0317	64.9298	35.4842	51.1679
5	49.6973	43.3836	54.2835	61.6928	79.3652	25.5048	75.4674	66.3605	30.0810	53.9818
6	51.6288	46.4577	45.5643	35.4001	35.3005	49.4366	54.5525	77.2835	78.1380	52.6402
7	53.3256	27.4623	59.7192	76.4494	52.5922	71.7285	20.5115	47.9774	70.1768	53.3270
8	49.7997	75.0673	65.6376	61.5809	21.2702	64.0382	76.9825	51.5027	74.3060	60.0206
9	42.8136	71.2806	43.1861	74.0209	76.3645	20.6063	75.5673	66.1525	58.3835	58.7084
10	64.8112	57.6858	69.5942	35.4901	75.3026	71.5510	58.6209	77.9676	69.0517	64.4528

- **Next**: Compare the distribution of the X's with the distribution of the Mean

The Central Limit Theorem, Part 2, cont.

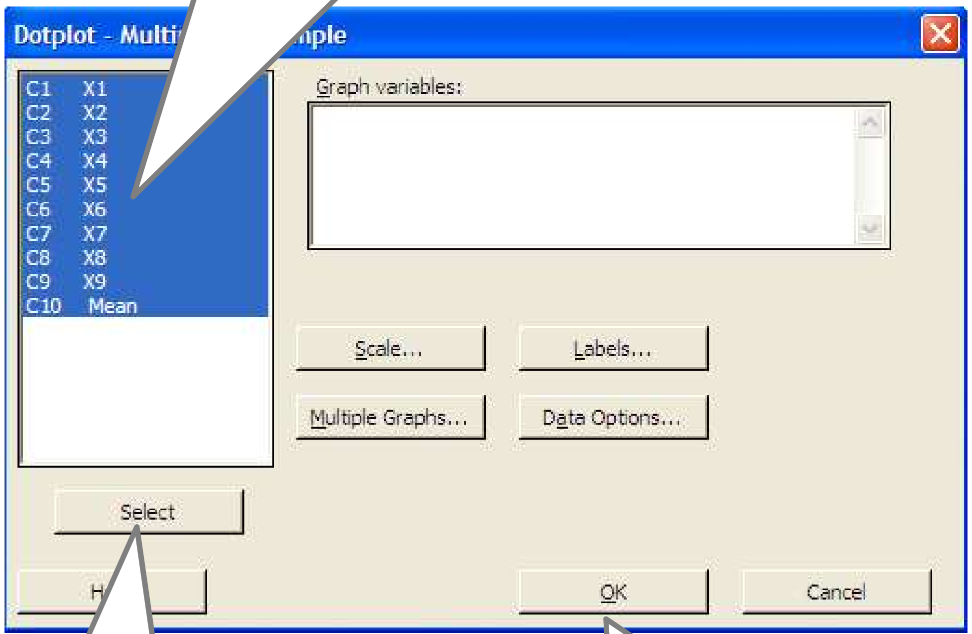
- From the main menu, click on Graph > Dotplot…

1. Select Multiple Y's Simple



2. Click OK

3. Highlight X1 through Mean

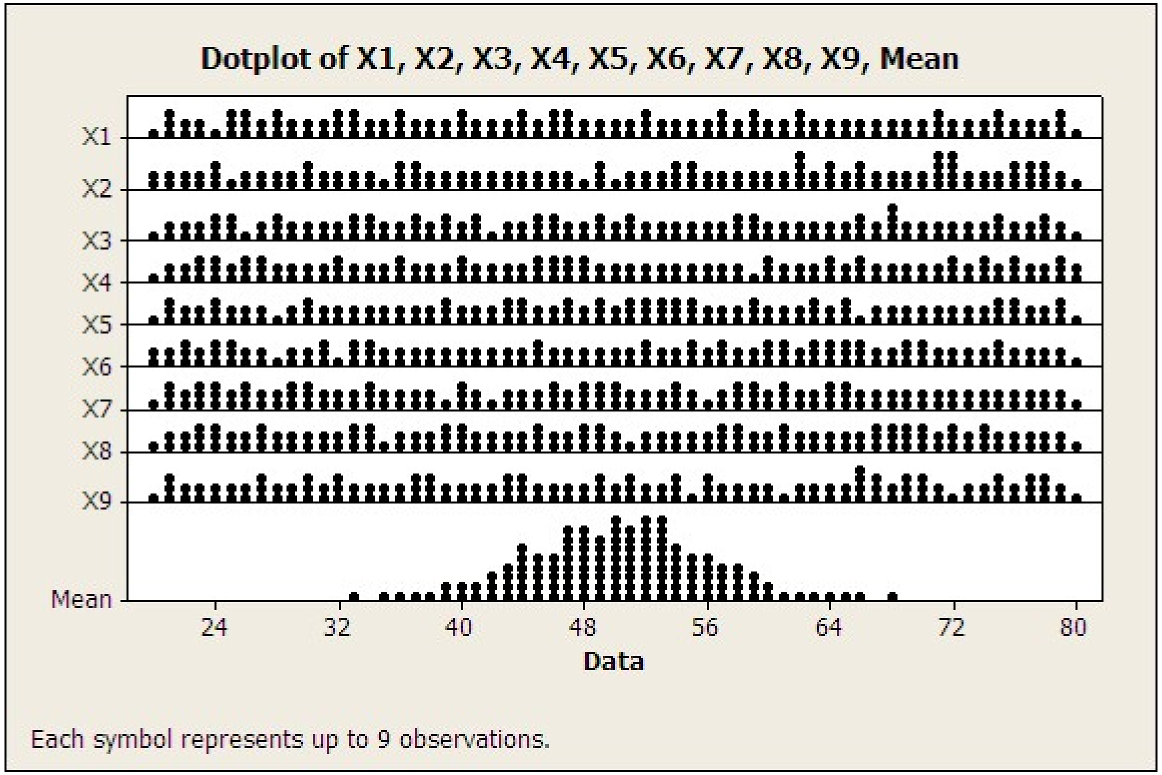


4. Click Select

5. Click OK

The Central Limit Theorem, Part 2: Conclusion

- The dot plot shows that even though the distribution of the X columns is uniform, the distribution of the Mean column approximates the normal distribution

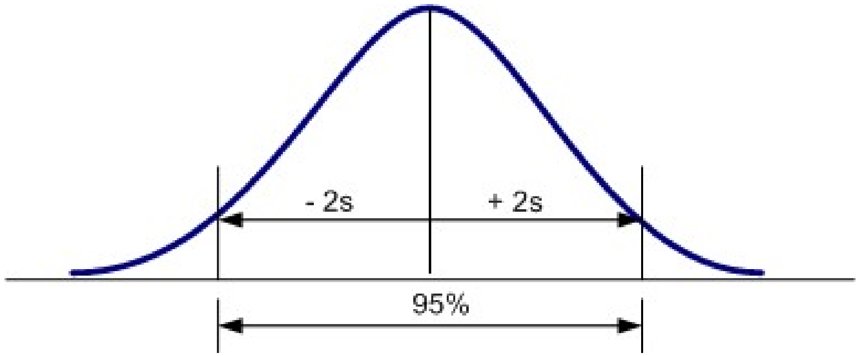


Confidence Intervals

- An important application of the Central Limit Theorem and the normal distribution is the concept of confidence interval
- The issue: the need to know the mean of a "population" to make business decisions
- The question: how much confidence do we have when using a representative sample?
- The answer: calculate a confidence interval from the sample that is likely to contain the mean of the population

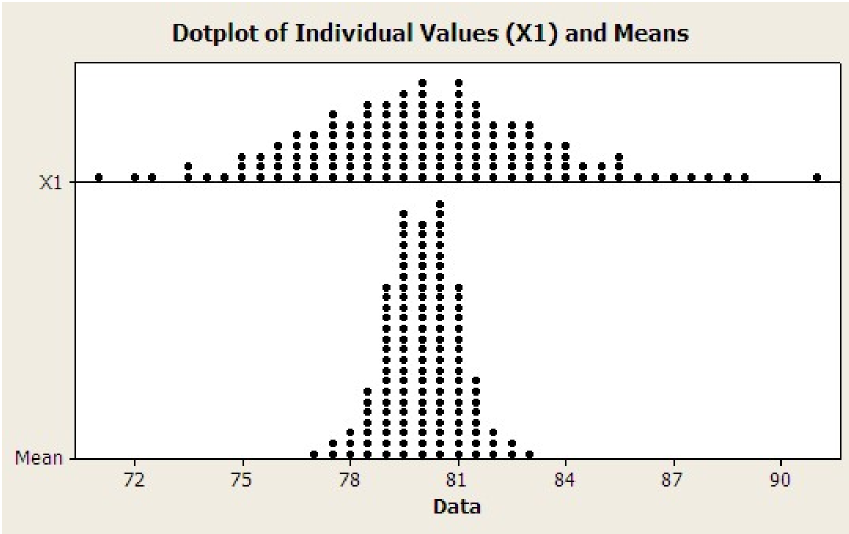
Confidence Intervals, cont.

From the normal distribution



95% of the data within ± 2 std. dev.

From the Central Limit Theorem



$$\text{Std. Dev. Means} = \frac{\text{Std. Dev Xs}}{\sqrt{n}}$$

Confidence Intervals, cont.

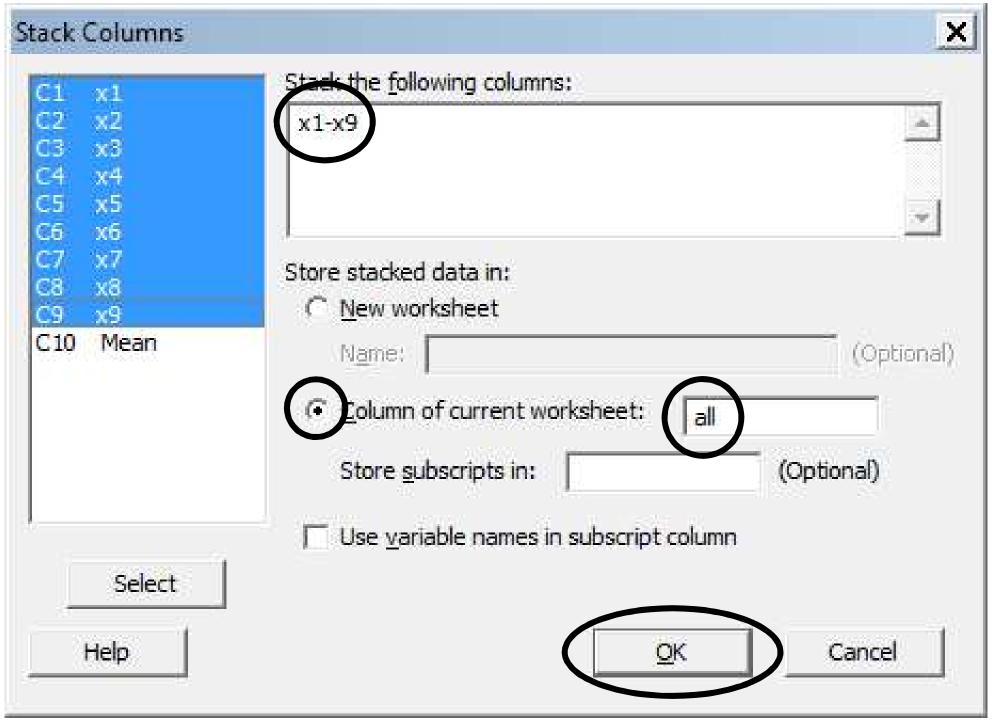
- A 95% confidence interval on an average is given by the formula:

$$\overline{X} \pm 2\frac{S}{\sqrt{n}}$$

- Because roughly 95% of normal data falls within 2 standard deviations of the mean, we can use the above formula to compute the 95% confidence interval on a mean or average

Calculating the 95% Confidence Interval

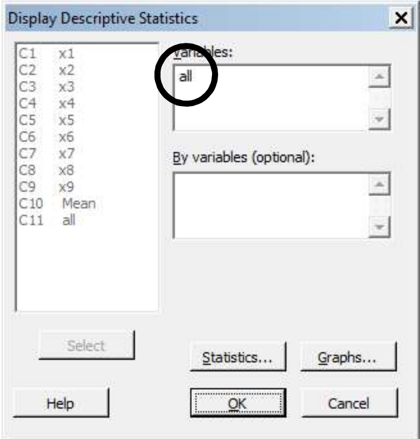
- Stack columns 1-9 and compute the standard deviation:
  Data > Stack > Columns



Calculating the 95% Confidence Interval, cont.

- Display the basic statistic for column all

  Stat > Basic Statistics > Display Basic Statistics




```
Descriptive Statistics: all

Variable     N  N*    Mean  SE Mean  StDev  Minimum      Q1  Median      Q3
all       9000   0  49.711    0.183 17.382   20.002  34.601  49.829  64.743

Variable  Maximum
all        79.992
```

- The true mean of all the data we generated was 50.
- 95% of the time the confidence interval around our overall mean (in the above example, 49.711) will contain the true mean, 50. Here, the CI is 49.711± 2 × 0.183 = (49.345 to 50.08) and contains the true mean. Does your CI contain the mean?

Summary

- Many statistical tools are built based on the assumption of normality (e.g., process capability)
- Understanding the properties and characteristics of the normal distribution is indispensable to Black Belts
- The Central Limit Theorem (CLT) impacts many statistical tools (e.g., control charts, hypothesis testing)
- Confidence intervals measure the “uncertainty” there is in our conclusions

Anexas Consultancy Services

Sample Size Calculations

Sample Size

Purpose of Sample	Formula
Estimate average (e.g., determine baseline cycle time) CONTINUOUS / VARIABLE DATA	$n = \left(\frac{2s}{d}\right)^2$ (Where d = precision: ± __ units) S = estimate of standard deviation
Estimate proportion (e.g., determine baseline % defective) ATTRIBUTE / DSICRETE DATA	$n = \left(\frac{2}{d}\right)^2 (p)(1-p)$ (Where d = precision: ± __ units) P = proportion of defective in the output

Thumb Rule

Variable Data = Optimum Sample Size is 30 to 50
Attribute Data = Optimum sample size is 200 to 1100

Precision (d)

- Precision is how narrow you want the range to be for an estimate of a characteristic
  - Estimate cycle time within 2 days
- Use the symbol d to represent precision
- Precision is equal to half the width of a confidence interval
  - A 95% CI = (48, 52) for cycle time (in days) means we are 95% confident the interval from 48 days to 52 days contains the average cycle time
  - Width of the CI = 4 days
  - Precision = d = 2 days (= estimate is within ± 2 days)
- You decide what precision you want
- Precision is inversely proportional to the square root of sample size $\frac{1}{\sqrt{n}}$

Precision and Sample Size

- To improve precision, you need to increase sample size (which incurs more cost)
- There is no clear-cut answer about how much precision you need; the answer depends on the business impact of using the estimate
- Each situation is unique; don't pattern your decisions after someone else's decision
- As a thumb rule 3% to 4% of the mean (for Continuous data) or 3% of uncertainty in proportion estimate (for Attribute data) can be taken as precision in absence of any guideline

Example: Choosing a Precision Level

Background:

- Suppose you work in a telephone call center that usually answers 2,000 incoming calls/day
  - You want to time a sample of calls to find average call length
- Before advising you on how many calls to sample, a quality consultant asks what level of precision you want in the estimate: "Does your estimate have to be within 5 minutes? 1 minute? 30 seconds?"
- You intend to use the average call length to help you make staffing decisions
  - You figure that if average call length changes by 1/4 minute, you will need to add (or drop) a staff person to answer incoming calls
- Half of 1/4 minute is 1/8 minute, so the quality consultant assigns the value of 1/8 minute to d, the precision
  - The range of your estimate will therefore be ± 1/8 minute

Sample Size for Estimating an Average

95% confidence* means a factor of 2

$$n = \left(\frac{2s}{d}\right)^2$$

Estimate of the standard deviation

Precision you desire

Sample Size for Estimating an Average, cont.

Example

- What is the sample size required to estimate the average cycle time (in days) of a new process?
  - Historical data from similar processes show a typical standard deviation = 5 days and you want the estimate to be within 1 day
  - How does the sample size change if you want the estimate to be within 2 days?

$$n = \left(\frac{(2)(5)}{1}\right)^2 = 10^2 = 100$$

$$n = \left(\frac{(2)(5)}{2}\right)^2 = 5^2 = 25$$

Exercise: Sample Size for Estimating Averages

Objective: Practice using sample size formula for averages

Instructions:

- Use the sample size formula for averages to answer the following questions

$$\mathbf{n} = \left(\frac{\mathbf{2s}}{\mathbf{d}}\right)^{2}$$

1. **Supposing you want to estimate** the average length of incoming phone calls within 1 minute, what sample size do you need? (Historical data show a typical standard deviation = 3 minutes)
2. **How many calls do you need** to sample to get an estimate within 1/8 minute?

Time: 3 minutes

Exercise Answers: Sample Size for Estimating Averages

Question 1

$$n = \left(\frac{(2)(3)}{1}\right)^2 = 6^2 = 36$$

Question 2

$$n = \left(\frac{(2)(3)}{1/8}\right)^2 = 48^2 = 2304$$

How to Estimate the Standard Deviation

The Catch-22

- To estimate sample size, you need to know the standard deviation
- You need to have some idea of the amount of variation in the data because as the variability increases, the necessary sample size increases
- But if you haven't sampled anything yet, how can you know the standard deviation?

How to Estimate the Standard Deviation, cont.

Options for estimating standard deviation:

- Find existing data and calculate s
- Use a control chart (for individuals) from a similar process

$$s = \frac{UCL - LCL}{6} \quad \text{or} \quad s = \frac{UCL - Average}{3}$$

- Collect a small sample and calculate s
- Take an educated guess based on your process knowledge and memory of similar data (most people are not too good at this)

Sample Size for Estimating a Proportion

$$n = \left(\frac{2}{d}\right)^2 (p)(1-p)$$

95% confidence means a factor of 2

Guess* for p (sample size changes dramatically from p = .01 to p = 0.50)

Precision you desire

Sample Size for Estimating a Proportion, cont.

Example

- What is the sample size required to estimate the defect rate, with 95% confidence, when you expect it to be around "10% defective" and you want the estimate to be within 3%?
- How does the sample size change if you want the estimate to be within ±1%?

$$n = \left(\frac{2}{.03}\right)^2 (.10)(1-.10)$$

$$= (4444.4)(.10)(.90)$$

$$= 400$$

$$n = \left(\frac{2}{.01}\right)^2 (.10)(1-.10)$$

$$= 3600$$

Exercise: Sample Size for Estimating Proportions

Objective: Practice using the sample size formula for proportions

Instructions:

$$n = \left(\frac{2}{d}\right)^2 (p)(1-p)$$

- Use the sample size formula for proportions to answer the following questions

1. **Suppose you want to estimate** (within 2%) the proportion of customers who will buy a new service
   - You're guessing that 50% of them will buy
   - What sample size do you need?
2. **How many customers do you need** to sample for your estimate to be within 4%?

Time: 3 minutes

Exercise Answers : Sample Size for Estimating Proportions

Question 1

$$n = \left(\frac{2}{.02}\right)^2 (.5)(1-.5)$$

$$= 2500$$

Question 2

$$n = \left(\frac{2}{.04}\right)^2 (.5)(1-.5)$$

$$= 625$$

Using Precision to Justify Sample Sizes

1. Determine how many samples you can afford (n)
2. Then ask, what will that sample provide in terms of precision?
   - That is, an average within ± d units $d = \frac{2s}{\sqrt{n}}$
   - Or a proportion within ± d% $d = 2\sqrt{\frac{(p)(1-p)}{n}}$
3. Is that precise enough?
4. If not precise enough:
   - Make a table of precision and cost for various sample sizes to determine the gain in precision per dollar spent on samples
   - Then choose a sample size that you can justify based on the gain in precision or the needed precision for your situation

Sampling from a Limited (Finite) Population

- The sample size formulas assume the sample size (n) is small relative to the population (N)
- If $\frac{n}{N}$ is > .05
  - You are sampling more than 5% of the population
  - You can adjust the sample size with the finite population formula:

$$n_{finite} = \frac{n}{1 + n/N}$$

Sampling from a Limited (Finite) Population, cont.

Example

- You want to know the average assembly cycle time, within ± 1.5 days, of a complex device your facility assembles
- Given a st. dev. of 12 days (from another study of cycle time), the number of files to sample is 256

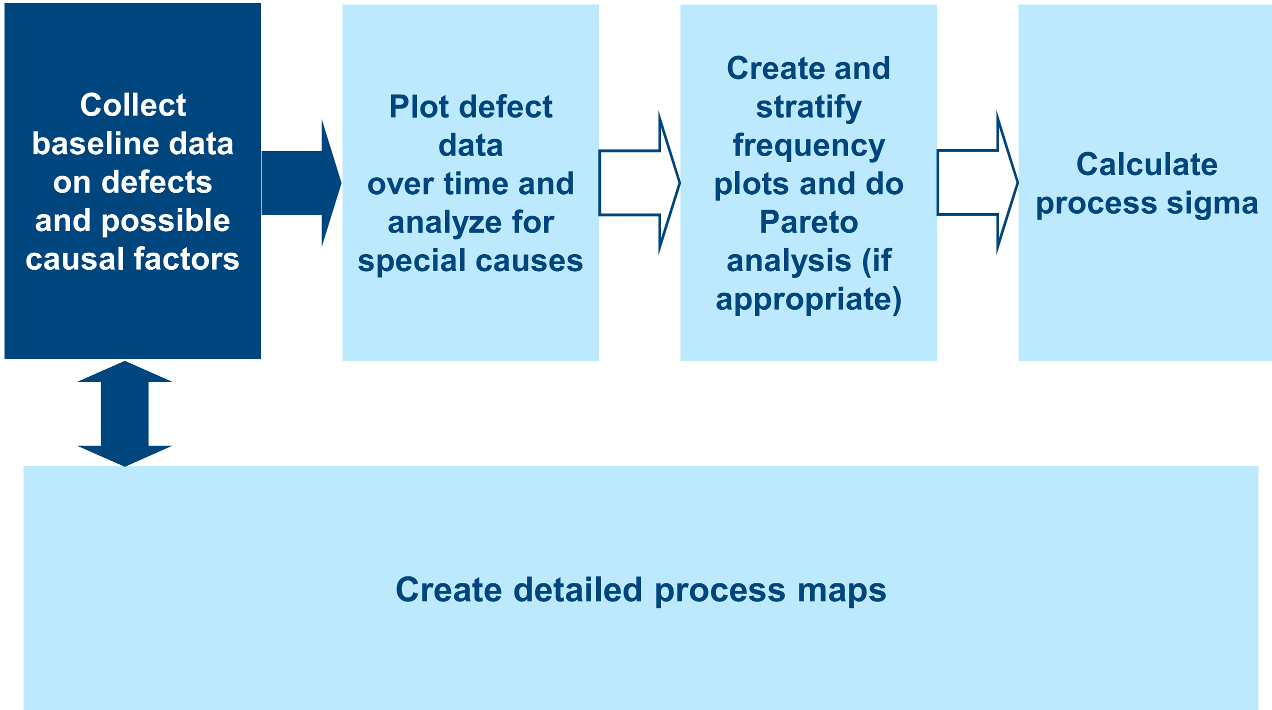
$$\mathbf{n} = \left(\frac{24}{1.5}\right)^2 = 256$$

- Suppose that only 300 units were made in the last year, since the cycle time data started to be collected
  - Do you need to sample nearly all 300 units?
  - No, you can use the finite population formula
  - Applying finite population formula, the sample size would be 140

Anexas Consultancy Services

Data Collection

You Are Here


Collect baseline data on defects and possible causal factors
Plot defect data over time and analyze for special causes
Create and stratify frequency plots and do Pareto analysis (if appropriate)
Calculate process sigma
Create detailed process maps

Five-Step Data Collection Process

1. Clarify data collection goals
2. Develop operational definitions and procedures
3. Validate the measurement system
4. Begin data collection
5. Continue improving measurement consistency

Project Worksheet: Data Collection Plan (Preview)

Data Collection Plan

Project ____________________

What questions do you want to answer?

Data		Operational Definition and Procedures			
What	Measure type/ Data type	How measured [1]	Related conditions to record [2]	Sampling notes	How/where recorded (attach form)

How will you ensure consistency and stability?

What is your plan for starting data collection? (attach details if necessary)

How will the data be displayed? (Sketch below)

Notes

1) Be sure to test and monitor any measurement procedures/instruments.

2) "Related factors" are stratification factors or potential causes you want to monitor as you collect data.

Data Collection Plan Features

Data Collection Plan

Project ____________________________

What questions do you want to answer?

Being clear about your question will help you make sure you collect the right data

Data		Operational Definition and Procedures			
What	Measure type/ Data type	How measured[2]	Related conditions to record[2]	Sampling notes	How/where recorded (attach form)

Recording what data you are going to collect reminds you what you want to accomplish; noting the type of data helps you decide how you should analyze the data

An operational definition defines exactly how you will go about collecting and recording the data

Data Collection Plan Features, cont.

How will you ensure consistency and stability?

What will you do to make sure the data collected at one point in time are comparable to data collected at other times? That is, that no biases have been introduced in the way the data are collected?

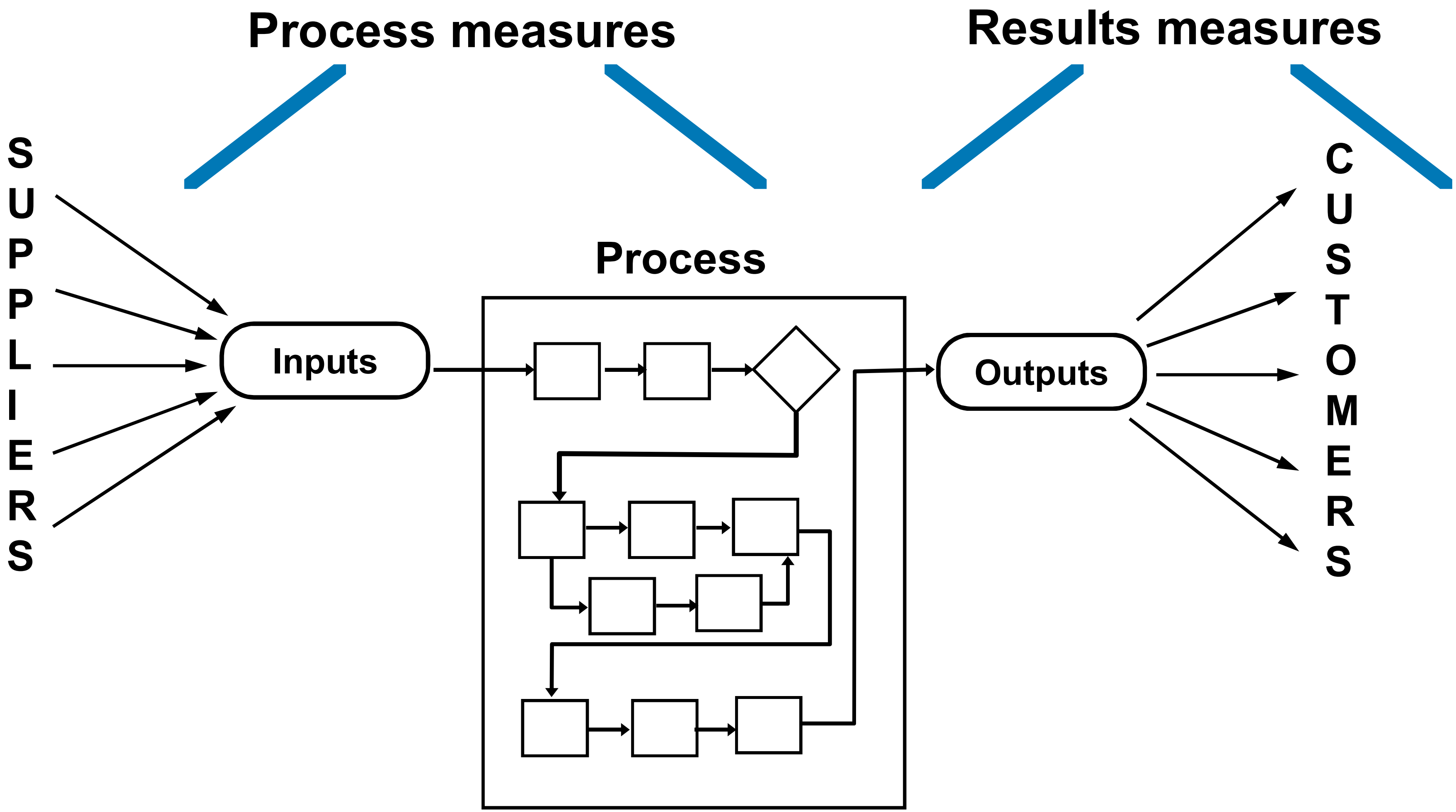
What is your plan for starting data collection? (Attach details if necessary)

Just how will you go about collecting the data?

How will the data be displayed? (Sketch below)

Thinking about how you will display the data will help you make sure you're getting the right kind of data to answer the question you have in mind

Where to Collect Data: Process or Result?



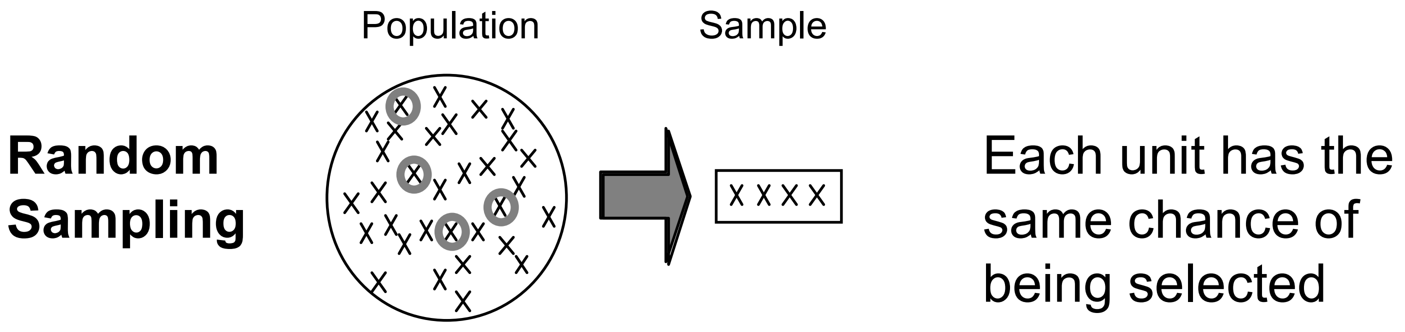
Examples of Data

Type/How Obtained	Examples
Continuous: (or "variables") Measuring instrument or a calculation	**Service:** Elapsed time to complete transaction, average length of phone calls **Manufacturing:** Elapsed cycle time, metal purity, gauge production rates, weight, length, speed **Both:** Budget vs. actual (dollars), average customer satisfaction score, amount purchased
Discrete: Percentage or proportion Count occurrences and non occurrences	**Service:** Proportion of late applications, incorrect invoices **Manufacturing:** Proportion of defective items, reworked items, damaged items, late shipments **Both:** Proportion of employees absent, incomplete orders
Discrete: Count Count occurrences in an area of opportunity	**Service:** Number of applications, errors, complaints, etc. **Manufacturing:** Number of computer malfunctions, machine breakdowns, accidents
Discrete: Attribute Observation	**Service:** Type of application, type of request **Manufacturing:** Type of product **Both:** Type of customer, type of method used (new vs. old), location of activity (city/state)
Discrete: Ordinal Observation or ranking	**Both:** Customer rating (1=very satisfied/ 5= very dissatisfied); day of week (MTWRF), date, time order

Anexas Consultancy Services

Sampling Approaches

Selecting a Random Sample



- Many people think they can select a random sample from a list without the aid of statistical techniques
- Statistician Brian Joiner likes to point out that “haphazard sampling is not the same as random sampling”
- When trying to choose a sample, do not merely choose whatever items you like from a list or population

Minitab Follow-Along: Select a Random Sample

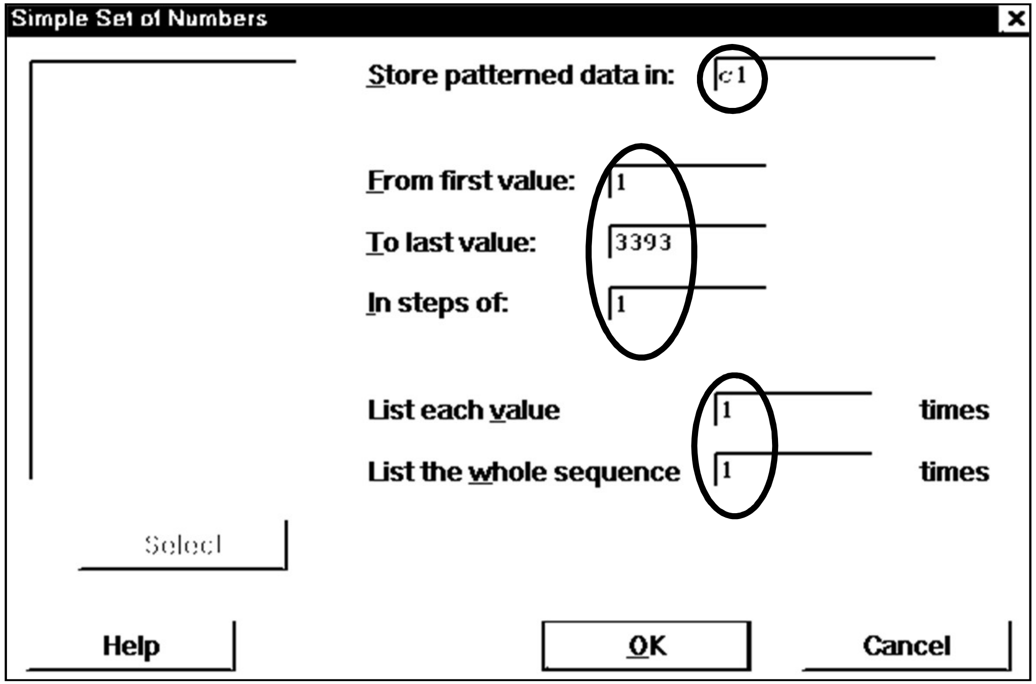
Background: Suppose you have 3,393 customers listed in alphabetical order and you wish to randomly sample 100 of them to determine their expectations regarding cycle time for resolving complaints

Minitab Follow-Along: Select a Random Sample, cont.

Instructions:

1. Open a blank worksheet in Minitab
2. Generate ID numbers between 1 and 3,393 and store them in C1

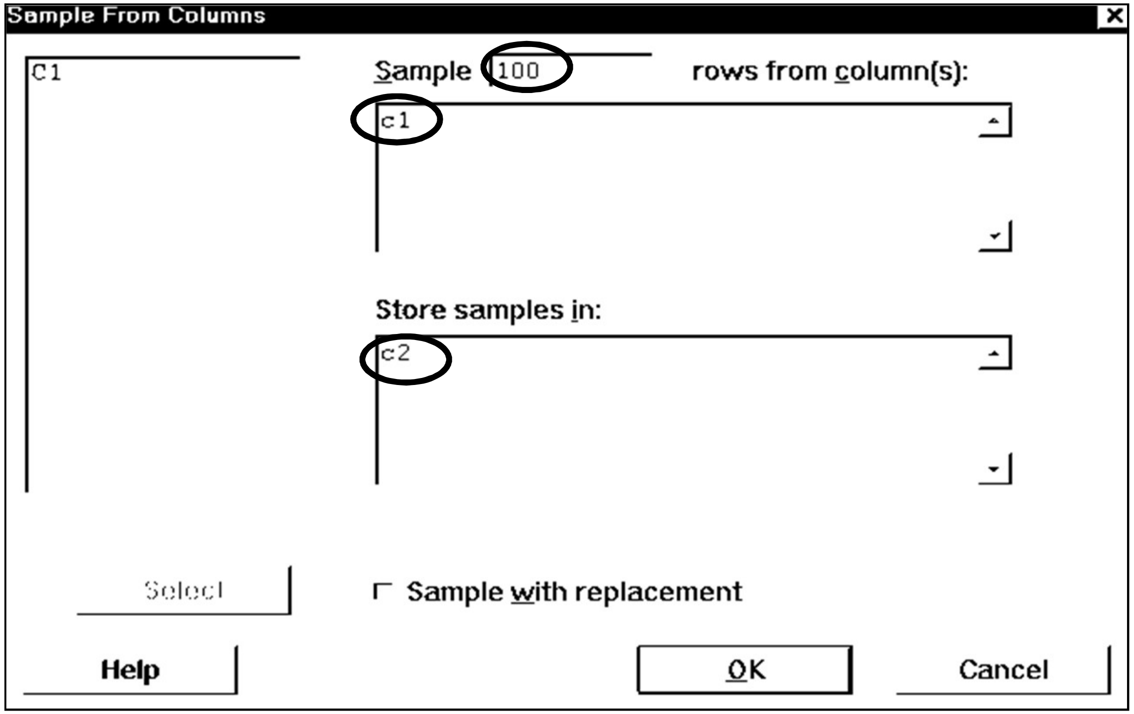
   Calc > Make Patterned Data > Simple Set of Numbers



Minitab Follow-Along: Select a Random Sample, cont.

3. Randomly select 100 ID numbers from C1 and store them in C2

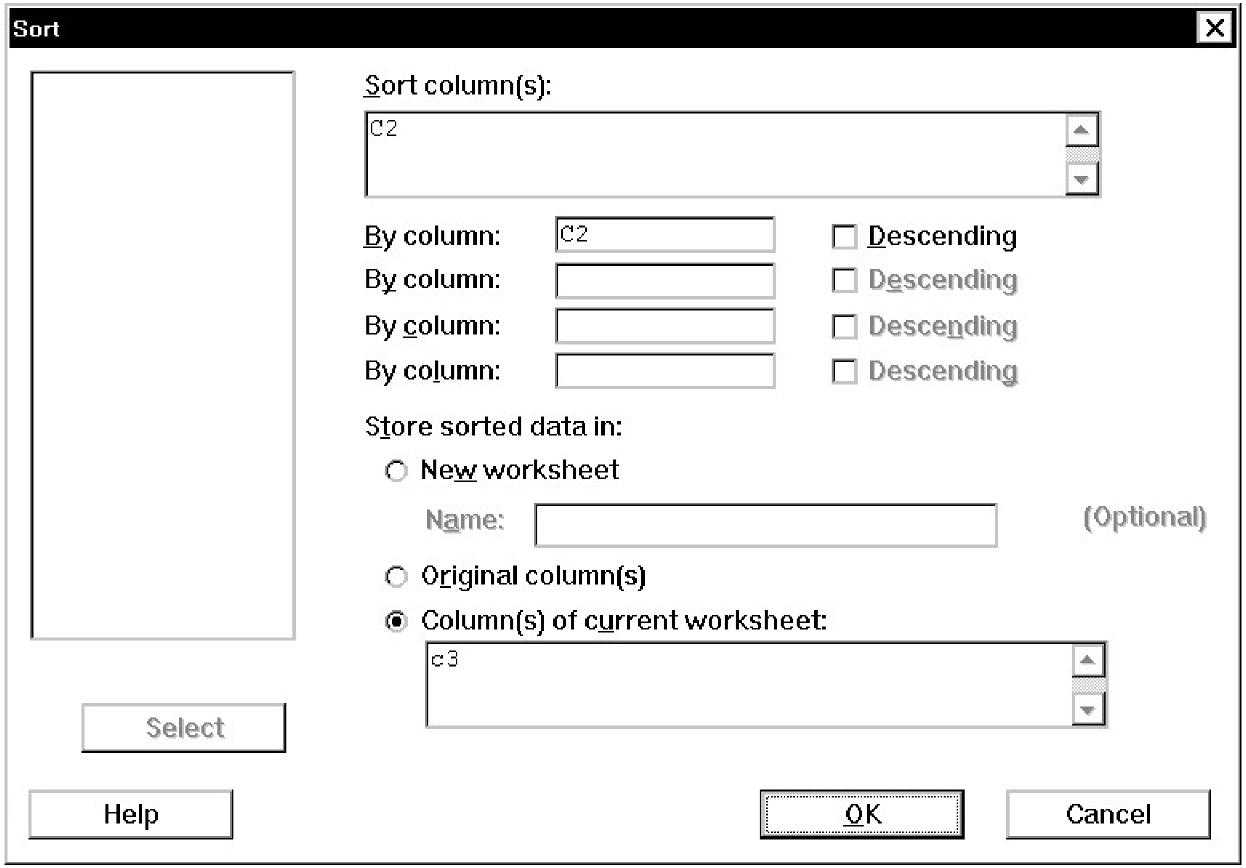
   Calc > Random data > Sample from Columns > …



Minitab Follow-Along: Select a Random Sample, cont.

4. Sort the sample ID numbers in order and store them in C3

   Data > Sort…



Minitab Follow-Along: Select a Random Sample, cont.

5. Compare your sample with your neighbor’s sample. Did you get the same ID numbers?

6. How would you use the ID numbers in C3 to select your sample?

How Random Sampling Ensures Representativeness of a Population

- Even with small populations, there are many ways that a random sample could turn out
  - Example: There are 1.73E13 (17.3 trillion) ways of selecting 10 units randomly from 100 units

Number of Ways to Select n Units From N

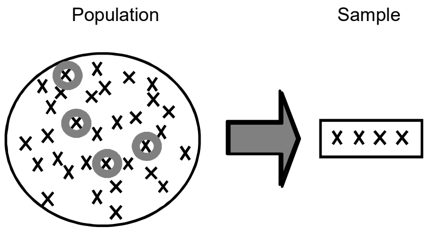
Sample size (n)	Population size (N)		
	100	1000	10000
10	$1.73\ E^{13}$	$2.63E^{23}$	$2.74E^{33}$
100	1	$6.39E^{139}$	$6.52E^{241}$
1000		1	$8.73E^{1409}$

How Random Sampling Ensures Representativeness of a Population, cont.

- There are relatively few ways to choose a sample that is systematically different from the rest of the units
  - Example: It is possible to randomly draw the 10 smallest (or largest) units from a list of 100, but the chance is astronomically small (2 in 17.3 trillion)
- The vast majority of the trillions of combinations will adequately represent the diversity of the population as a whole
- Random sampling ensures the sample is not chosen to make a predetermined (biased) case—even unconsciously—because each unit has the same chance of being chosen

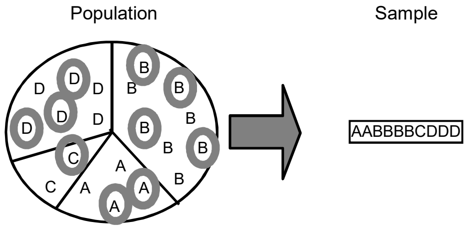
Sampling Approaches

Random Sampling



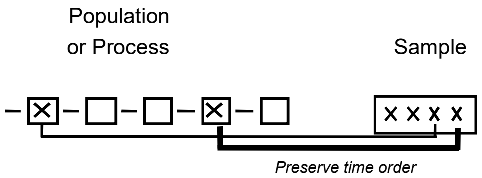
Each unit has the same chance of being selected

Stratified Random Sampling



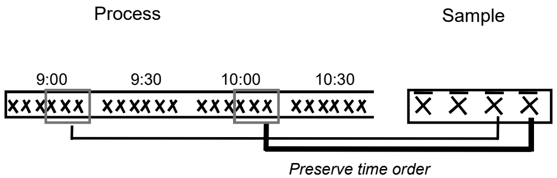
Randomly sample a proportionate number from each group

Systematic Sampling



Sample every nth one (e.g., every 3rd)

Subgroup Sampling



Sample n units every t^{th} time (e.g., 3 units every hour); then calculate the mean (proportion) for each subgroup

Anexas Consultancy Services

Measurement Systems Analysis (MSA)

Why Measure?

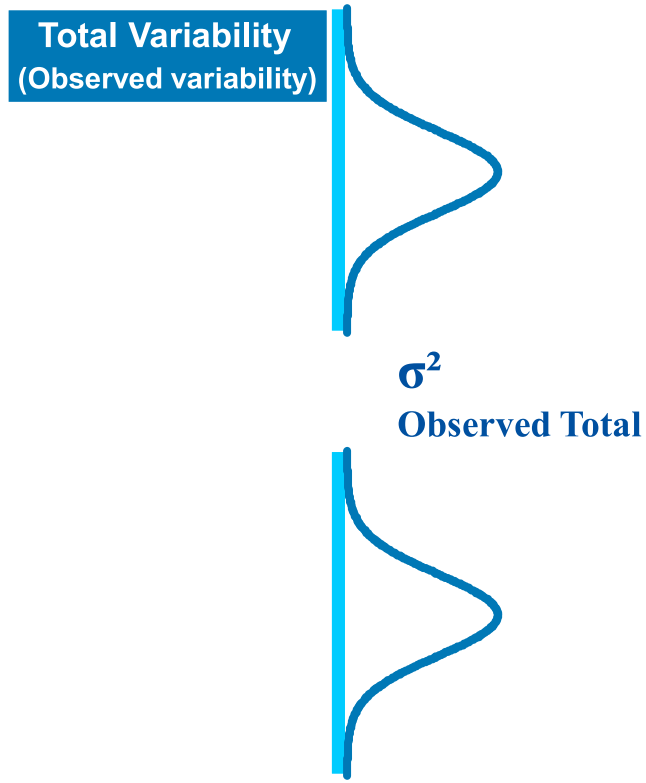
- To understand a decision:
  - Meet standards & specifications
  - Detection / reaction oriented
  - Short-term results
- Stimulate continuous improvement:
  - Where to improve?
  - How much to improve?
  - Is improvement cost effective?
  - Prevention oriented
  - Long-term strategy

"If you cannot measure, you cannot improve!"
--Taguchi

Observed Variation

Process A

Process B

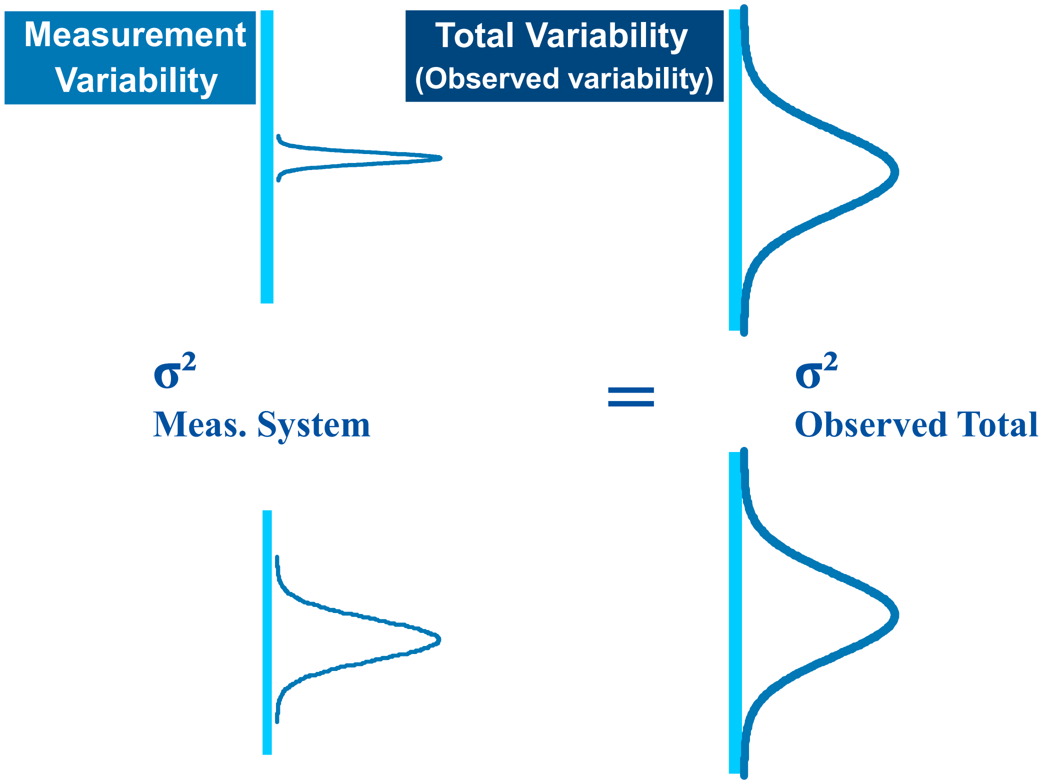


Which process is best?

Measurement Variation

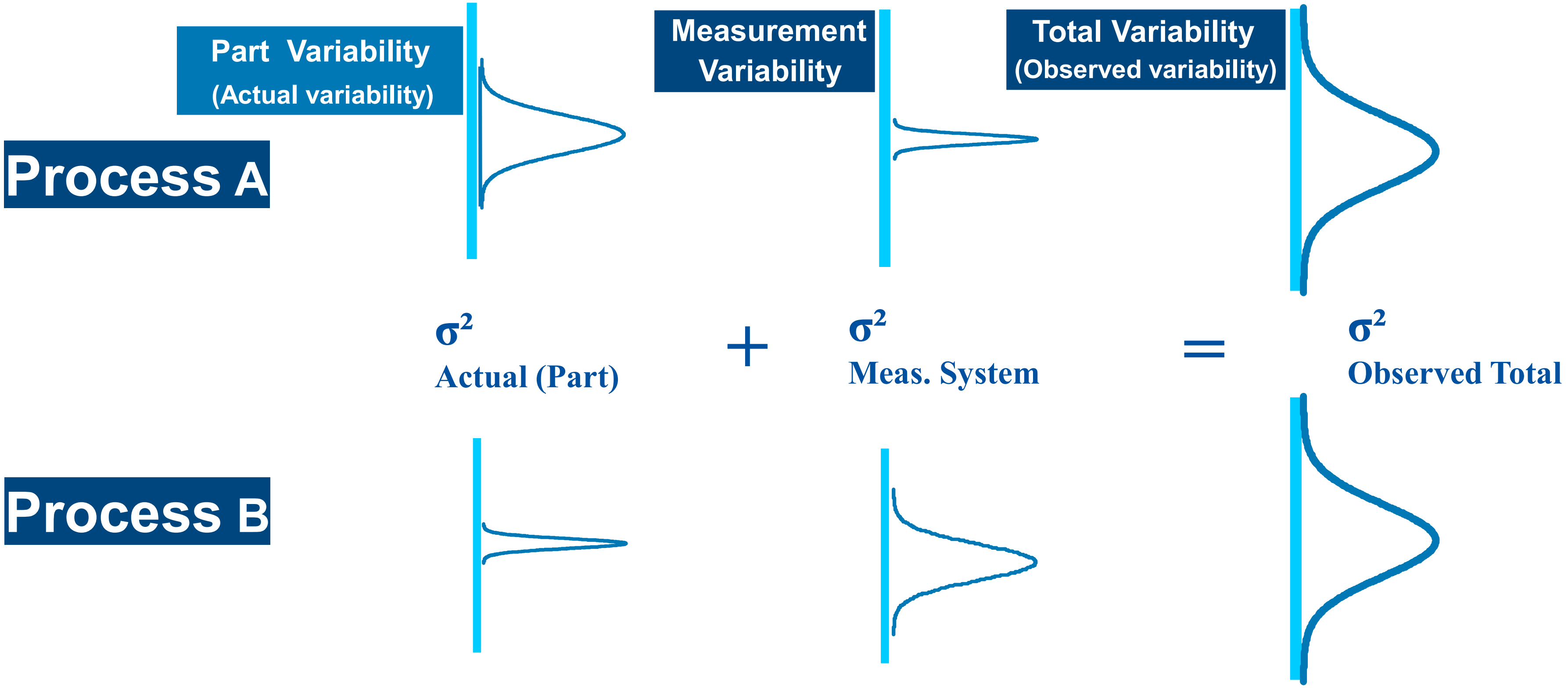
Process A

Process B



Which process is best?

Part Variation



Which process is best?

What is an MSA

- Scientific and objective method of analyzing the validity of a measurement system
- A “tool” which quantifies:
  1) Equipment Variation
  2) Appraiser (Operator) Variation
  3) The Total Variation of a Measurement System
- MSA is NOT just Calibration
- MSA is NOT just Gage Repeatability & Reproducibility (R&R)

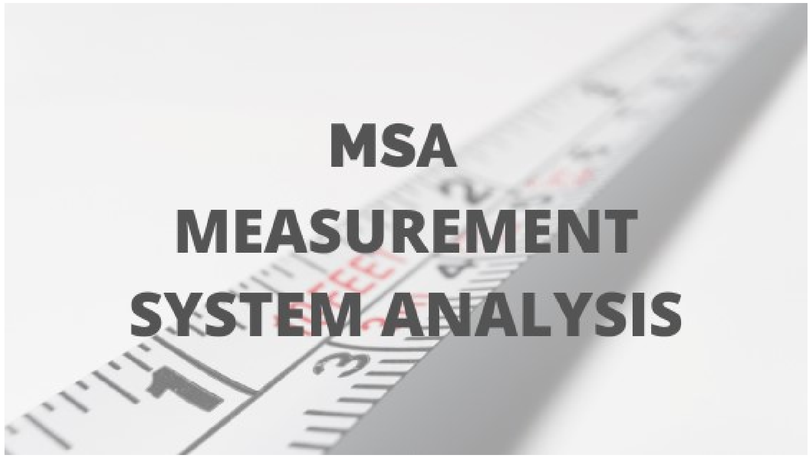
Measurement System Analysis is often a “project within a project”

Anexas Consultancy Services

Components of Measurement Error

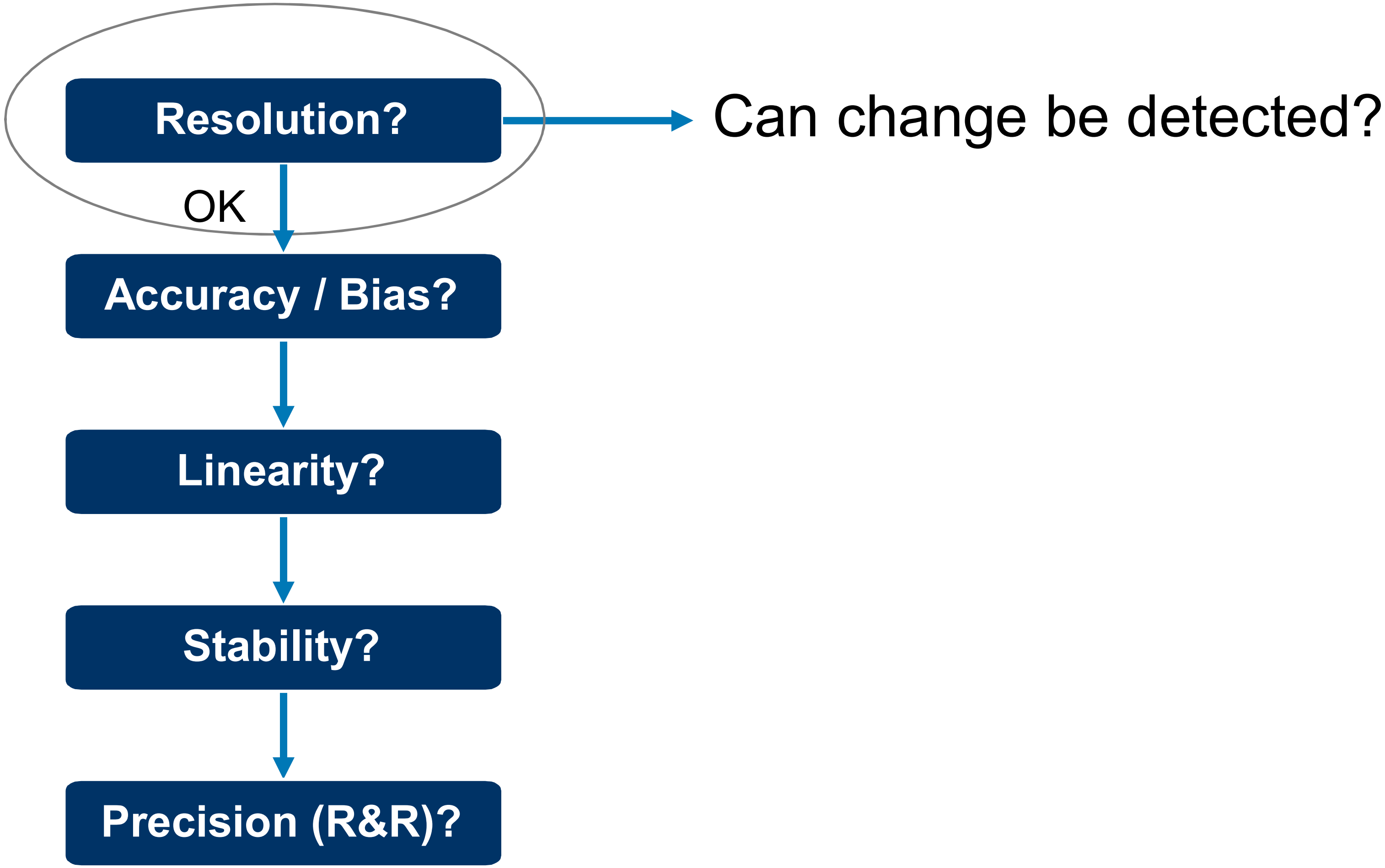
Components of Measurement Error

- Resolution / Discrimination
- Accuracy (bias effects)
- Linearity
- Stability (consistency)
- Repeatability (test-retest)
- Reproducibility



Each component of measurement error can contribute to variation causing wrong decisions to be made

Resolution / Discrimination



Resolution

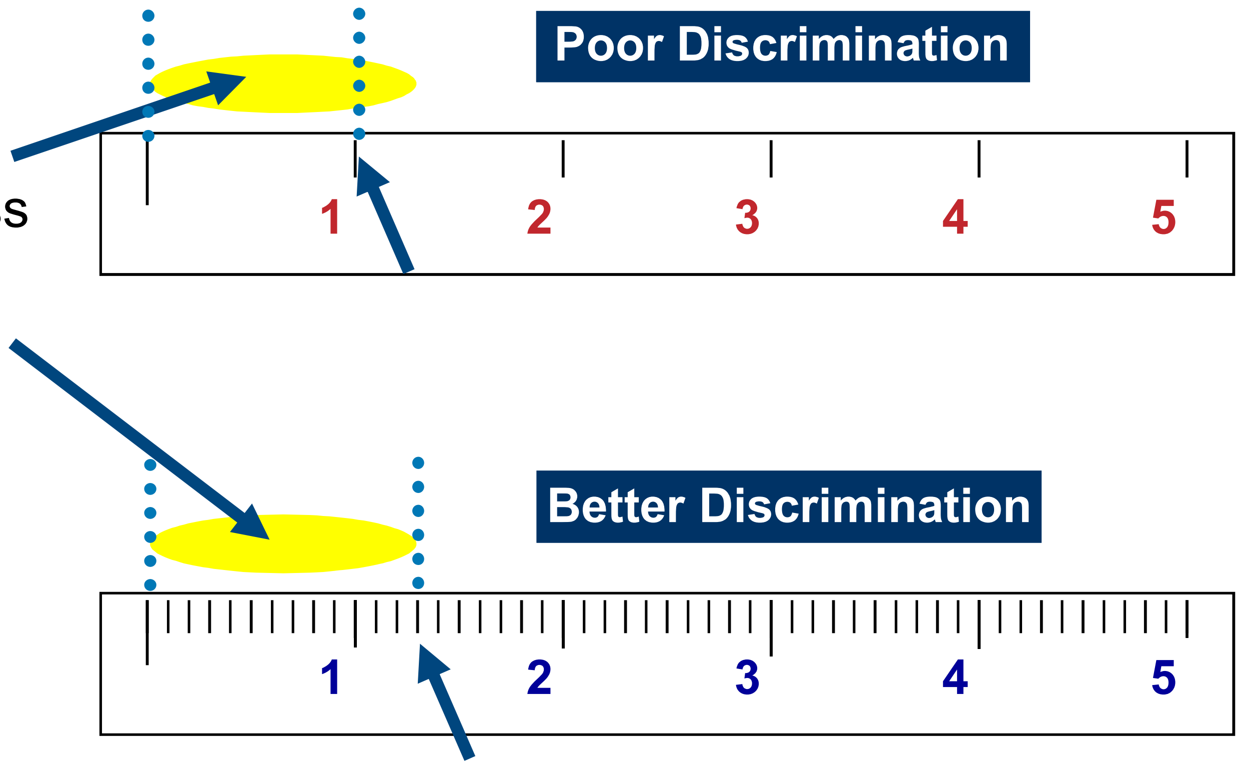
- Simplest measurement system problem
- Poor resolution is a common issue
- Impact is rarely recognized and/or addressed
- Easily detected
- No special studies are necessary
- No “known standards” are needed

Definitions:

- Resolution / Discrimination
  - Capability to detect the smallest tolerable changes
- Inadequate Measurements Units
  - Measurement units too large to detect variation present
- Guideline: "10 Bucket Rule"
  - Increments in the measurement system should be one-tenth the product specification or process variation

Resolution / Discrimination

Same process output being measured



Resolution

Given this form :

Customer Name ______________________________

Date Received ______________________________

Date Issued ______________________________

What percent of requests are processed within 4 hours of receipt?

Resolution

Given this NEW form :

Customer Name ______________________

Date Received ______________________

Time Received ______________________

Date Issued ______________________

Time Issued ______________________

What percent of requests are processed (issued) within 4 hours of receipt?

Resolution

On Hold complaints per hour

Complaint	Number
Transfers	50
Disputes	210
Information	143
Other	12
Total	415

What is the customer's biggest complaint?

Resolution

On Hold complaints per hour

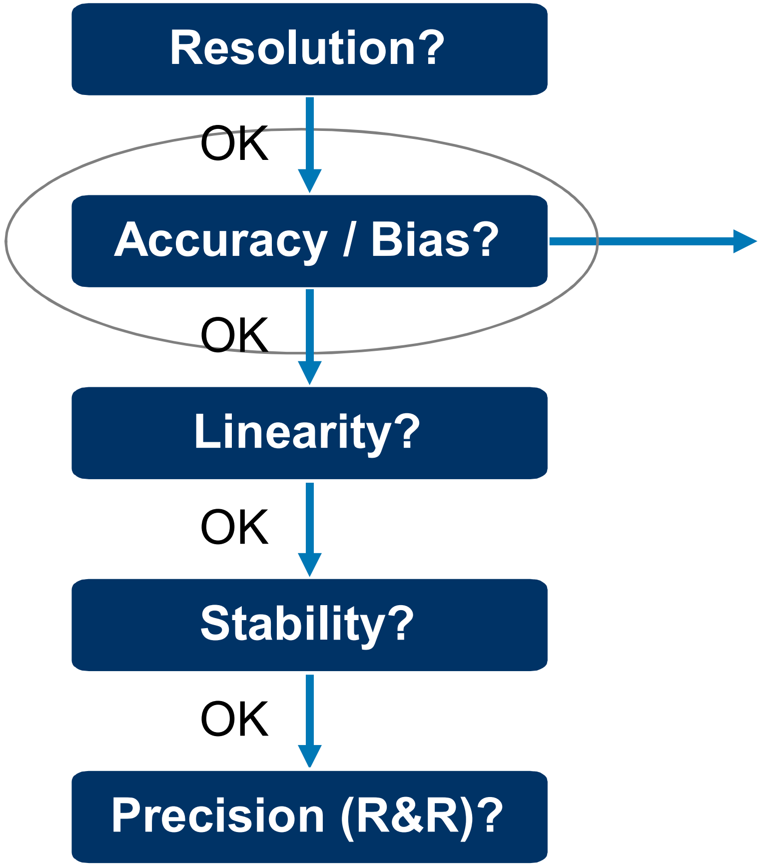
Complaint	Number
Transfers	50
Set up or Maintenance Disputes	70
Service Received Disputes	60
Billing Amount Disputes	80
Update Account Information	115
Request Information	28
Other	12
Total	415

What is the customer's biggest complaint?

Resolution Actions

- Measure to as many decimal places as possible
- Use a device that can measure smaller units
- Live with it, but document that the problem exists
- Larger sample size may overcome problem
- Priorities may need to involve other considerations:
  - Engineering tolerance
  - Process Capability
  - Cost and difficulty in replacing device

Accuracy / Bias

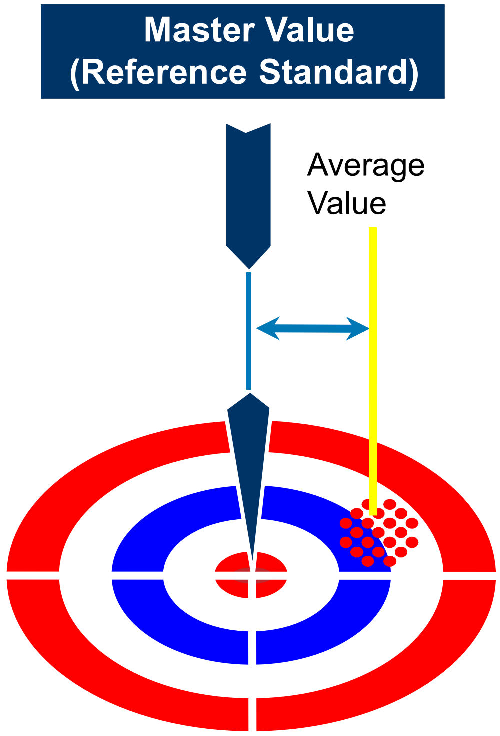


Measurements are “shifted” from “true” value

Accuracy / Bias

Difference between the observed average value of measurements and the master value

Master value is an accepted, traceable reference standard



Accuracy / Bias

More accurate

Less accurate

Accuracy / Bias

Customers Surveyed . . .
"*Please Comment on Our Service . . .*"

Do You Have Any Complaints?

- ❑ No
- ❑ Yes

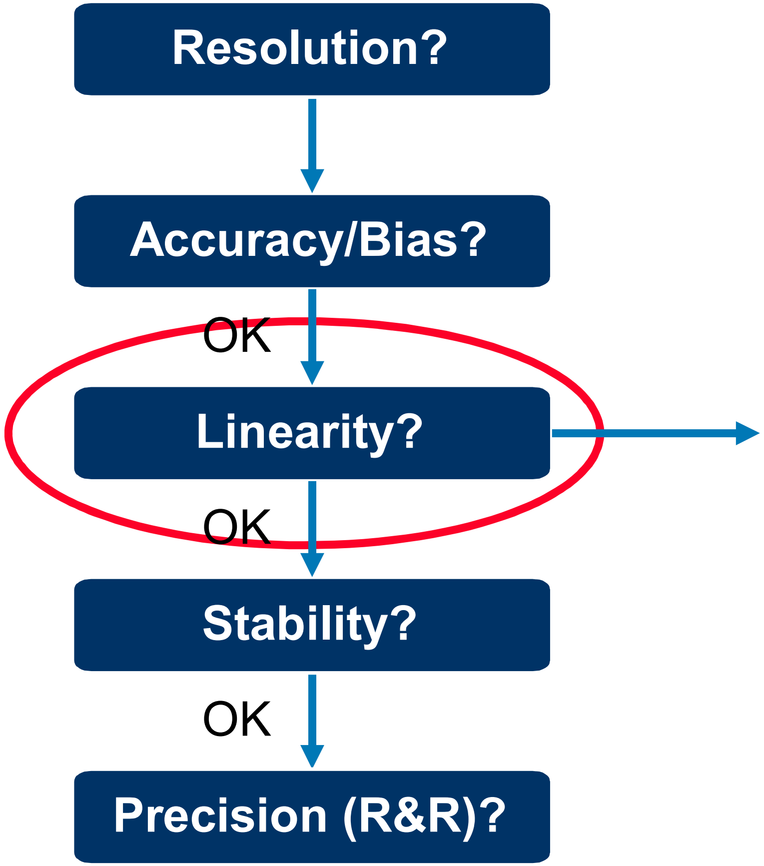
(If "Yes," Please complete the following):

1. List the Problems ______________________
   ____
   ____
2. Date ______________________
3. Time ______________________
4. Name of Rep. ______________________

Accuracy / Bias Actions

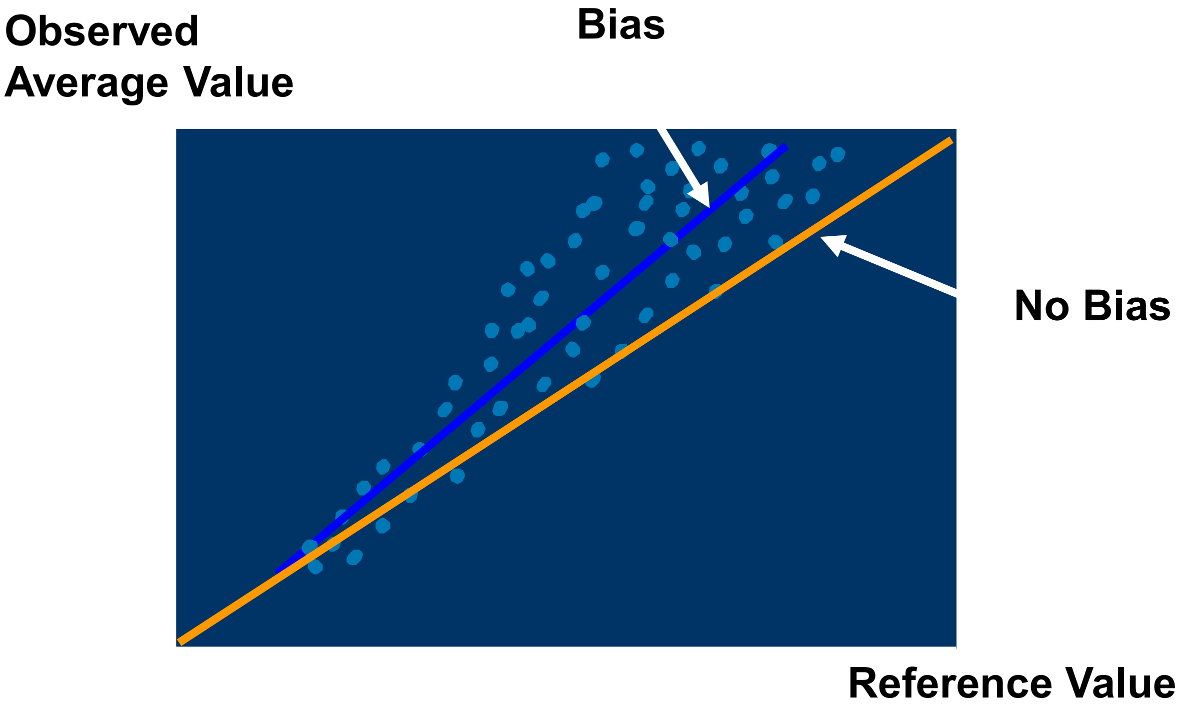
- Calibrate when needed / scheduled
- Use operations instructions
- Review specifications
- Review software logic
- Create Operational Definitions

Linearity



Measurement is not “true” and/or consistent across the range of the “gage”

Linearity



Full Range of Gage

Linearity – Attribute Example

Survey scoring:

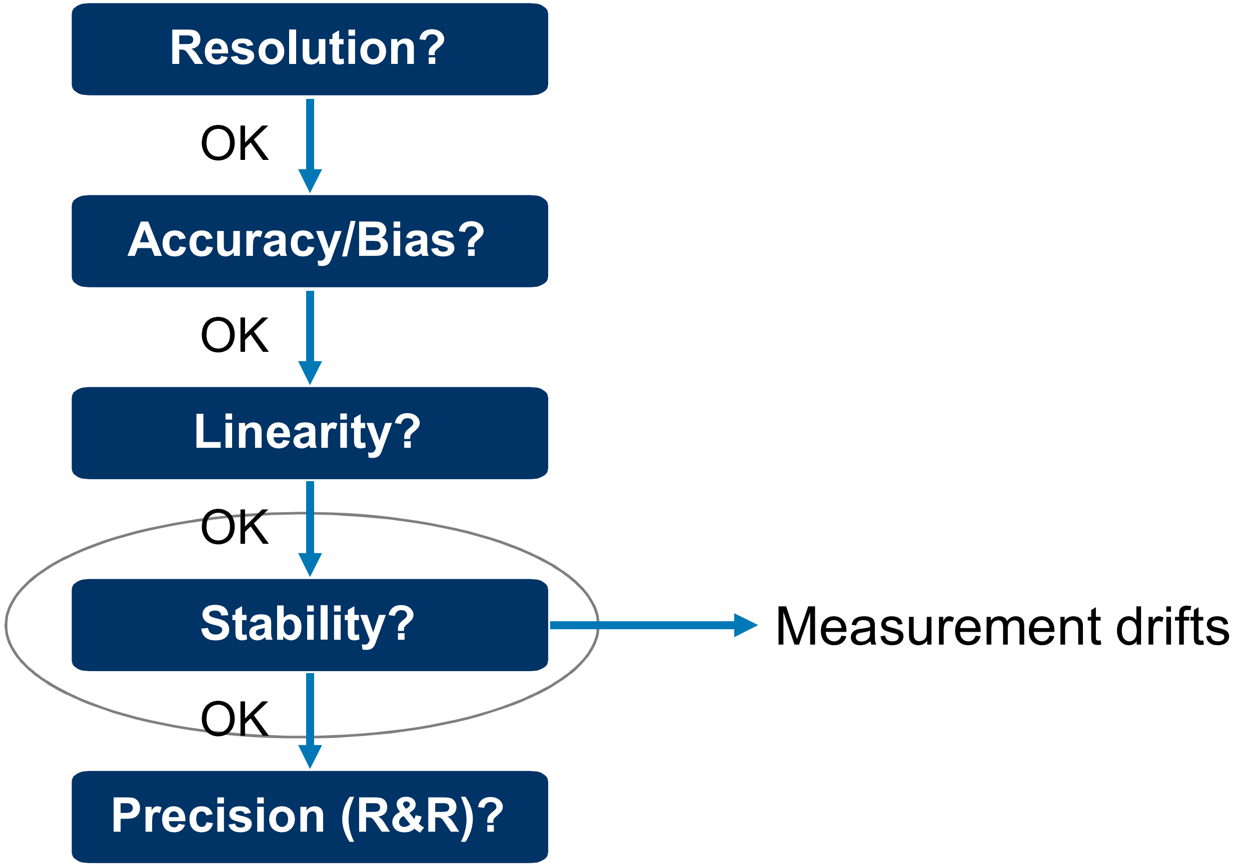
____	Super Outstanding!	10
____	Outstanding!	9
____	Incredible	8
____	Excellent	7
____	Great	6
____	Very Good	5
____	Good	4
____	OK	3
____	Fair	2
____	Poor	1

Is this a fair scale?

Linearity Actions

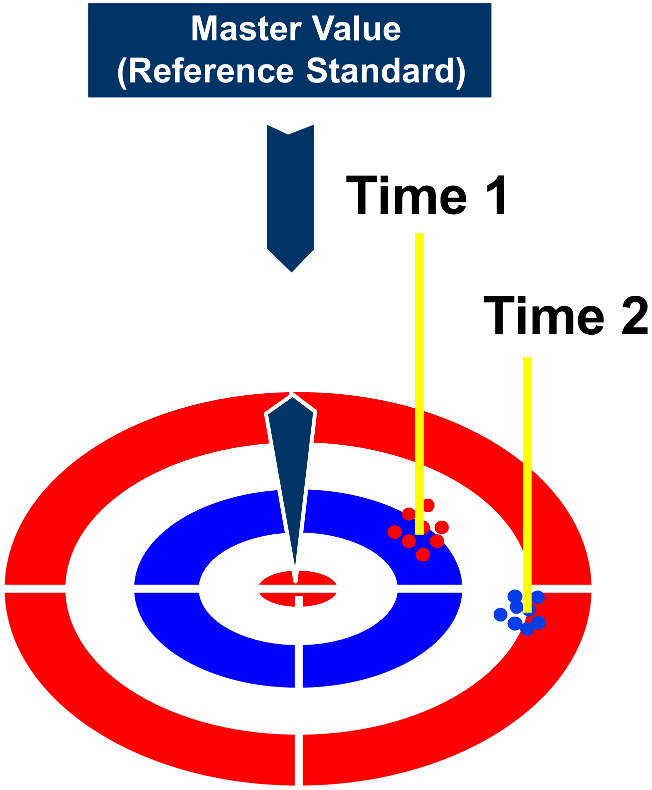
- Use only in restricted range
- Rebuild
- Use with correction factor / table / curve
- Sophisticated study required and will not be discussed in this course

Stability

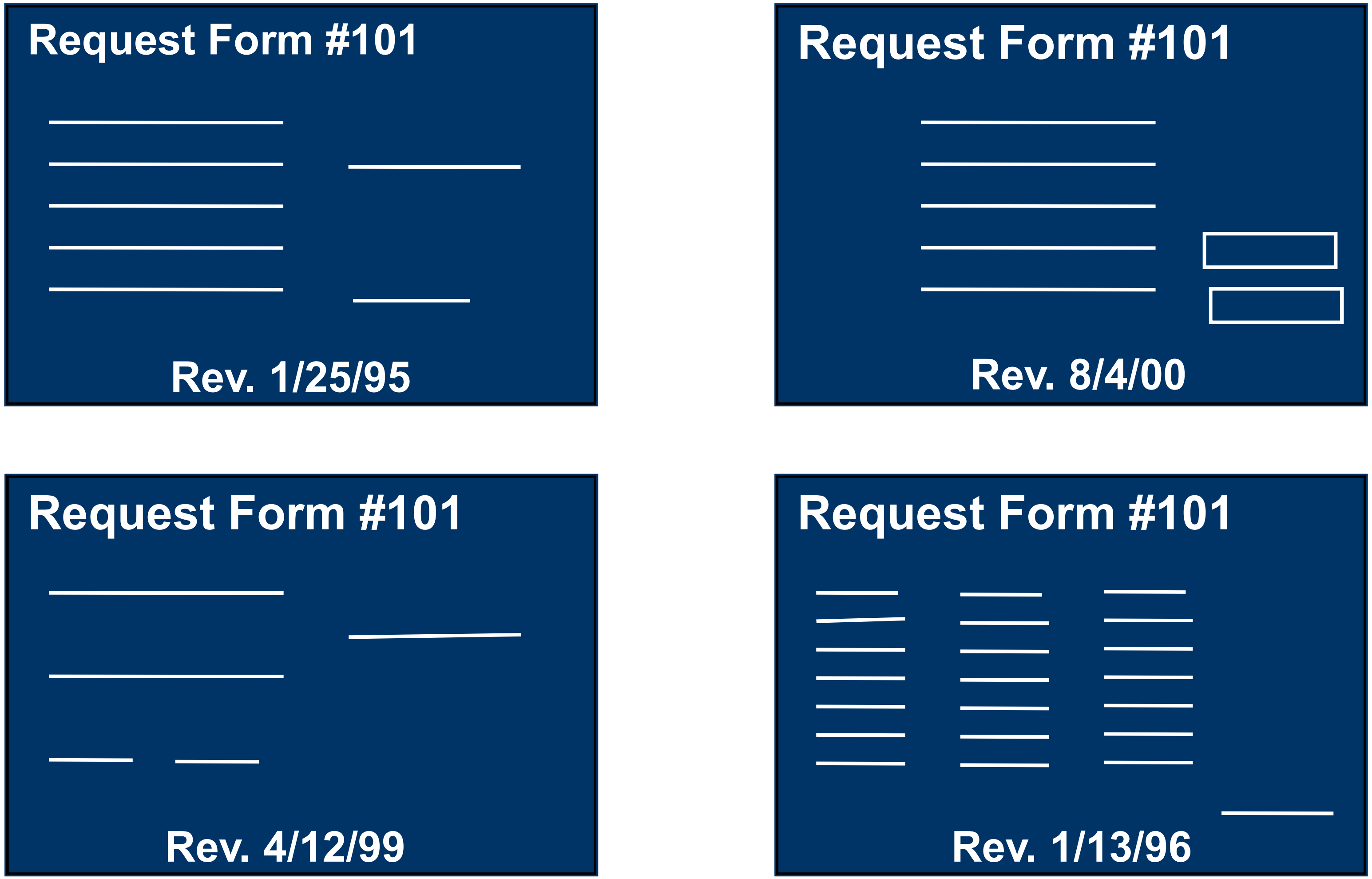

Resolution?
OK
Accuracy/Bias?
OK
Linearity?
OK
Stability?
Measurement drifts
OK
Precision (R&R)?

Stability

- Measurements remain constant and predictable over time
  - for both mean and standard deviation
- No drifts, sudden shifts, cycles, etc.
- Evaluated using control charts



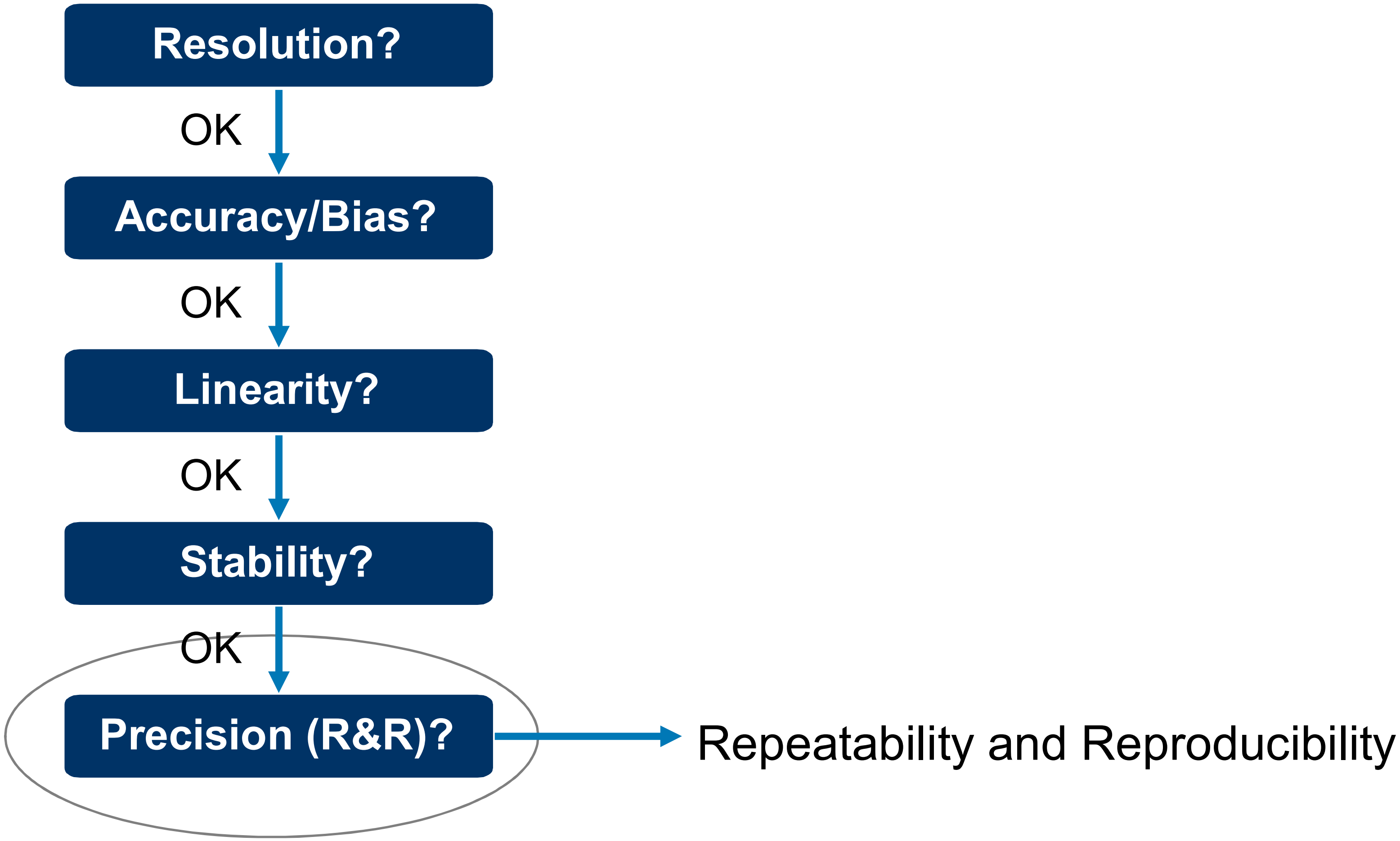
Stability – Attribute Example



Stability Actions

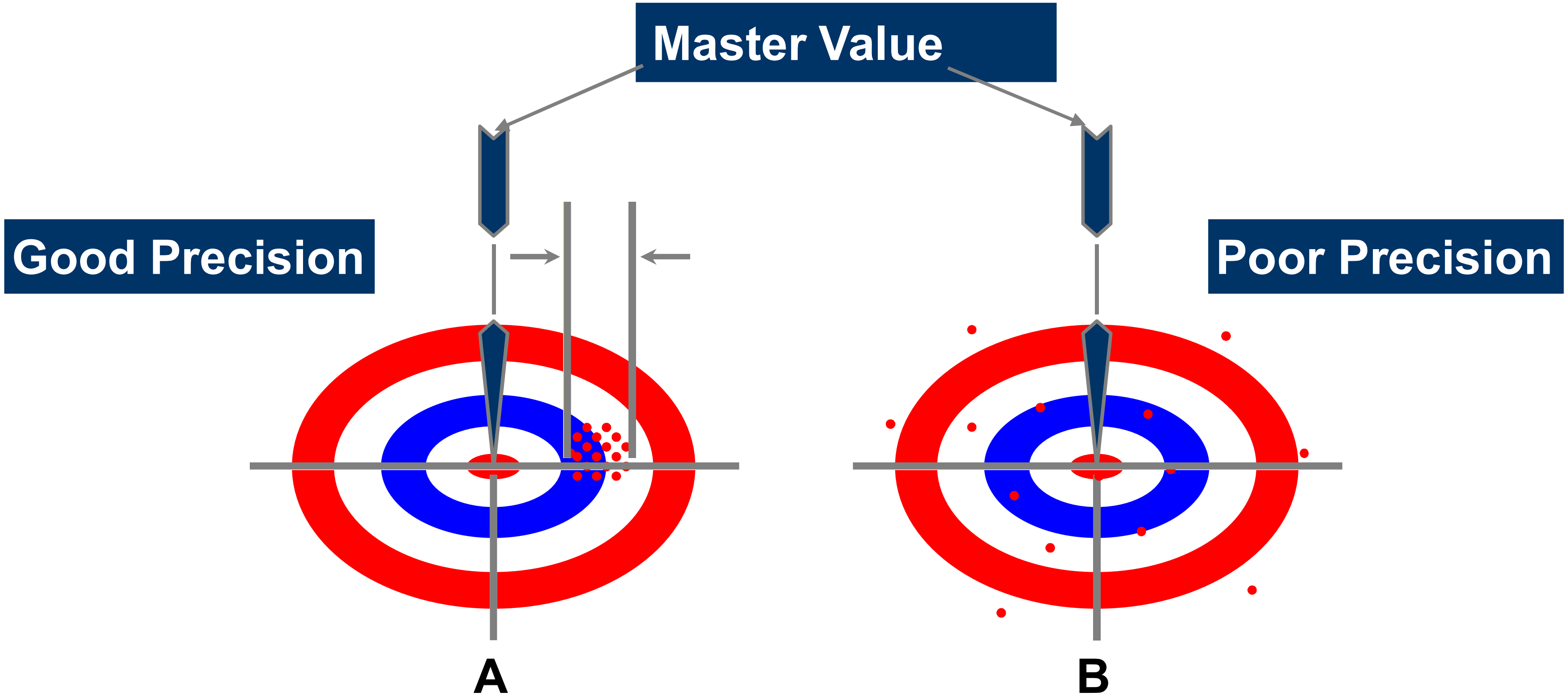
- Change / adjust components
- Establish “life” timeframe
- Use control charts
- Use / update current SOP

Precision


Resolution?
OK
Accuracy/Bias?
OK
Linearity?
OK
Stability?
OK
Precision (R&R)?
Repeatability and Reproducibility

Precision

$$\sigma^2_{total} = \sigma^2_{product / process} + \sigma^2_{repeatability} + \sigma^2_{reproducibility}$$



Also known as Gage R & R

Repeatability (A Component of Precision)

- Variation that occurs when repeated measurements are made of the same item under absolutely identical conditions
  - Same:
    - operator
    - set-up
    - units
    - environmental conditions
  - Short-term

Reproducibility (A Component of Precision)

- The variation that results when different conditions are used to make the measurements
  - Different:
    - operators
    - set-ups
    - test units
    - environmental conditions
    - locations
    - companies
  - Long-term

R & R

The Big Picture: Linking Them All Together

$$\sigma^2_{Total} = \sigma^2_{R\&R} + \sigma^2_{Process\ output}$$

$$\sigma^2_{Total} = \sigma^2_{Repeat} + \sigma^2_{Reproducibility} + \sigma^2_{Process\ output}$$

$$\sigma^2_{Total} = \sigma^2_{Repeat} + \sigma^2_{Oper} + \sigma^2_{Oper.\ Process\ output} + \sigma^2_{Process\ output}$$

R & R Actions

- Repeatability
  - Repair, replace, adjust equipment
  - SOP
- Reproducibility
  - Training
  - SOP

Anexas Consultancy Services

Attribute Measurement Studies

Purpose of Attribute MSA

- Assess standards against customers' requirements
- Determine if all appraisers use the same criteria
- Quantify repeatability and reproducibility of operators
- Identify how well measurement system conforms to a "known master"
- Discover areas where:
  - Training is needed
  - Procedures are lacking
  - Standards are not defined

Attribute MSA – Excel Method

- Allows for R & R analysis within and between appraisers
- Test for effectiveness against standard
- Limited to nominal data at two levels

Attribute MSA Example:

↓	C1-T	C2-T	C3-T	C4-T	C5-T	C6-T	C7-T
	Attribute	Appraiser 1 Trial 1	Appraiser 1 Trial 2	Appraiser 2 Trial 1	Appraiser 2 Trial 2	Appraiser 3 Trial 1	Appraiser 3 Trial 2
1	Pass	Pass	Pass	Pass	Pass	Pass	Pass
2	Pass	Pass	Pass	Pass	Pass	Pass	Pass
3	Pass	Pass	Pass	Pass	Pass	Pass	Pass
4	Pass	Pass	Pass	Pass	Pass	Fail	Pass
5	Fail	Fail	Fail	Fail	Fail	Pass	Fail
6	Fail	Pass	Pass	Pass	Pass	Pass	Pass
7	Pass	Pass	Pass	Pass	Pass	Pass	Pass
8	Pass	Pass	Pass	Pass	Pass	Pass	Pass
9	Fail	Fail	Fail	Fail	Fail	Fail	Fail
10	Pass	Pass	Pass	Pass	Pass	Pass	Pass
11	Pass	Pass	Pass	Pass	Pass	Pass	Pass
12	Pass	Pass	Pass	Pass	Pass	Pass	Pass
13	Pass	Pass	Pass	Pass	Pass	Pass	Pass

Open file *Attribute MSA.mpj*

Scoring Example:

% APPRAISER SCORE - >	100.00%	78.57%	100.00%
% SCORE VS. ATTRIBUTE - >	78.57%	64.29%	71.43%

SCREEN % EFFECTIVE SCORE - >	57.14%
SCREEN % EFFECTIVE SCORE vs. ATTRIBUTE - >	42.86%

- 100% is target for all scores
  - <100% indicates training required
- % Appraiser score = repeatability
- Screen % Effectiveness Score = reproducibility
- % Score vs. Attribute
  - individual error against a known population
- Screen % Effective vs. Attribute
  - Total error against a known population

Attribute MSA – Minitab Method

- Allows for R & R analysis within and between appraisers
- Test for effectiveness against standard
- Allow nominal data with two levels
- Allows for ordinal data with more than two levels

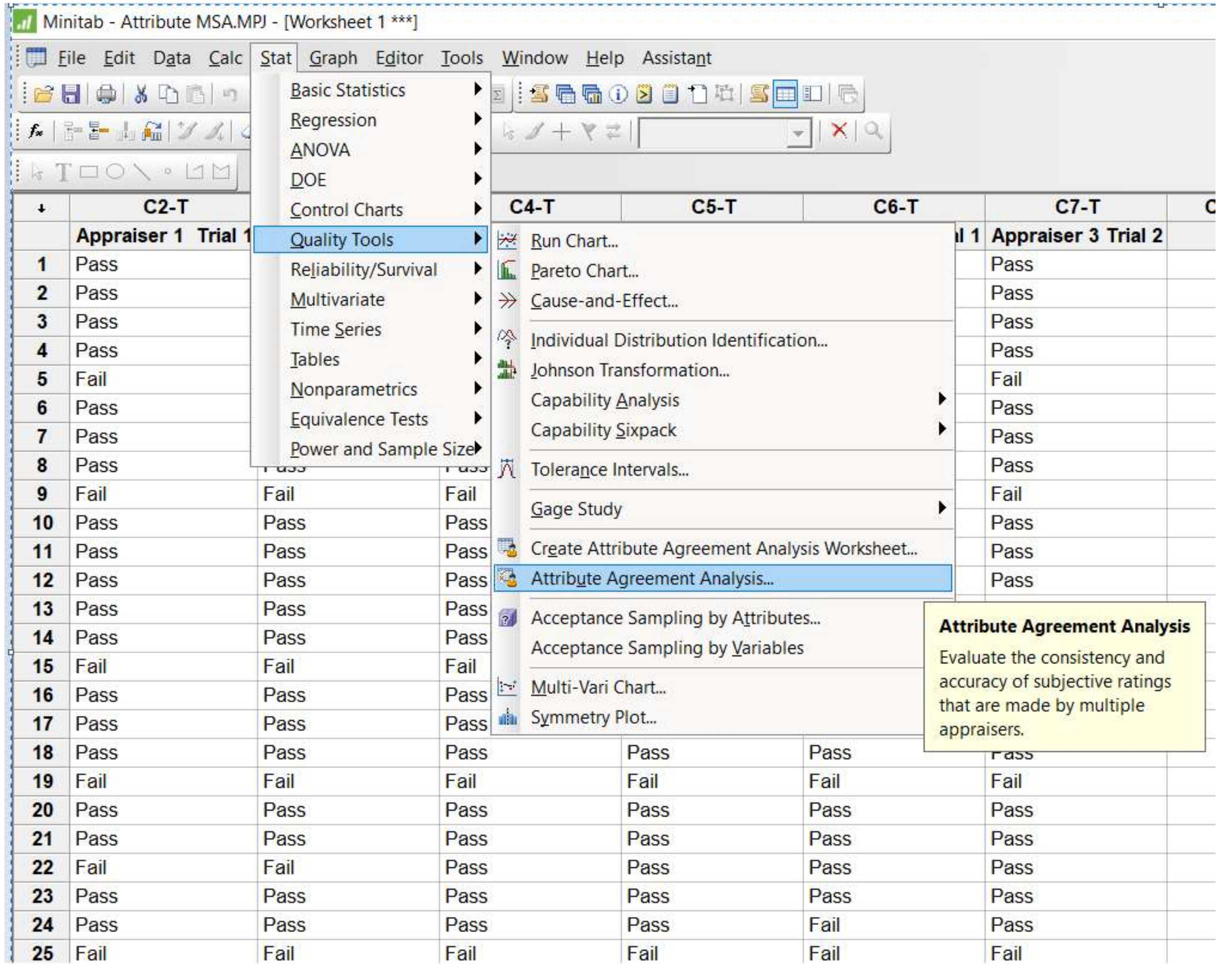
Minitab Method -- Data Entry

↓	C1-T	C2-T	C3-T	C4-T	C5-T	C6-T	C7-T
	Attribute	Appraiser 1 Trial 1	Appraiser 1 Trial 2	Appraiser 2 Trial 1	Appraiser 2 Trial 2	Appraiser 3 Trial 1	Appraiser 3 Trial 2
1	Pass	Pass	Pass	Pass	Pass	Pass	Pass
2	Pass	Pass	Pass	Pass	Pass	Pass	Pass
3	Pass	Pass	Pass	Pass	Pass	Pass	Pass
4	Pass	Pass	Pass	Pass	Pass	Fail	Pass
5	Fail	Fail	Fail	Fail	Fail	Pass	Fail
6	Fail	Pass	Pass	Pass	Pass	Pass	Pass
7	Pass	Pass	Pass	Pass	Pass	Pass	Pass
8	Pass	Pass	Pass	Pass	Pass	Pass	Pass
9	Fail	Fail	Fail	Fail	Fail	Fail	Fail
10	Pass	Pass	Pass	Pass	Pass	Pass	Pass
11	Pass	Pass	Pass	Pass	Pass	Pass	Pass
12	Pass	Pass	Pass	Pass	Pass	Pass	Pass
13	Pass	Pass	Pass	Pass	Pass	Pass	Pass

- Same data as Excel example
- Arranged in multiple columns
- Data can also be stacked in single column

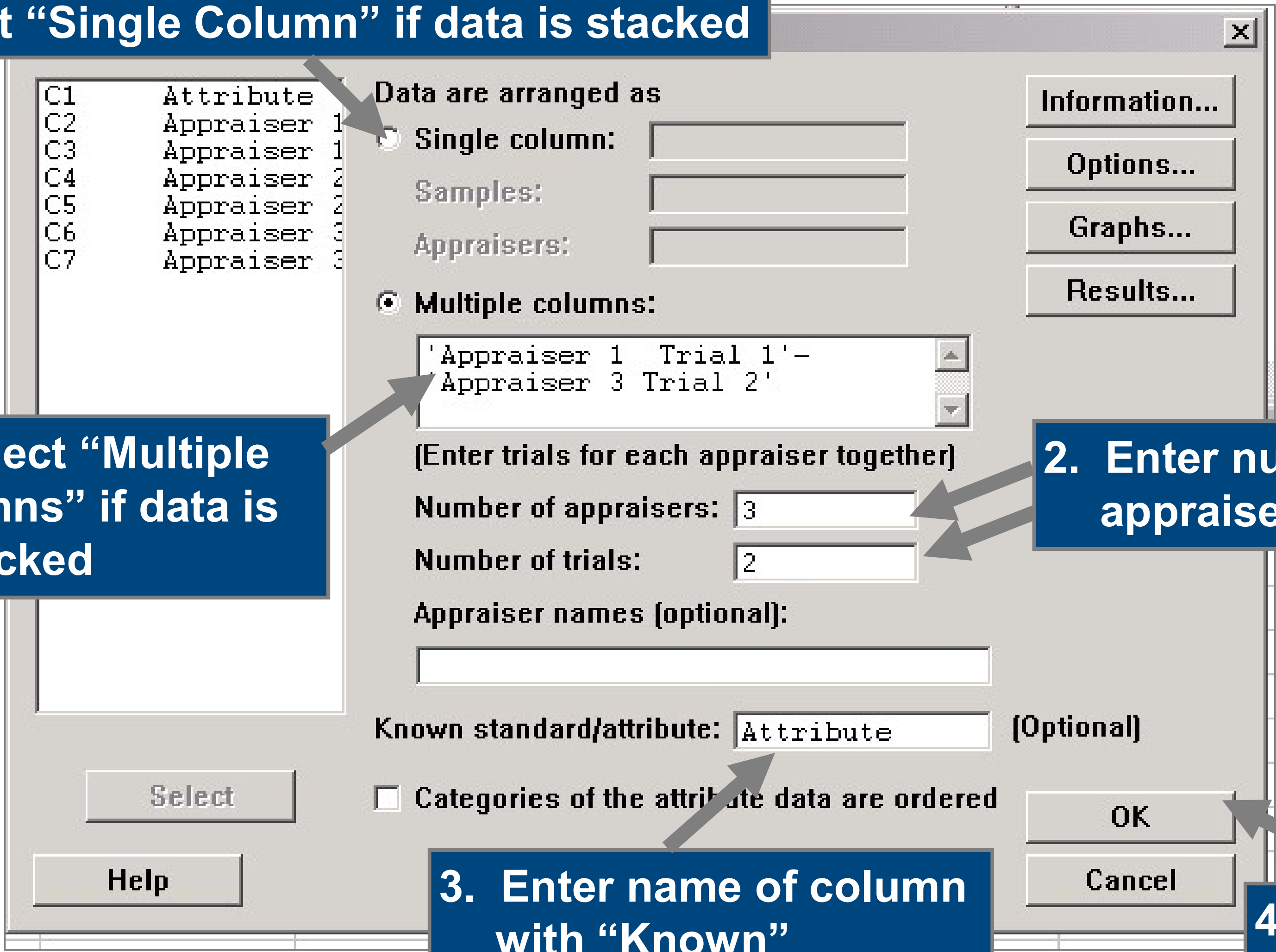
Attribute Study – Minitab Analysis

Tool Bar Menu > Stat > Quality Tools > Attribute Gage R&R Study



Attribute Study – Minitab Analysis (Continued)

1. Select "Single Column" if data is stacked



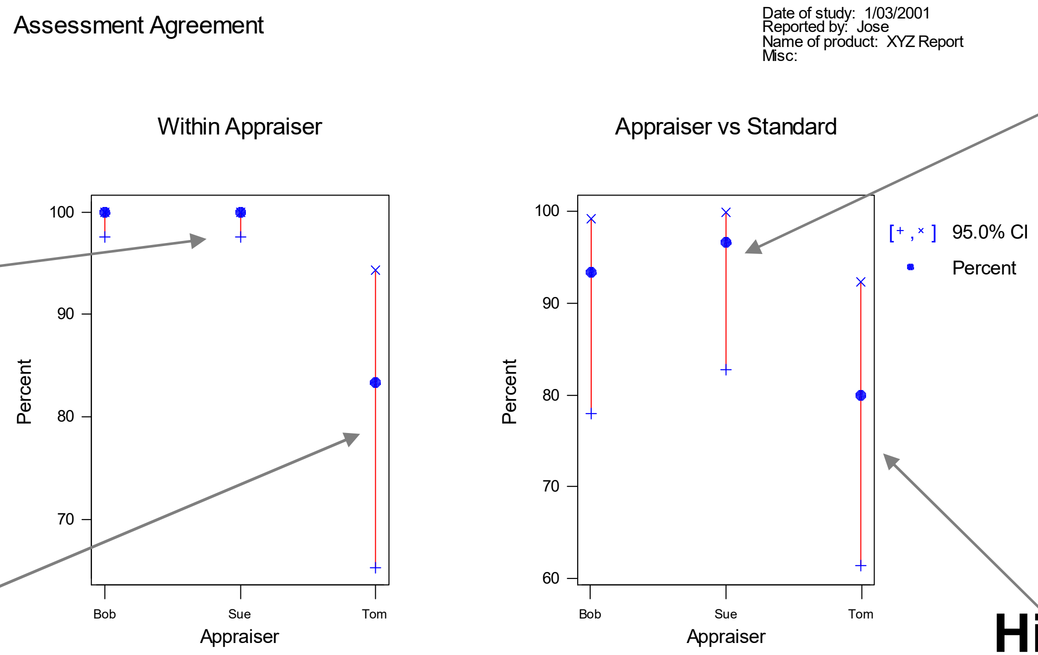
1. Select "Multiple Columns" if data is unstacked

2. Enter number of appraisers and trials

3. Enter name of column with "Known"

4. Select OK

Attribute MSA – Minitab Graphical Output



Lower variation within appraiser

Higher variation within appraiser

Lower variation appraiser vs. standard

Higher variation appraiser vs. standard

Not included if no “Known”

Attribute MSA – Session Window Results

- Each Appraiser vs Standard
- Assessment Agreement
- Appraiser # Inspected # Matched Percent (%) 95.0% CI
- Bob 30 28 93.3 (77.9, 99.2)
- Sue 30 29 96.7 (82.8, 99.9)
- Tom 30 24 80.0 (61.4, 92.3)
- # Matched: Appraiser's assessment across trials agrees with standard.
- Assessment Disagreement
- Appraiser # Pass/Fail Percent (%) # Fail/Pass Percent (%) # Mixed Percent (%)
- Bob 1 3.3 1 3.3 0 0.0
- Sue 1 3.3 0 0.0 0 0.0
- Tom 1 3.3 0 0.0 5 16.7
- # Pass/Fail: Assessments across trials = Pass / standard = Fail.
- # Fail/Pass: Assessments across trials = Fail / standard = Pass.
- # Mixed: Assessments across trials are not identical.
- Between Appraisers
- Assessment Agreement
- # Inspected # Matched Percent (%) 95.0% CI
- 30 24 80.0 (61.4, 92.3)
- # Matched: All appraisers' assessments agree with each other.
- All Appraisers vs Standard
- Assessment Agreement
- # Inspected # Matched Percent (%) 95.0% CI
- 30 23 76.7 (57.7, 90.1)
- # Matched: All appraisers' assessments agree with standard.

Individual vs. Standard

Disagreement assessment (repeatability)

Between appraisers (reproducibility)

Total agreement (against known)

Anexas Consultancy Services

Variables Measurement Studies

Six Step Variables MSA

1. Conduct initial gage calibration (or verification)
2. Perform trials and data collection
3. Obtain statistics via Minitab
4. Analyze, interpret results
5. Check for inadequate measurement units
6. On-going evaluation
   – What would be your long-term gage plan ?

Trials and Data Collection

- Generally two to three operators
- Generally 5-10 process outputs to measure
- Each process output is measured 2-3 times (replicated) by each operator

Randomization is Critical

Randomization, Repeats, Replicates

Randomization

- Runs are made in an arbitrary vs. patterned order
- Average out effects of noise or unknown factors
- Tradeoff - Invalid results versus slight inconvenience (if any)

Repeats

- Running more than one sample of a single run
- Results are averaged

Replication

- Running entire experiment in a time sequence
- MSA allows for repeatability study

Variables MSA – Minitab Example

USL=1.5

LSL=0.5

Replicate 1

Replicate 2
(Randomized order)

Part Trial 1	Operator Trial 1	Response Trial 1	Parts Trial 2	Operator Trial 2	Response Trial 2
1	1	0.60000	8	1	0.85000
2	1	1.00000	2	1	1.00000
3	1	0.80000	10	1	0.60000
4	1	0.95000	6	1	1.00000
5	1	0.45000	5	1	0.55000
6	1	1.00000	4	1	0.85000
7	1	0.95000	7	1	0.95000
8	1	0.80000	1	1	0.65000
9	1	1.00000	9	1	1.00000
10	1	0.70000	3	1	0.85000
1	2	0.55000	1	2	0.55000
2	2	0.95000	2	2	1.05000
3	2	0.75000	3	2	0.80000
4	2	0.75000	4	2	0.80000
5	2	0.40000	5	2	0.40000
6	2	1.05000	6	2	1.00000
7	2	0.90000	7	2	0.95000
8	2	0.70000	8	2	0.75000
9	2	0.95000	9	2	1.00000
10	2	0.50000	10	2	0.55000
1	3	0.55000	1	3	0.50000
2	3	1.00000	2	3	1.05000
3	3	0.80000	3	3	0.80000
4	3	0.80000	4	3	0.80000
5	3	0.50000	5	3	0.45000
6	3	1.05000	6	3	1.00000

Open file Variable *MSA.mtw*

MSA Using Minitab

10 Process Outputs
3 Operators
2 Replicates

- **Have Operator 1 measure all samples once (as shown in the outlined block)**
- **Then, have Operator 2 measure all samples once**
- **Continue until all operators have measured samples once (this is Replicate 1)**
- **Repeat these steps for the required number of Replicates**
- **Enter data into Minitab in 3 columns as shown**

USL=1.5

LSL=0.5

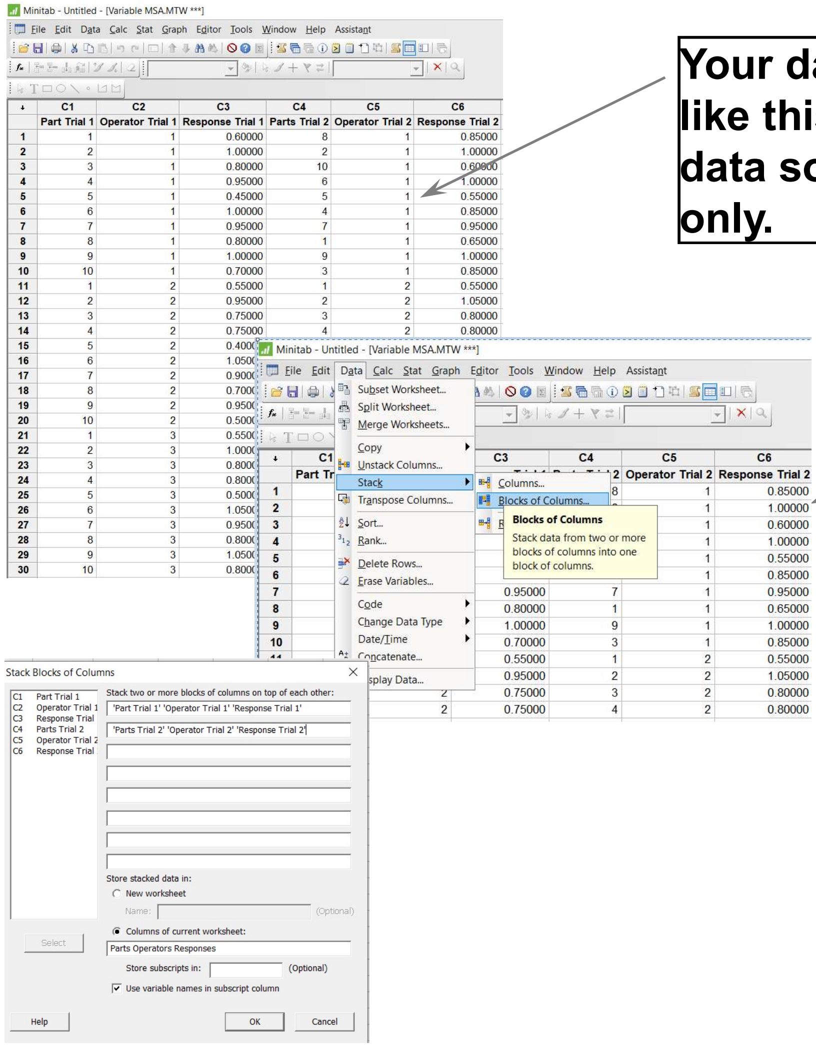
Replicate 1

Replicate 2

(Randomized order)

Part Trial 1	Operator Trial 1	Response Trial 1	Parts Trial 2	Operator Trial 2	Response Trial 2
1	1	0.60000	8	1	0.85000
2	1	1.00000	2	1	1.00000
3	1	0.80000	10	1	0.60000
4	1	0.95000	6	1	1.00000
5	1	0.45000	5	1	0.55000
6	1	1.00000	4	1	0.85000
7	1	0.95000	7	1	0.95000
8	1	0.80000	1	1	0.65000
9	1	1.00000	9	1	1.00000
10	1	0.70000	3	1	0.85000
1	2	0.55000	1	2	0.55000
2	2	0.95000	2	2	1.05000
3	2	0.75000	3	2	0.80000
4	2	0.75000	4	2	0.80000
5	2	0.40000	5	2	0.40000
6	2	1.05000	6	2	1.00000
7	2	0.90000	7	2	0.95000
8	2	0.70000	8	2	0.75000
9	2	0.95000	9	2	1.00000
10	2	0.50000	10	2	0.55000
1	3	0.55000	1	3	0.50000
2	3	1.00000	2	3	1.05000
3	3	0.80000	3	3	0.80000
4	3	0.80000	4	3	0.80000
5	3	0.50000	5	3	0.45000
6	3	1.05000	6	3	1.00000
7	3	0.95000	7	3	0.95000
8	3	0.80000	8	3	0.80000

Stack the Data



Your data in Minitab should initially look like this. You will need to STACK your data so that all like data is in one column only.

Use the commands
> Data
> Stack
> Stack Blocks of Columns
(Stack all Process Outputs, Operators, and Responses so that they are in one column only).

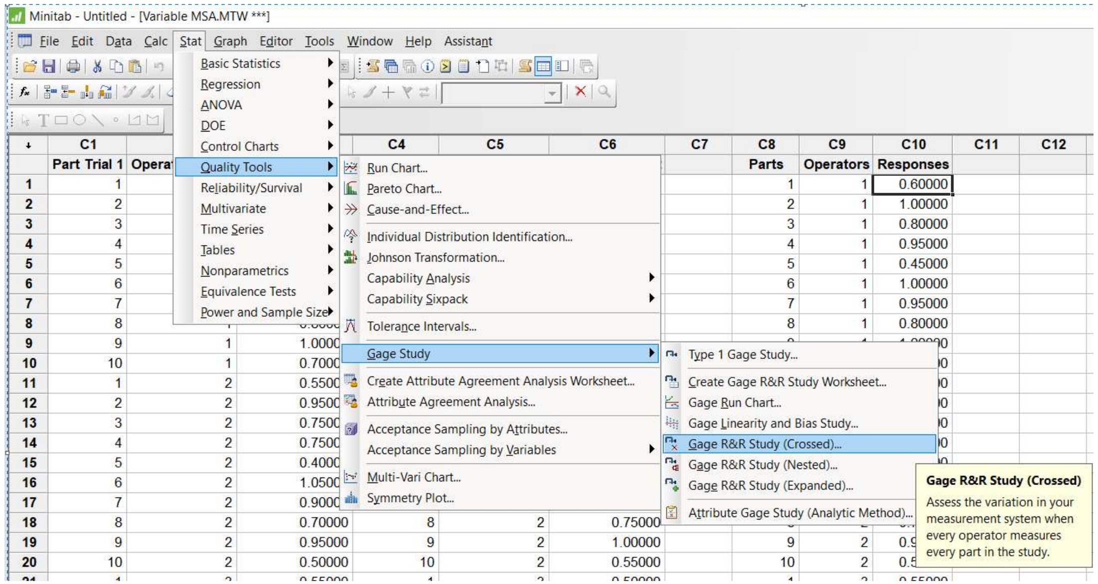
Now you are ready to run the macro for data analysis

Stacked and Ready for Analysis

C8	C9	C10	C11
Parts	Operators	Responses	
1	1	0.60000	
2	1	1.00000	
3	1	0.80000	
4	1	0.95000	
5	1	0.45000	
6	1	1.00000	
7	1	0.95000	
8	1	0.80000	
9	1	1.00000	
10	1	0.70000	
1	2	0.55000	
2	2	0.95000	
3	2	0.75000	
4	2	0.75000	
5	2	0.40000	
6	2	1.05000	
7	2	0.90000	
8	2	0.70000	
9	2	0.95000	

NOTE:
C08 C09, C10 are the columns in which the respective data are found in our example. You must have ALL data STACKED in these columns and named those columns as mentioned

Prepare the Analysis

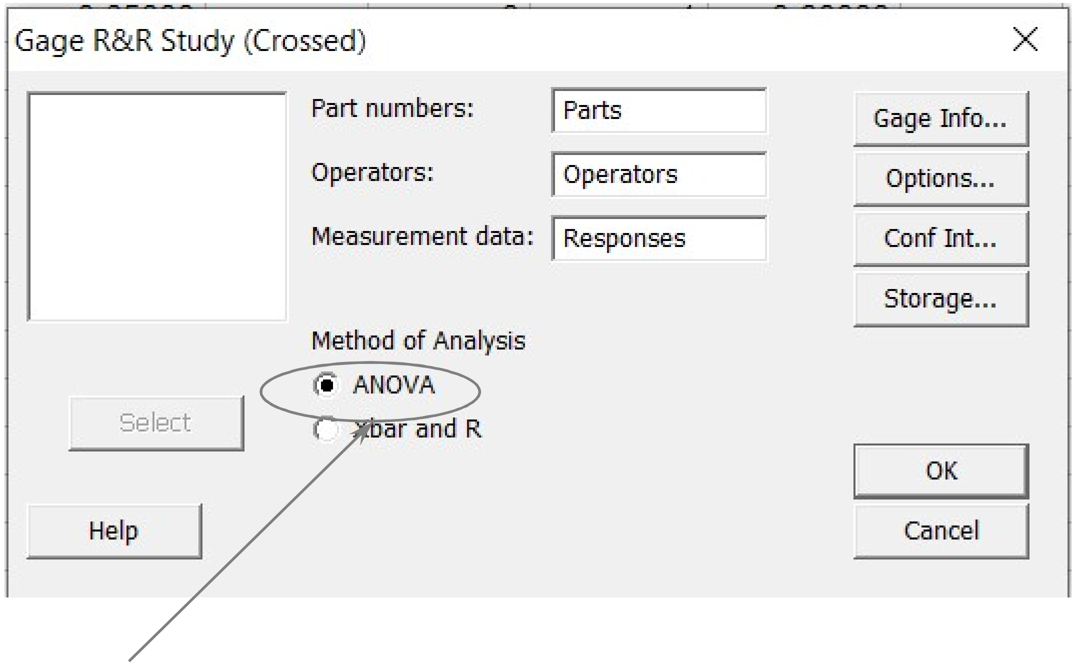


Use the commands
> Stat > Quality Tools
> Gage R&R Study (Crossed)
Each process output measured by each operator

OR

> Gage R&R Study (Nested)
For "destructive tests" where each process output is measured uniquely by each operator

Choose Method of Analysis



ANOVA method is preferred

- Gives more information

MSA Output:

Session Window

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Part	9	2.05871	0.228745	39.7178	0.00000
Operator	2	0.04800	0.024000	4.1672	0.03256
Operator*Part	18	0.10367	0.005759	4.4588	0.00016
Repeatability	30	0.03875	0.001292		
Total	59	2.24912			

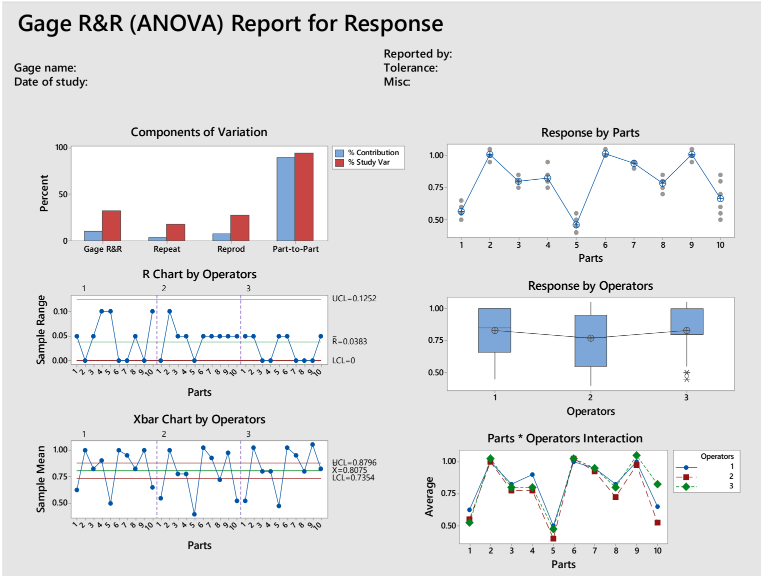
Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.004437	10.67
Repeatability	0.001292	3.10
Reproducibility	0.003146	7.56
Operator	0.000912	2.19
Operator*Part	0.002234	5.37
Part-To-Part	0.037164	89.33
Total Variation	0.041602	100.00

Source	StdDev (SD)	Study Var (5.15*SD)	%Study Var (%SV)
Total Gage R&R	0.066615	0.34306	32.66
Repeatability	0.035940	0.18509	17.62
Reproducibility	0.056088	0.28885	27.50
Operator	0.030200	0.15553	14.81
Operator*Part	0.047263	0.24340	23.17
Part-To-Part	0.192781	0.99282	94.52
Total Variation	0.203965	1.05042	100.00

Number of Distinct Categories = 4

Graphs

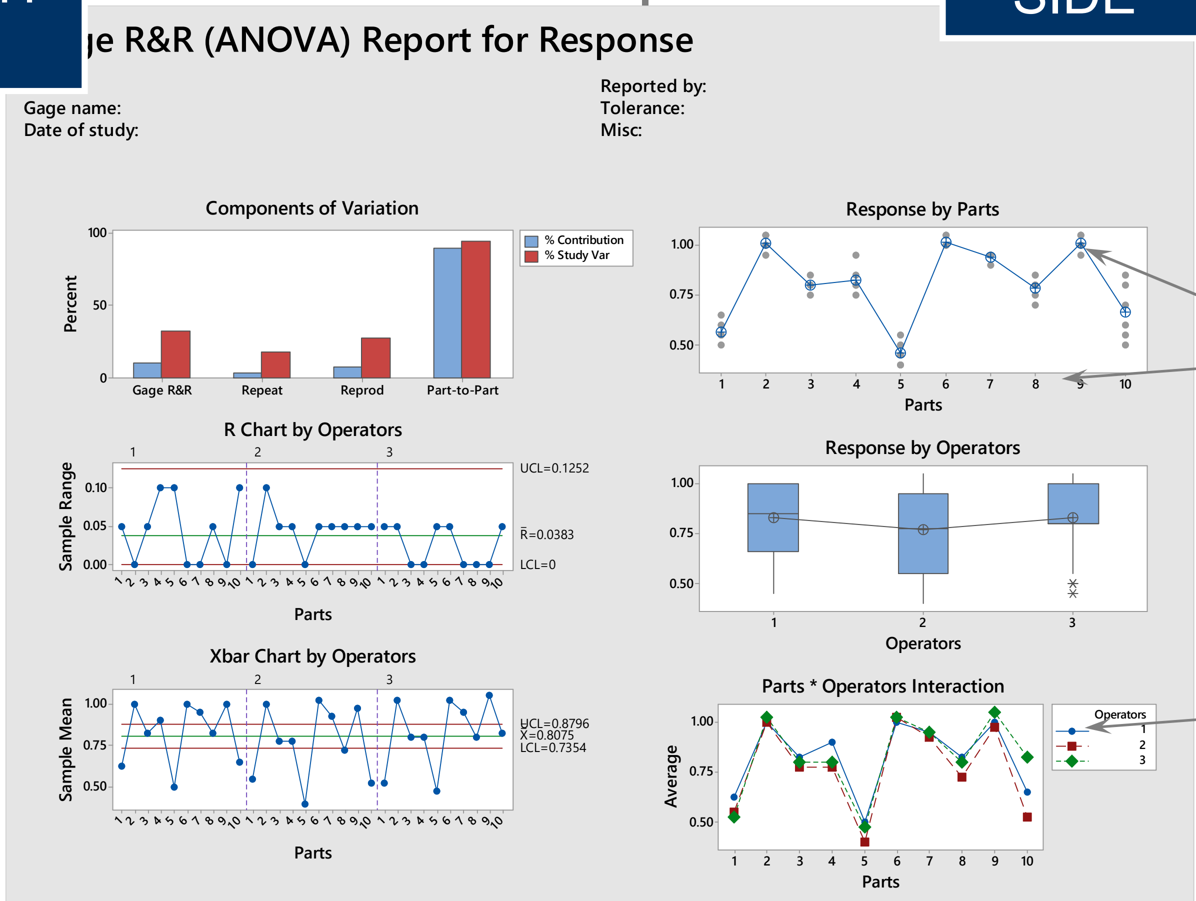


What does all this mean?

Graphical Output - 6 Graphs in All

MSA HEALTH SIDE

MSA TROUBLESHOOT SIDE



If only 1 operator, you won't get these graphs

If nested study, you won't get this graph

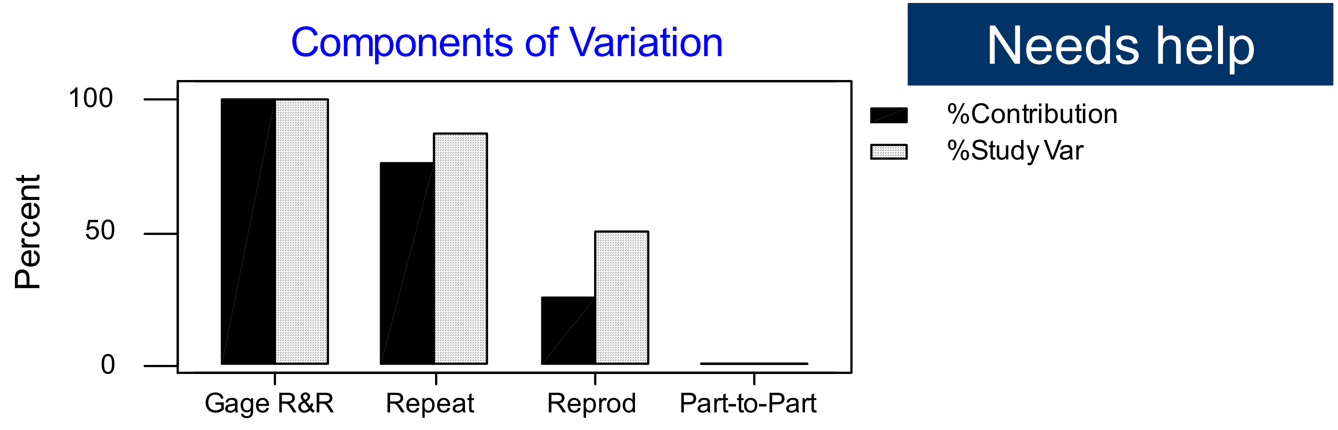
Graphical Output Metrics

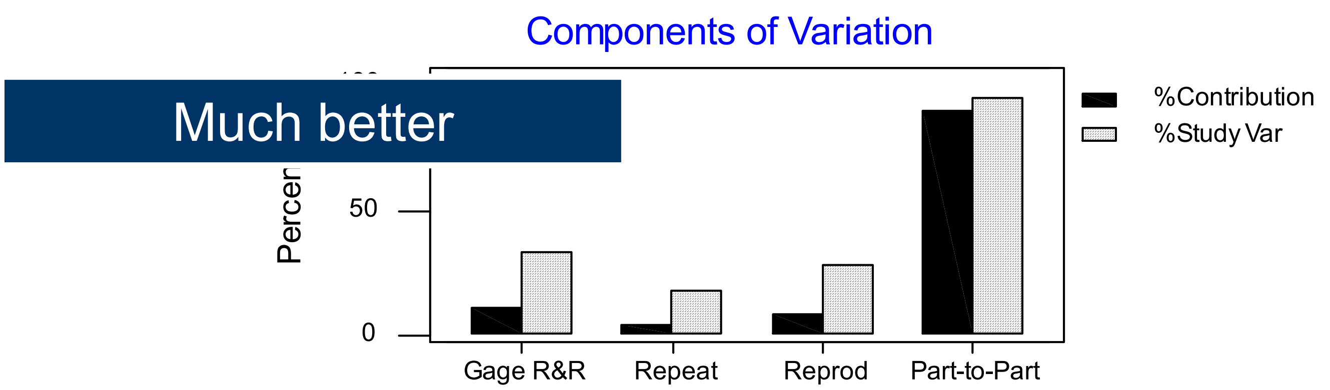
CHART OUTPUT

- **Xbar Chart: Shows sampled process output variety**
  - **Reproducibility / bias**
- **R Chart: Helps identify unusual measurements**
  - **Resolution / repeatability**
- **Bar Chart: Distinguishes R & R from Process Output-Process Output**
  - **Location of variation**

These are your leading graphical indicators

Bar Charts for Components

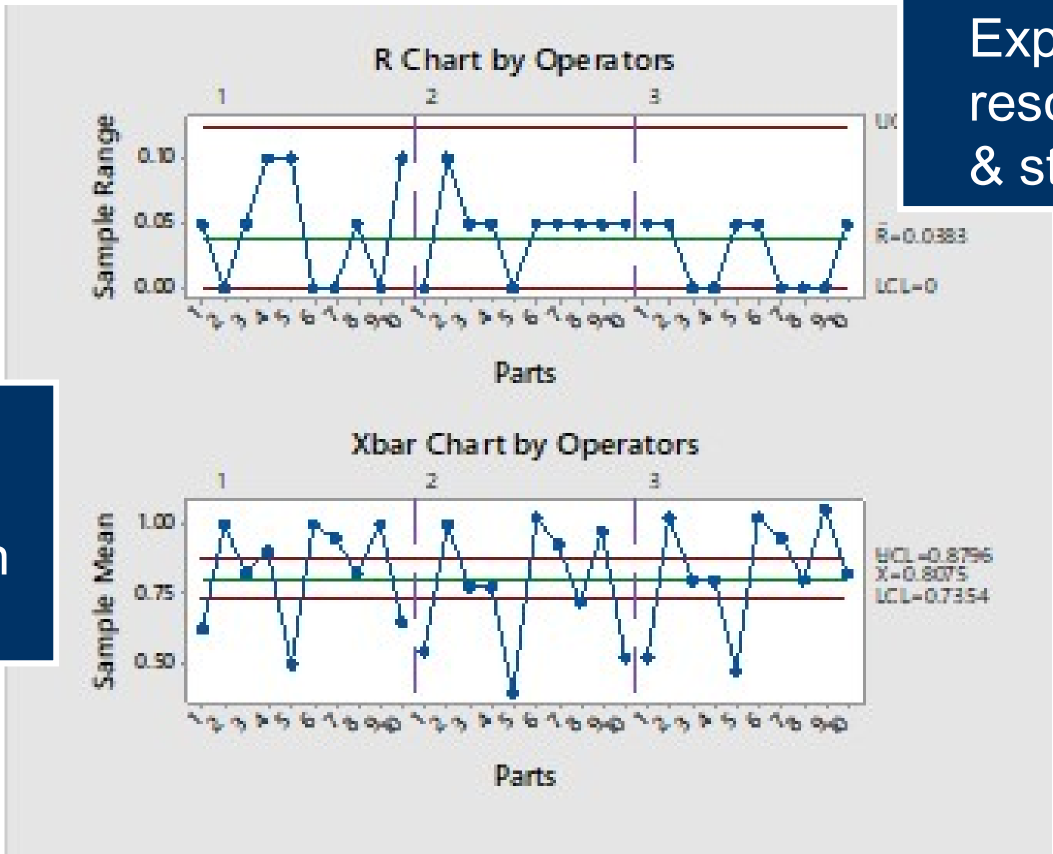




Answers: “Where is the variation?”

Closer Look at the Xbar & R Charts

R Chart:
Exposes gage resolution
& stability



Xbar Chart:
Test of sensitivity,
bias, & population
variety

Xbar: at least 50% outside limits; R chart: in control

Tabular Output Metrics

%Contribution

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.004437	10.67
Repeatability	0.001292	3.10
Reproducibility	0.003146	7.56
Operator	0.000912	2.19
Operator*Part	0.002234	5.37
Part-To-Part	0.037164	89.33
Total Variation	0.041602	100.00

%Study

%Tolerance

Source	StdDev (SD)	Study Var (5.15*SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	0.066615	0.34306	32.66	68.61
Repeatability	0.035940	0.18509	17.62	37.02
Reproducibility	0.056088	0.28885	27.50	57.77
Operator	0.030200	0.15553	14.81	31.11
Operator*Part	0.047263	0.24340	23.17	48.68
Part-To-Part	0.192781	0.99282	94.52	198.56
Total Variation	0.203965	1.05042	100.00	210.08

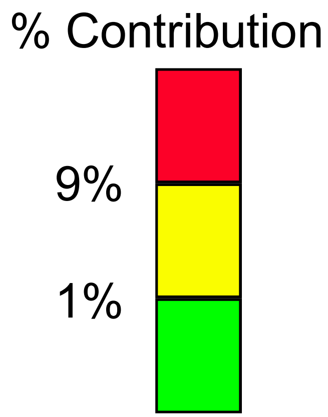
Number of Distinct Categories = 4

Number of Distinct Categories

% Contribution

$$\%\ \text{Contribution} = \frac{\sigma^2_{R\&R}}{\sigma^2_{Total}} * 100$$

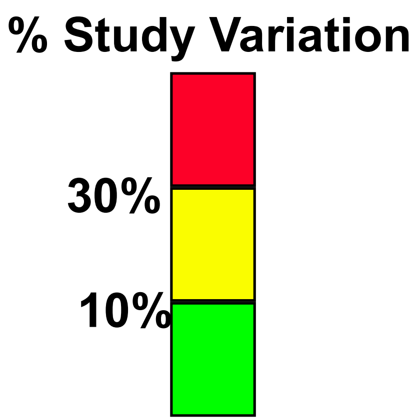
- Measurement System Variation (R & R) as a percentage of Total Observed Process Variation
- Includes both repeatability and reproducibility



% Study Variation

$$\text{\% Study Variation} = \frac{\sigma_{R\&R}}{\sigma_{Total}} * 100$$

- **Looks at standard deviations instead of variance**
- **Measurement System Standard Deviation (R & R) as a percentage of Total Observed Process Standard Deviation**
- **Includes both repeatability and reproducibility**



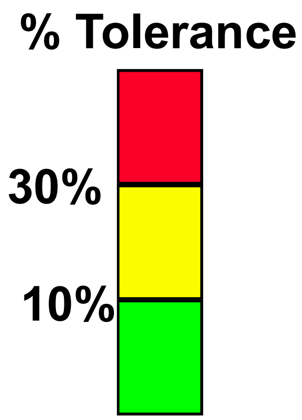
% Tolerance

Precision to Tolerance P/T

$$\% \text{ Tolerance} = \frac{5.15 * \sigma_{R\&R}}{\text{Tolerance}} * 100$$

- **Measurement error as a percent of tolerance**
- **Includes both repeatability and reproducibility**
- **5.15 Study Variation = 99%**

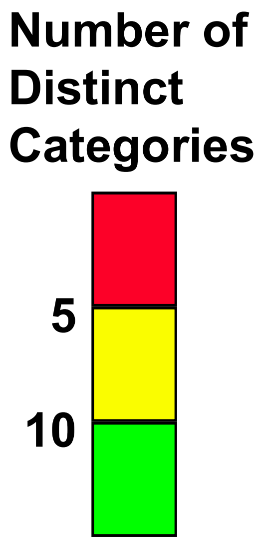
Acceptance Criteria



Distinct Categories

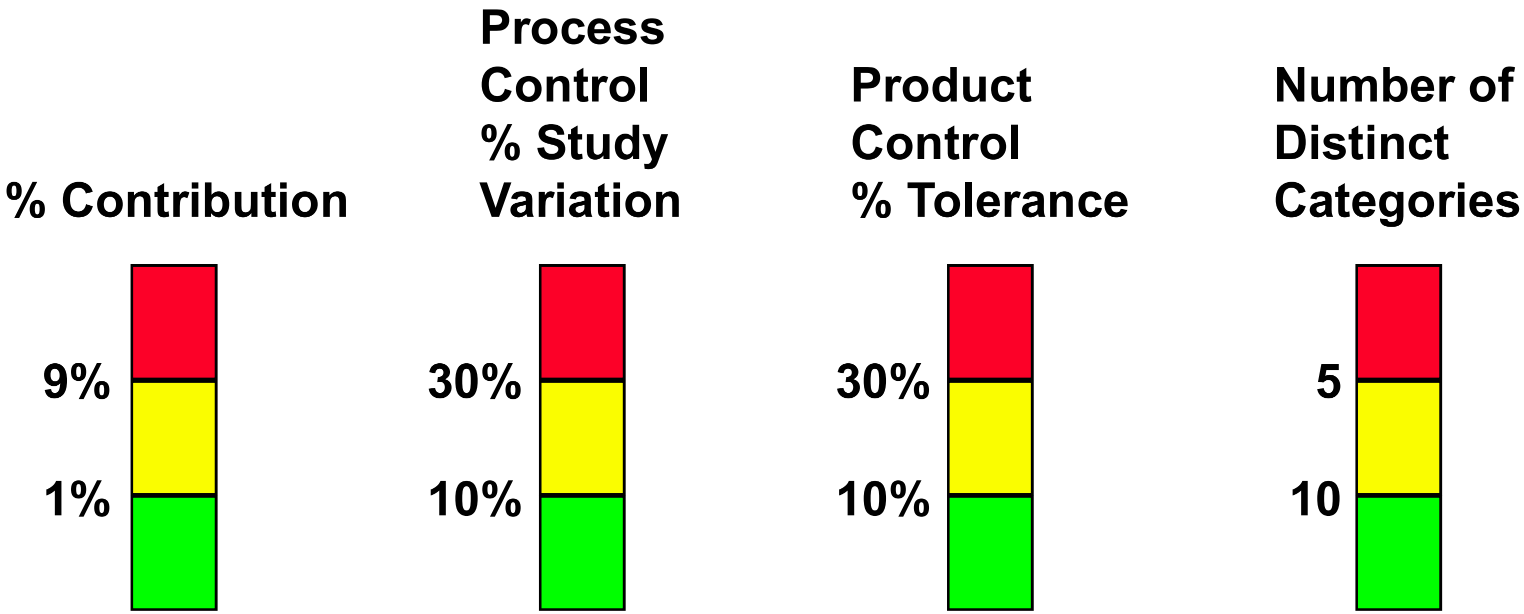
$$\text{Number of Distinct Categories} = \sqrt{2 * \left(\frac{\sigma^2_{\text{Process Output}}}{\sigma^2_{\text{R\&R}}} \right)}$$

- **Number of divisions that the Measurement System can accurately measure across the process variation**
- **How well a measurement process can detect process output variation--process shifts and improvement**
- **Less than 5 indicates Attribute conditions**



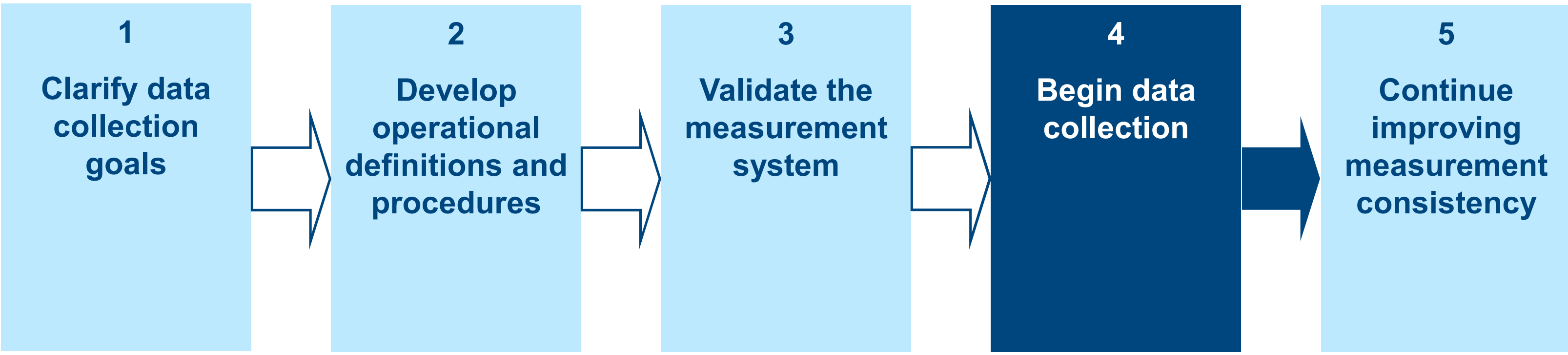
Acceptability Summary

Tabular Method



Desirable to Have All 4 Indicators Say “Go”

Data Collection, Step 4: Begin the Data Collection



Goal

- To ensure a smooth start-up of data collection

Data Collection, Step 5: Continue Improving Measurement Consistency and Stability

1. Clarify data collection goals
2. Develop operational definitions and procedures
3. Validate the measurement system
4. Begin data collection
5. **Continue improving measurement consistency**

Goal

- To check that data collection procedures are being followed and that changes are made as necessary to adapt to changing conditions

A Final Note: Do You Really Need New Data?

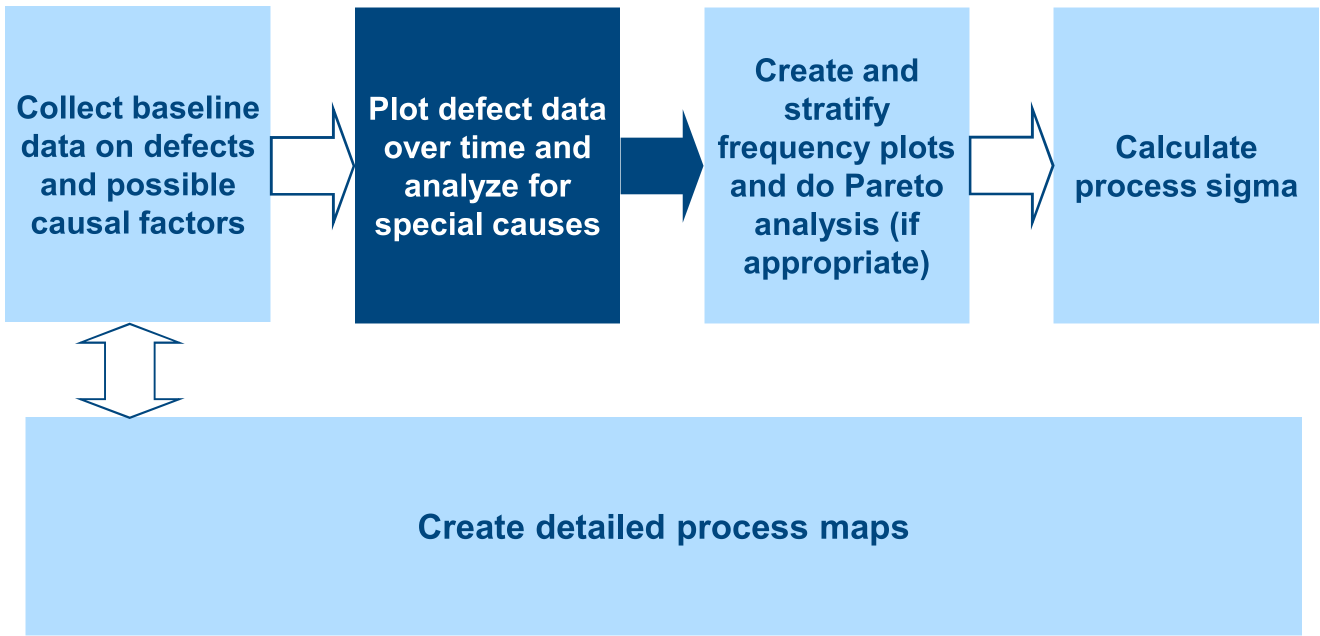
- Data collection can be time-consuming and expensive
- Before you collect new data, you may want to:
  – See if you have existing data that fits your needs—but use with caution
  – Use **observation** of the workplace as a way to gather information

Anexas Consultancy Services

Data Analysis I

Identifying Patterns over Time

You Are Here

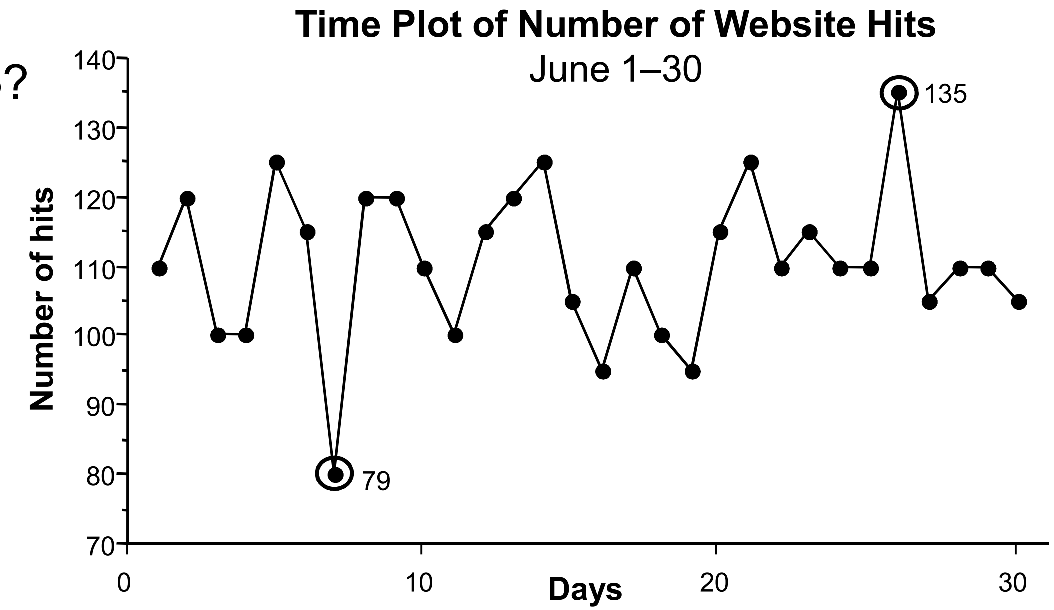

Collect baseline data on defects and possible causal factors
Plot defect data over time and analyze for special causes
Create and stratify frequency plots and do Pareto analysis (if appropriate)
Calculate process sigma
Create detailed process maps

Goals

- Given a situation involving a specific product or service, explain the customer's view of quality in terms of the Taguchi Loss Function
- Differentiate between common- and special-cause variation and select an appropriate response to each
- Given a set of data and an improvement problem, determine whether or not to use a time plot or control chart
- Given a set of data and an improvement problem, create and interpret a time plot using the run chart rules
- Given a set of data and an improvement problem, create and interpret an individuals control chart

Case Study: Website Hits

- The Information Services manager for a small company was told that the preceding month the new website had gotten 79 hits/day early in the month and 135 hits/day near the end of the month
  - His questions:
    - Was the 79 more typical? Or the 135? Was there a clear trend upwards?
    - How does looking at the data this way help?
  - His staff charted the hits/day for June



Anexas Consultancy Services

Data Analysis II

Looking for Patterns Not Related to Time

Goals

Given a set of data and an improvement problem:

- Determine whether or not to use a Box plot
- Determine whether or not to use a Pareto chart
- Create and interpret a Box plot
- Create and interpret a Pareto chart

Anexas Consultancy Services

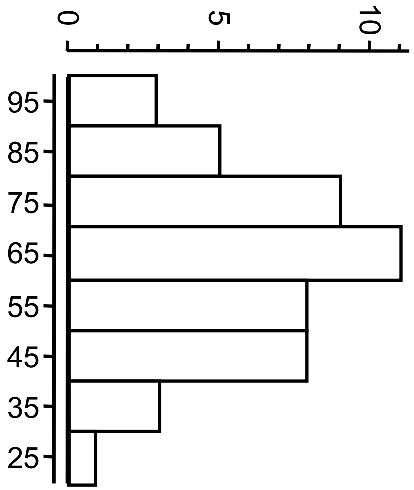
Studying the Distribution of Numeric Data

Anexas Consultancy Services

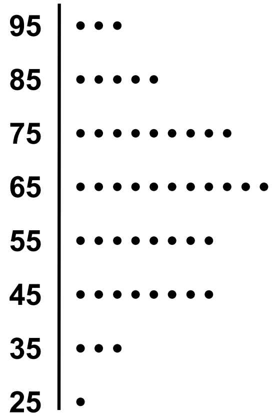
Minitab Exercises

Part 1: Histograms, Box Plots

Types of Frequency Plots



Histogram



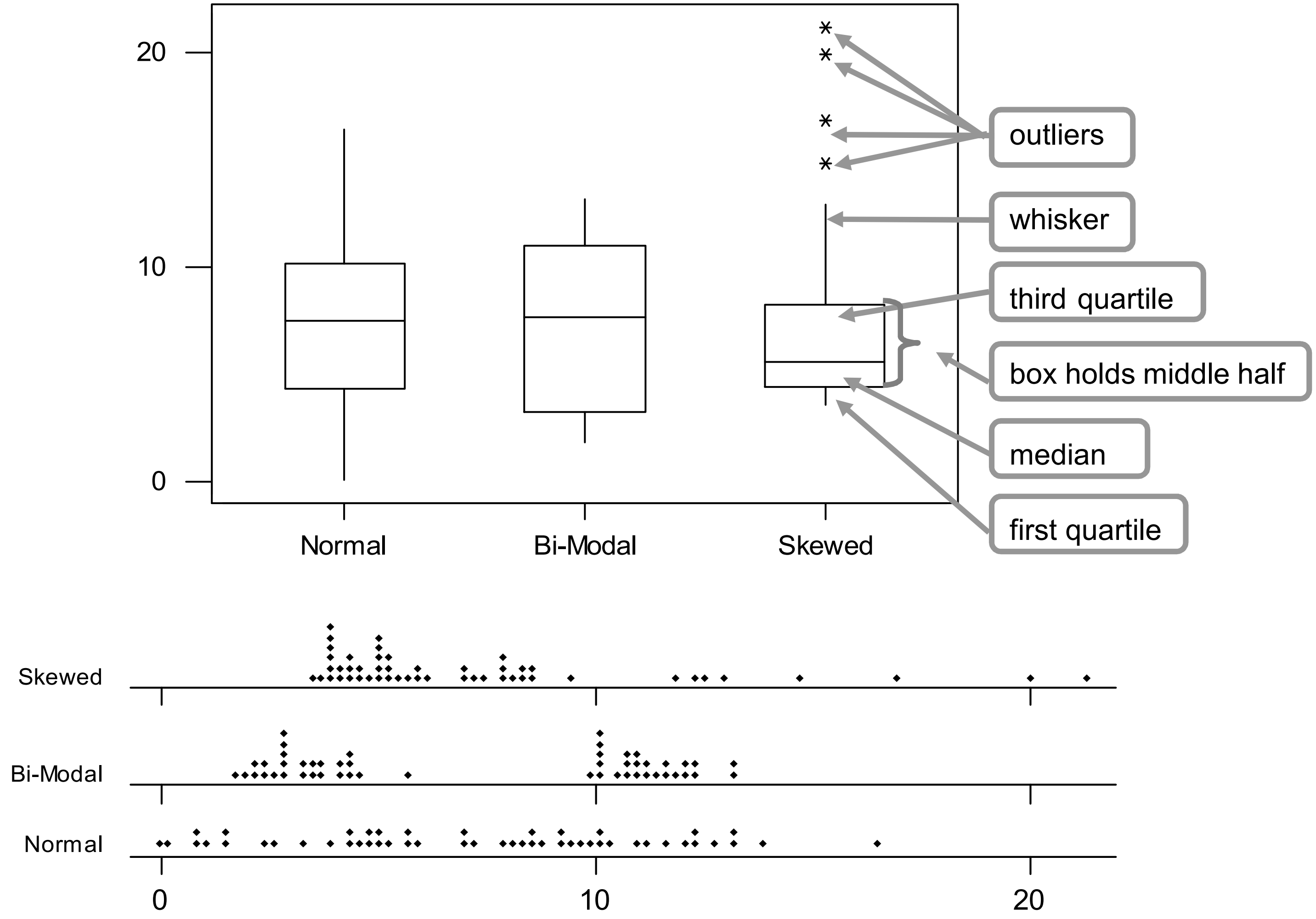
Dot Plot

9	149
8	25396
7	974532826
6	68274435082
5	42083443
4	90812156
3	349
2	1

StemandLeaf Plot

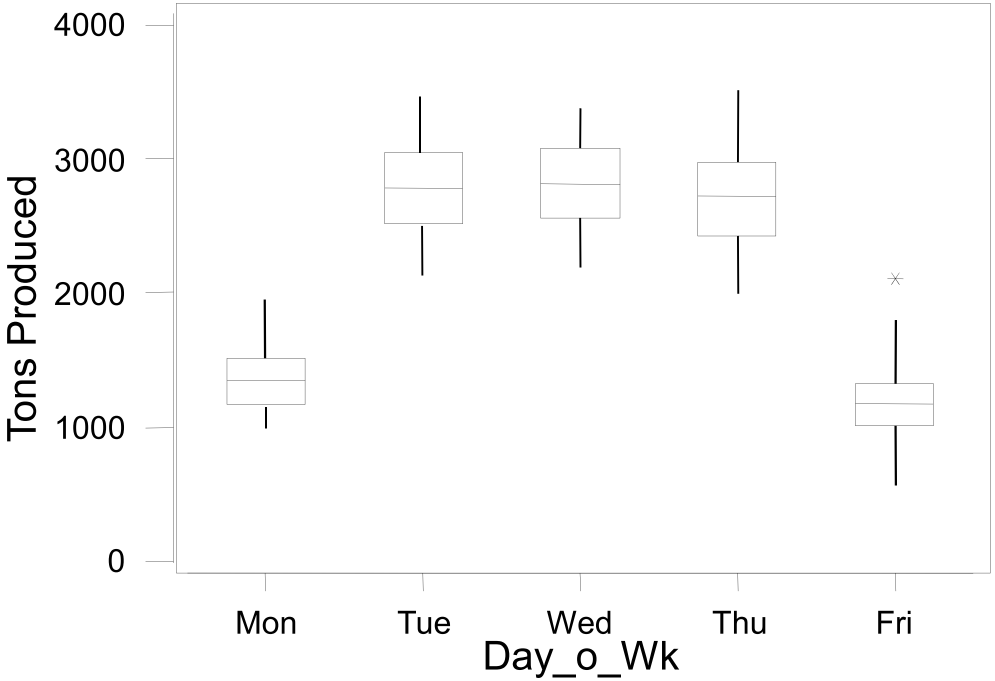
Box Plots—Shorthand Histograms

Box plot and dot plot of the same sets of data



Advantages of Box Plots

- Box plots let you look at the shape, center, and spread of many sets of data at the same time
- This allows you to look for similarities and differences across processes or strata



- These data show the daily volume of paper produced at a paper mill, stratified by day of the week
- What conclusions do you draw?

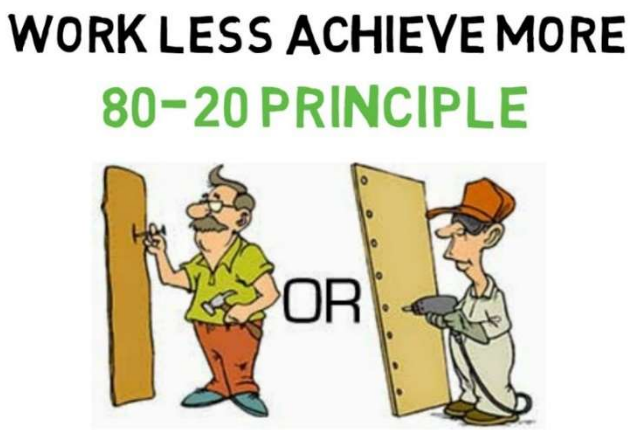
Anexas Consultancy Services

Minitab Exercises

Data Analysis II,
Part 2: Pareto Charts

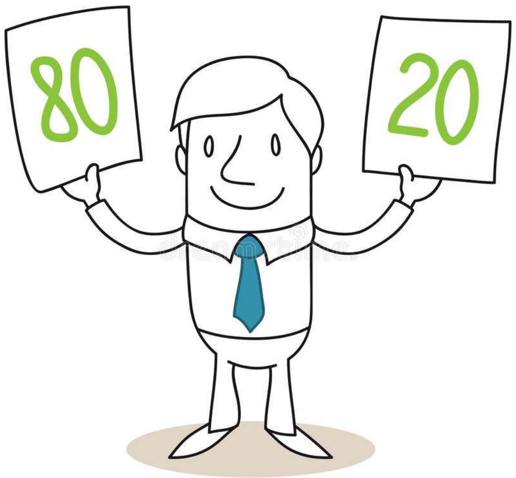
Pareto Charts: Uses

- Understand the pattern of occurrence for a problem
- Judge the **relative impact** of various parts of a problem
- Track down the biggest contributors to a problem
- Decide where to focus efforts

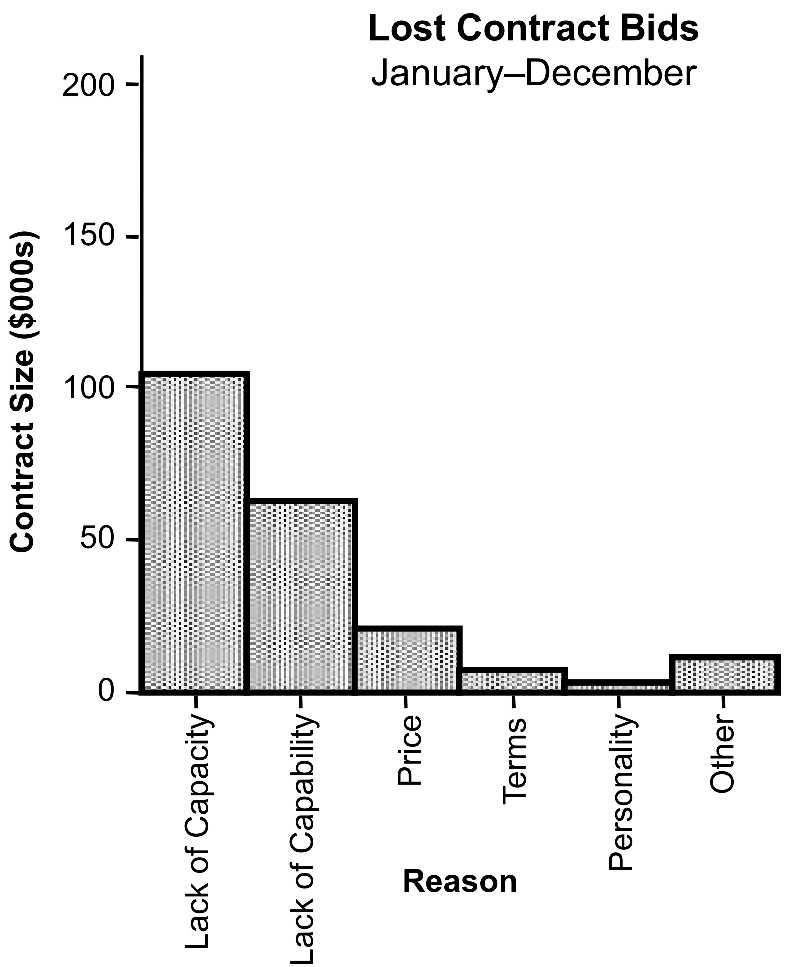


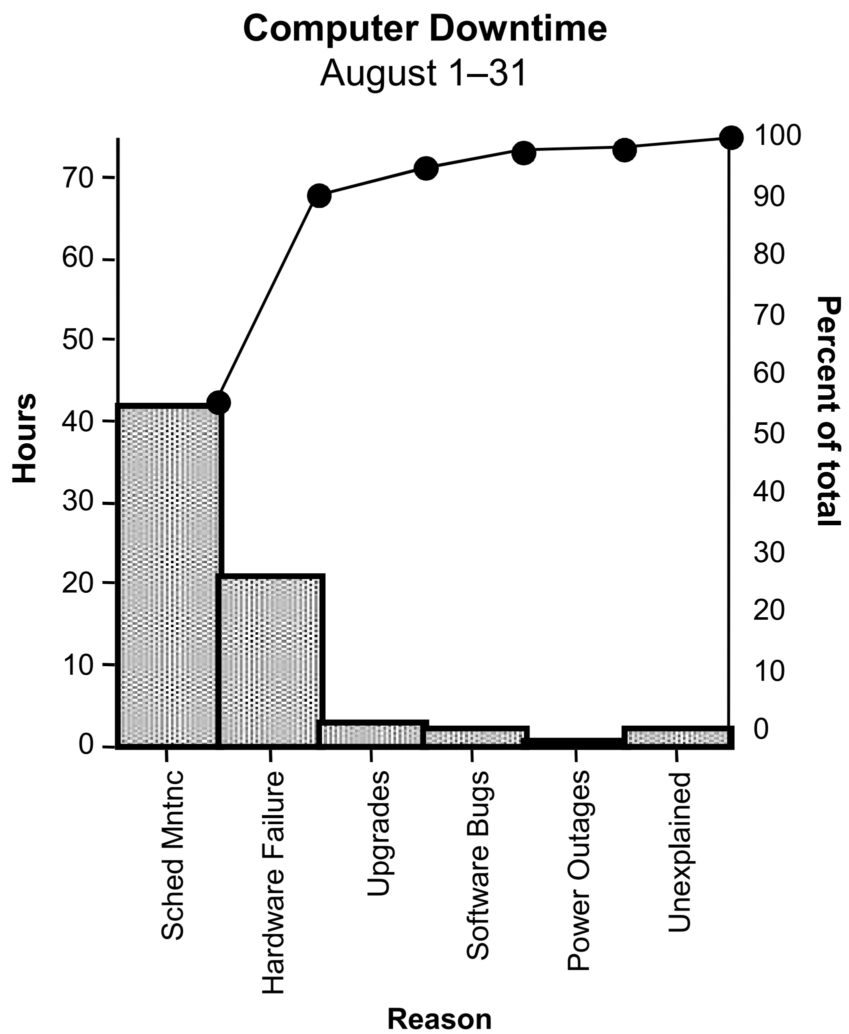
The Pareto Principle

- The Pareto principle, often called the "80/20 rule," says that, in many situations, roughly 80% of the problems are caused by only 20% of the contributing factors
- The Pareto principle implies that we can frequently solve a problem by identifying and attacking its "vital few" sources



Examples of Pareto Charts





Anexas Consultancy Services

Determining Process Sigma Level

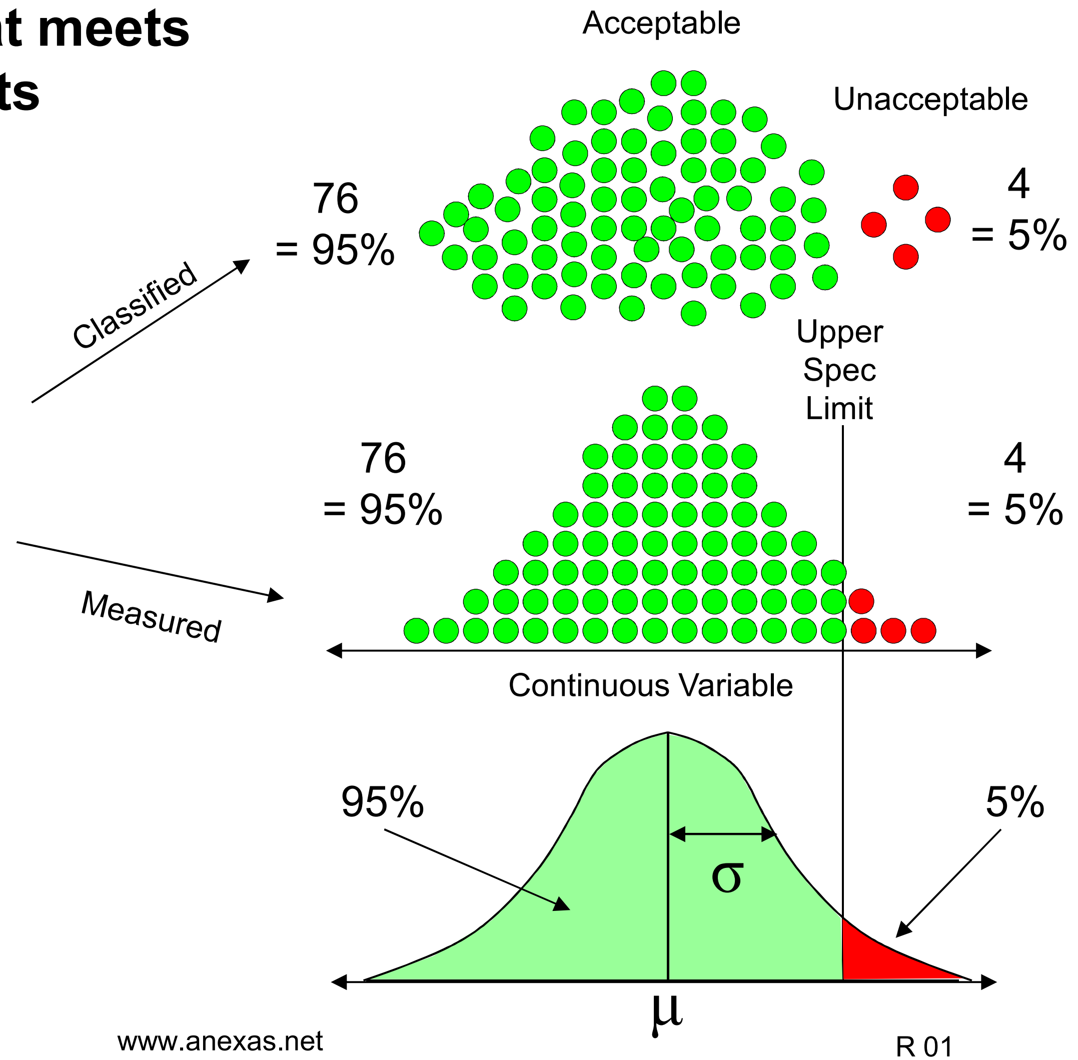
Goals

- Explain the value of measuring process performance
- Understand the various ways to measure process performance
- Calculation of Sigma level using DPMO method
- Automated Sigma level calculator

Process Yield

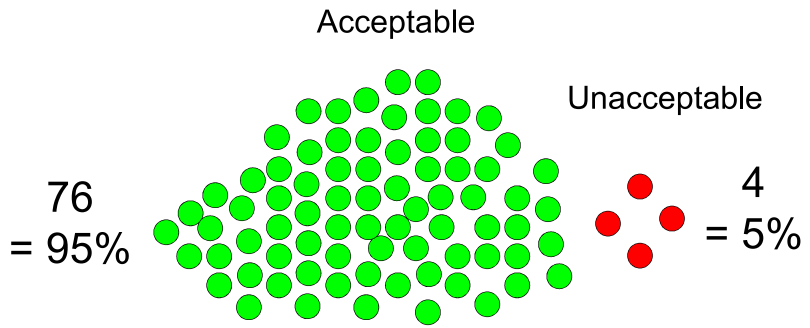
Percentage of output that meets customer requirements

- Method 1: Actual count
- Method 2: Estimated yield (continuous only)



Actual Count Method

- It involves simple and straightforward counting
- However, there must be at least five units in each category:
  - Usually there is no problem finding five good units
  - When quality is already good, large sample sizes may be required in order to find five bad units

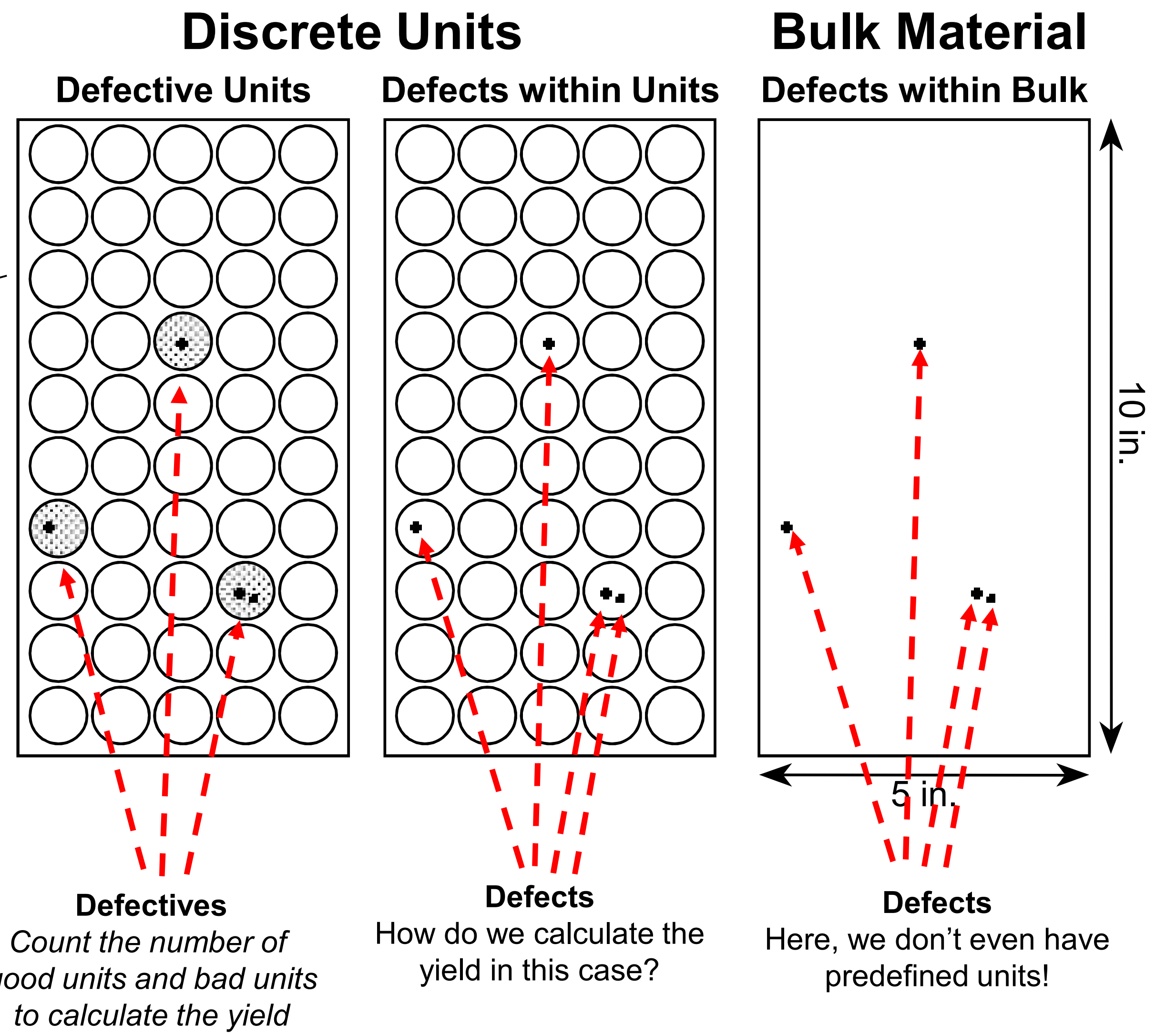


Defects and Defectives

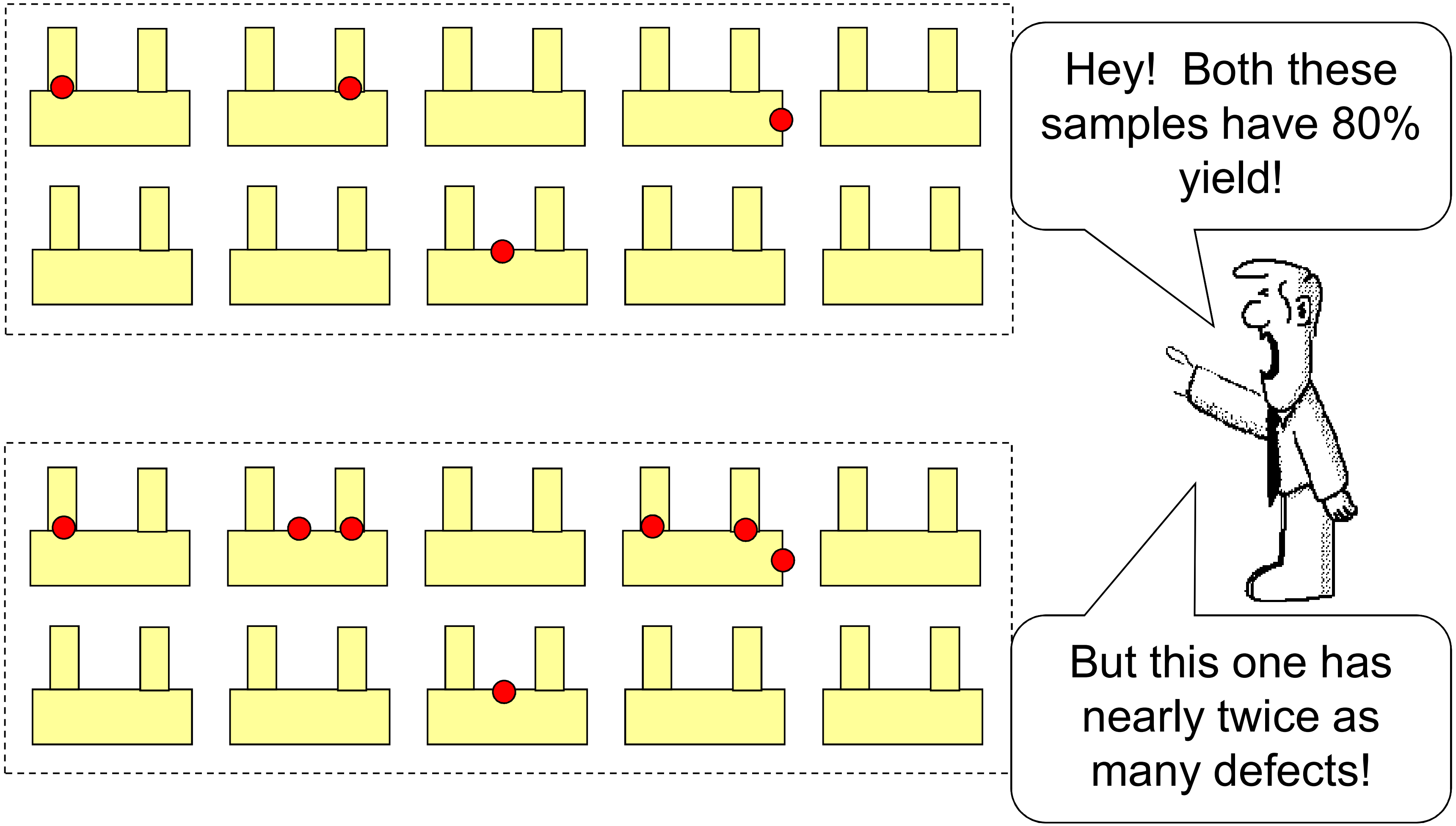
Unit: The item produced or processed

Defective: A unit of (unsalable) output that contains one or more defects

Defect: A feature that does not meet customers' requirements



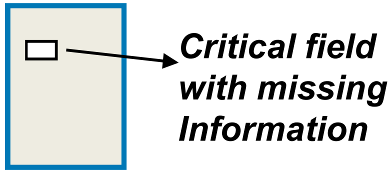
Difficulty: Multiple Defects per Unit?



Sigma Level Calculation

Unit: the item produced or processed

Defect: any event that does not meet the specification of a CTQ as defined by the customer



Defect opportunity: any event which can be measured that provides a chance of not meeting a customer requirement (specification)

Calculate process sigma : formula

Calculate the number of Defects Per Million Opportunities

$$DPMO = \frac{\text{(No. of Defects)}}{\text{No. Of Units x No. of opportunities}} \times 1\ 000\ 000$$

In the Sigma table, look at the Sigma value relating to the DPMO determined

Sigma Level Table

Long term Yield Rendement Long terme	Process Sigma Sigma du processus	Defects per 1,000,000 Défauts par 1.000.000	Long term Yield Rendement Long terme	Process Sigma Sigma du processus	Defects per 1,000,000 Défauts par 1.000.000
99.99966%	6.0	3.4	93.320%	3.0	66,800
99.9995%	5.9	5	91.920%	2.9	80,800
99.9992%	5.8	8	90.320%	2.8	96,800
99.9990%	5.7	10	88.50%	2.7	115,000
99.9980%	5.6	20	86.50%	2.6	135,000
99.9970%	5.5	30	84.20%	2.5	158,000
99.9960%	5.4	40	81.60%	2.4	184,000
99.9930%	5.3	70	78.80%	2.3	212,000
99.9900%	5.2	100	75.80%	2.2	242,000
99.9850%	5.1	150	72.60%	2.1	274,000
99.9770%	5.0	230	69.20%	2.0	308,000
99.9670%	4.9	330	65.60%	1.9	344,000
99.9520%	4.8	480	61.80%	1.8	382,000
99.9320%	4.7	680	58.00%	1.7	420,000
99.9040%	4.6	960	54.00%	1.6	460,000
99.8650%	4.5	1,350	50%	1.5	500,000
99.8140%	4.4	1,860	46%	1.4	540,000
99.7450%	4.3	2,550	43%	1.3	570,000
99.6540%	4.2	3,460	39%	1.2	610,000
99.5340%	4.1	4,660	35%	1.1	650,000
99.3790%	4.0	6,210	31%	1.0	690,000
99.1810%	3.9	8,190	28%	0.9	720,000
98.930%	3.8	10,700	25%	0.8	750,000
98.610%	3.7	13,900	22%	0.7	780,000
98.220%	3.6	17,800	19%	0.6	810,000
97.730%	3.5	22,700	16%	0.5	840,000
97.130%	3.4	28,700	14%	0.4	860,000
96.410%	3 .3	35,900	12%	0.3	880,000
95.540%	3.2	44,600	10%	0.2	900,000
94.520%	3.1	54,800	8%	0.1	920,000

Automated Sigma Level Calculator given in Template

Double click on the spreadsheet and enter data in the the shaded cells.

<u>Define the following</u>

CTQ:	your customer CTQ
Target:	your customer required target
Defect:	Describe here how you would identify a defect
Unit:	How do you define a unit
Opportunity:	What is the rationale behind the # of opportunities

DPMO

				enter
1	Number Of Units Processed		N=	100
2	Total Number Of Defects Made	(Include Defects Made And Later Fixed)	D=	20
3	Number Of Defect Opportunities	Per Unit	O=	4
4	Solve For Defects Per Million Opportunities			50000
5	Sigma will calculate		Sigma=	3.14

Some Rules for Counting Opportunities

- To facilitate before/after comparisons:
  - Use the same opportunity definitions as have been used in the past, provided they are operational
  - Keep the same number of opportunities per unit

But what if my solution *eliminates* an opportunity?

That's great mistake-proofing! But keep the eliminated opportunity *in your calculations*, so your Before/After comparison is made on the same basis.

DPMO: Making DPO "Visible"

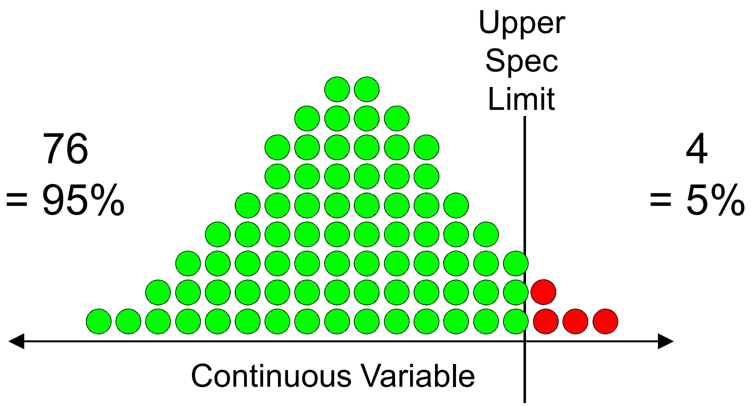
- Defects per million opportunities (DPMO)
- This is "scaling up" to make the number "visible"

But what if I don't produce a million units or opportunities?

You don't need a sample of 100 in order to calculate percentage, which means "per hundred." It's just a way of clearing out decimal places.

Process Yield: Continuous Variables (Actual Count)

- For continuous variables, we have two ways to calculate yield:
  - The first is simple and straightforward counting, as before
  - But there must be at least five units in each category (in spec and out of spec):
    - Usually there is no problem finding five units in spec
    - When quality is already good, larger sample sizes may be required to find five units that are out of spec



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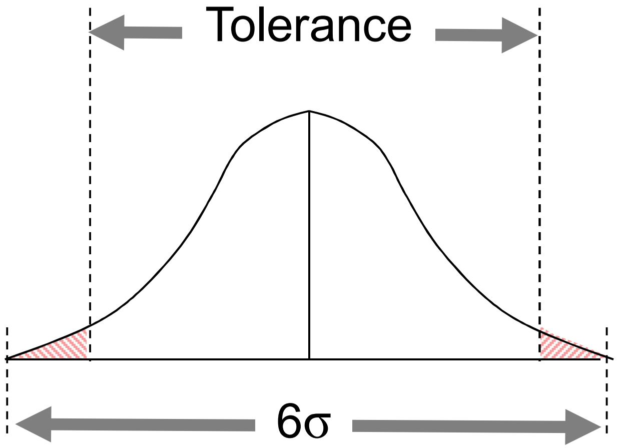
Process Capability Indices

Capability Indices

- **Specification limits:** what the process must do
- **Statistical distribution:** what the process can do
- **The collision:** when what we **can** do is not as good as what we **must** do:

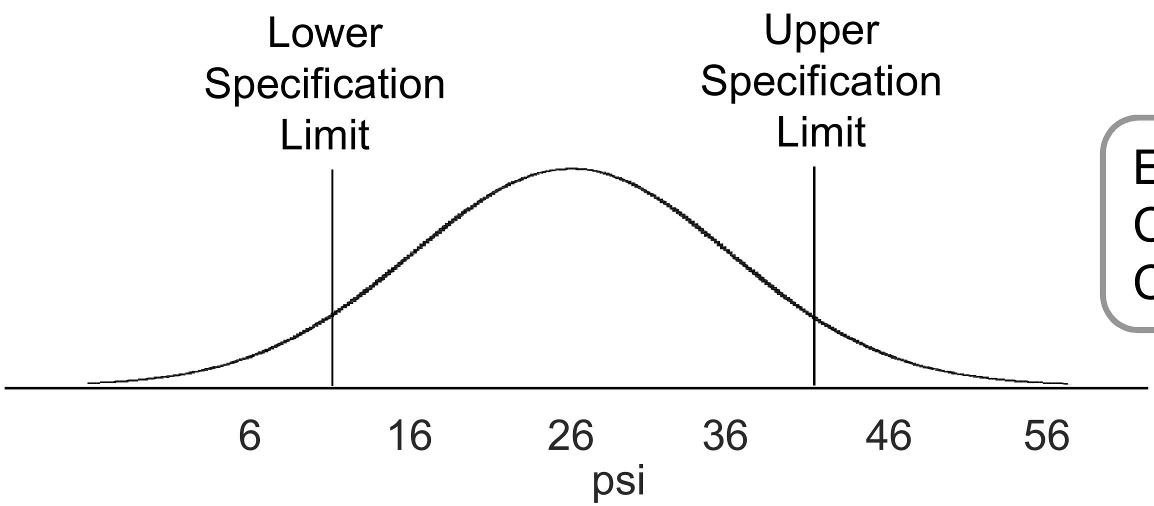


$$Cp = \frac{\text{Tolerance}}{6\sigma}$$

Design capability index: ratio of tolerance to process variation

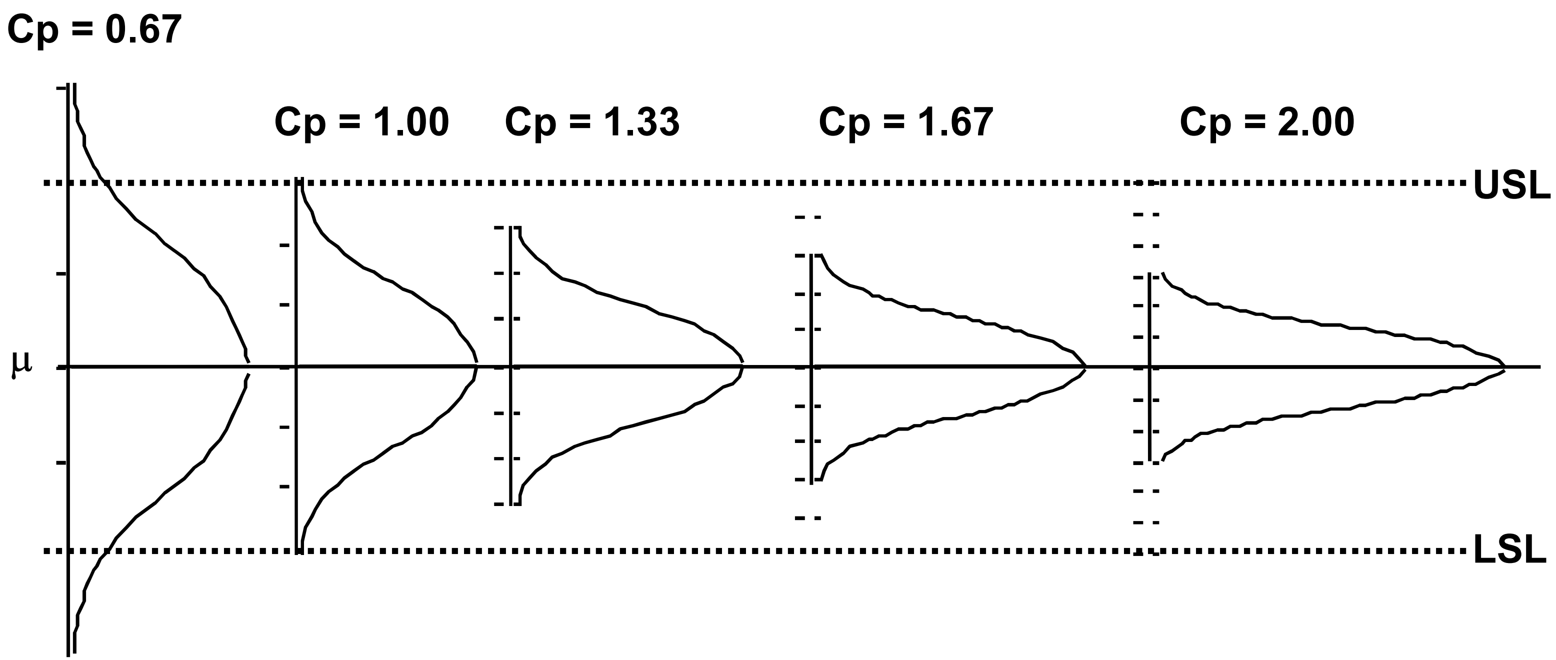
Design Capability Index Cp: Example

- Specification limits: 10–42 psi seal strength
- Process standard deviation: s = 10



Example:
Cp = (4210) / (6 x 10)
Cp = 32 / 60 = 0.533

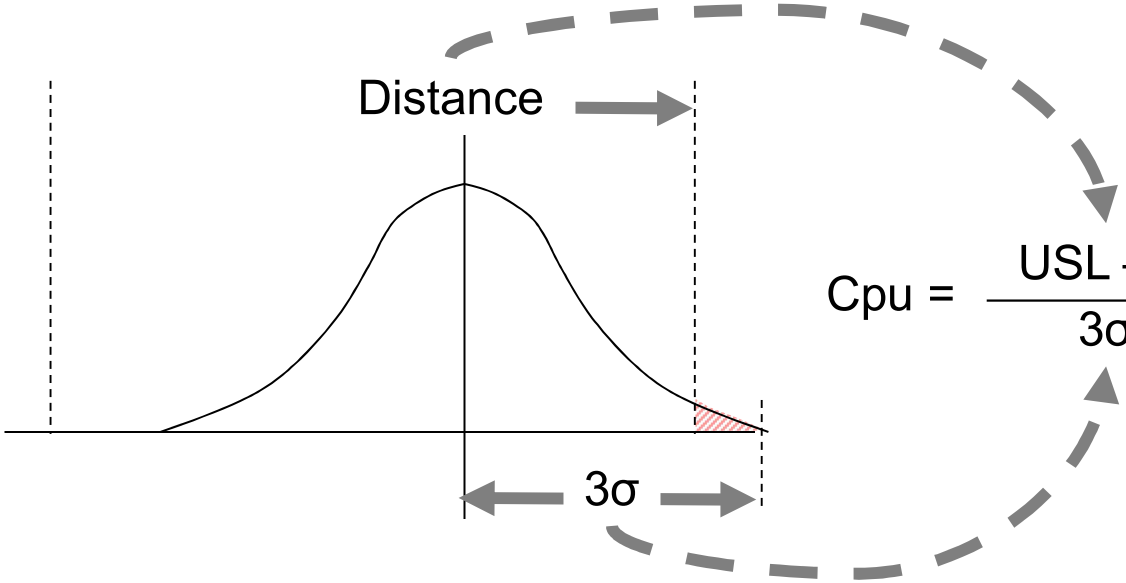
Design Capability Index Cp: Example, cont.



- Cp < 1 means the distribution does not fit between the specification limits
- Cp = 1 means it fits (except for the tails)
- Cp = 1.33 means the distribution occupies three-quarters of the tolerance range
- Cp = 1.67 means the distribution occupies 60% of the tolerance range
- Cp = 2.00 means the distribution occupies half the tolerance range

Difficulty: What If the Process Is Off-Centered?

- Cpk takes the targeting (mean) of the process into account:
  - Distance from the mean to the nearest spec limit
- Cpk = min{Cpu, Cpl} where Cpu and Cpl are calculated for the upper limit and lower limit, respectively

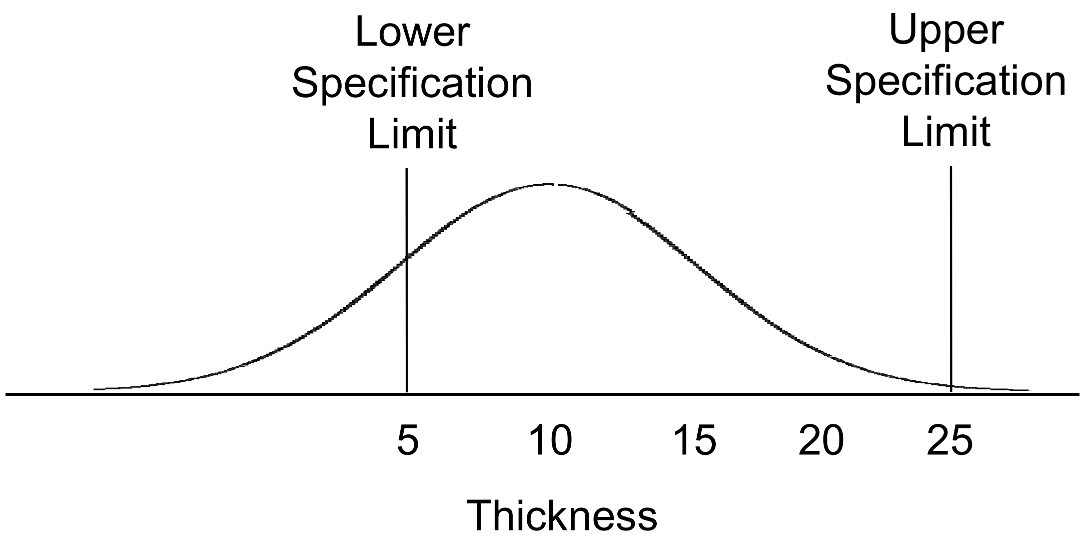


$$Cpu = \frac{USL - \overline{X}}{3\sigma}$$

Process capability index: ratio of distance from spec to process variation

Process Capability Index Cpk: Example

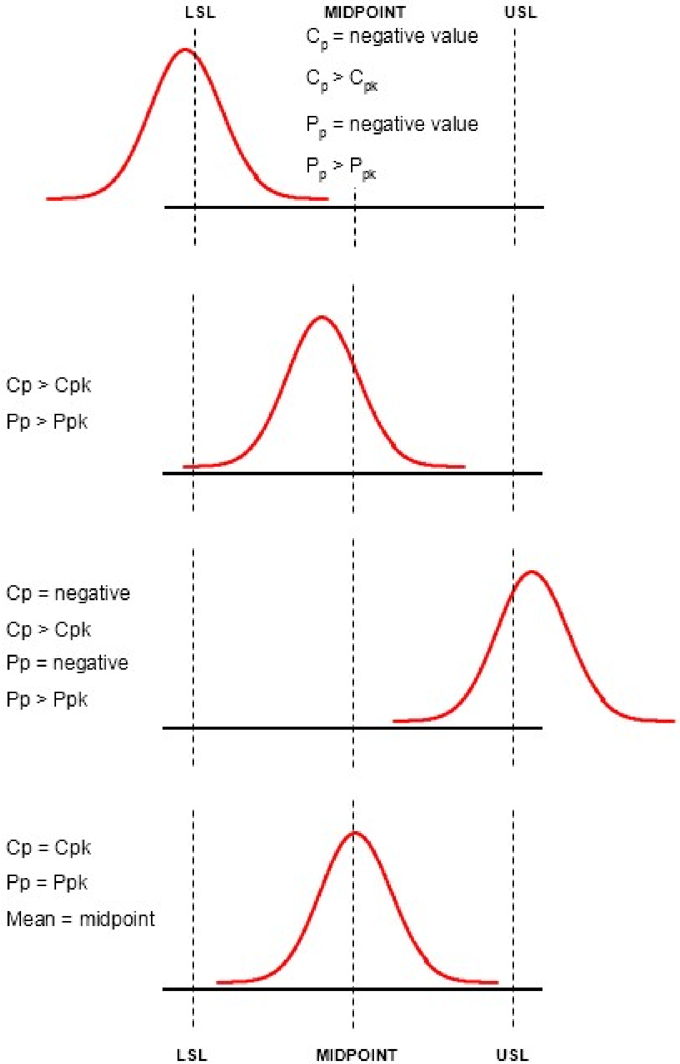
- Specification limits: 5–25 cm thickness
- Process mean: X = 10
- Process standard deviation: s = 5



Cpu = (2510) / (3*5) = 1
Cpl = (105) / (3*5) = 0.333
Cpk = minimum{CPU,CPL}
Cpk = 0.33

- Calculate for upper limit (Cpu) and lower limit (Cpl)
  - Cpk is the minimum of the two

Process Capability Indices



Drawbacks of Capability Indices

- They apply only to continuous variables:
  - There is no index for discrete variables
- One index number per variable:;
  - There is no "overall index"
- Assumes Normal distribution

TDU: Total Defects per Unit

- Calculate proportion out of spec for each continuous quality
- Calculate DPU for all discrete qualities combined
- Add them together:

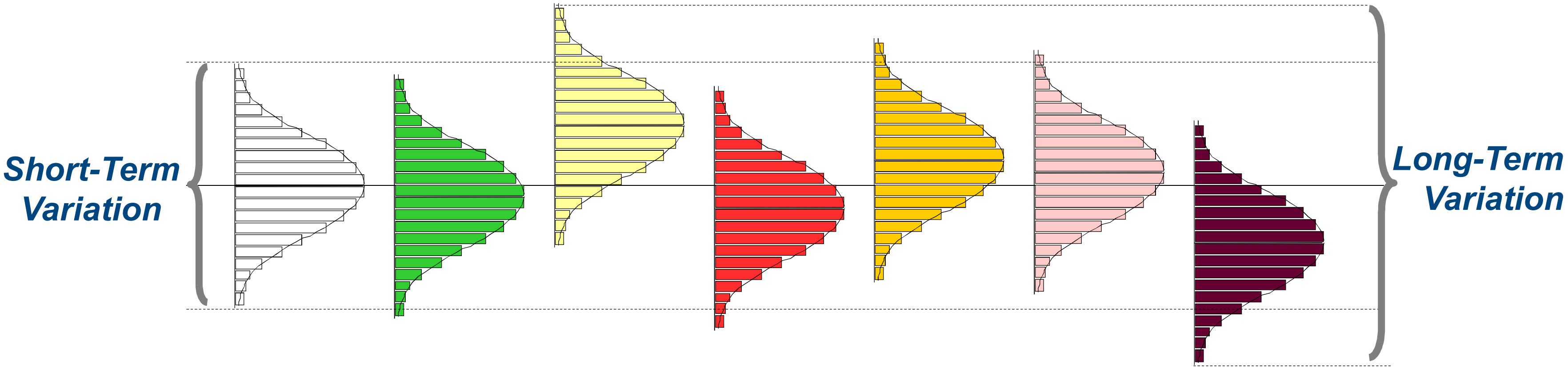
Bag thickness:	0.005
Bag strength:	0.002
Discrete DPU:	0.010
TDU:	0.017

- Rolled throughput yield: RTY = e-TDU:

RTY = exp (-0.017) = 0.983 = 98.3%

One Last Difficulty: Process Shift

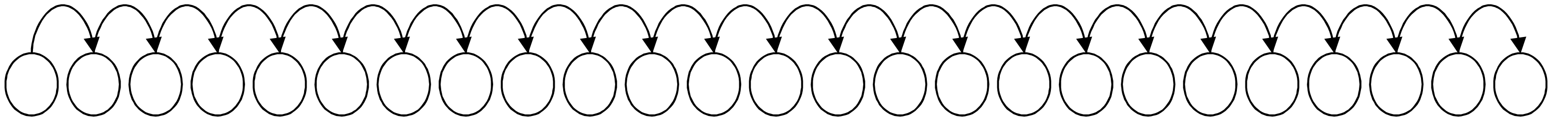
- Normal curve percentiles assume no shift in the mean
  - But even well-controlled processes experience some shift:



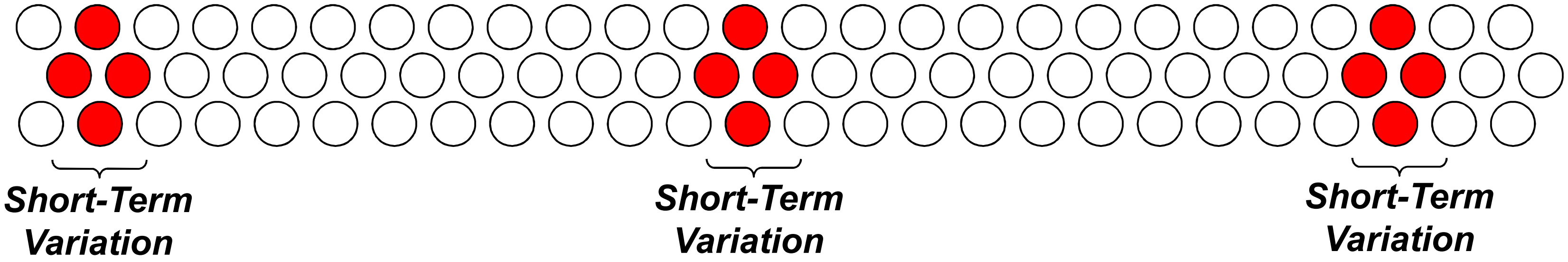
- **Short-term variation:** variation from cycle to cycle of process
- **Long-term variation:** includes time-to-time shifting of process:
  - Typically greater than short-term variation
- Magnitude of difference is the "shift"

Long-Term Variation vs. Short-Term Variation

- **Long-term variation** is the standard deviation of an entire data series over “a reasonable period of time”
- **Short-term variation** can be calculated in three ways:
  - Serial production: moving ranges



  - Mass production: subgroup ranges

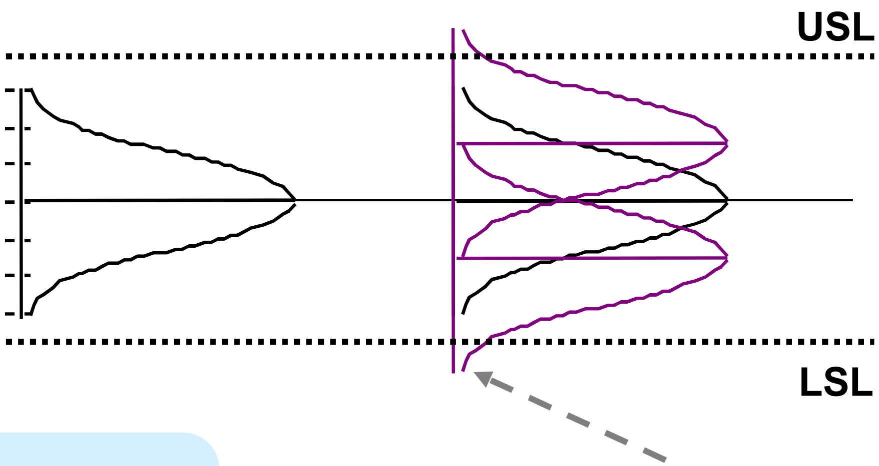


  - Selecting time periods in a data series when the process seems especially stable

Effect of Long-Term Variation on Yield

Random Process Variation

Imperfect Process Control



Process seems very capable of holding the specs

But when shift is taken into account, there are problems

- We need to evaluate the process performance, taking long-term shift into account

Process Performance vs. Process Capability

- Process performance index uses the same formulas:
  - But with long-term standard deviation instead of short-term

Capability Index (short-term st. dev.)	Performance Index (long-term st. dev.)
$C_p = \frac{USL - LSL}{6s_{ST}}$	$P_p = \frac{USL - LSL}{6s_{LT}}$
$C_{pu} = \frac{USL - \overline{X}}{3s_{ST}}$	$P_{pu} = \frac{USL - \overline{X}}{3s_{LT}}$
$C_{pl} = \frac{\overline{X} - LSL}{3s_{ST}}$	$P_{pl} = \frac{\overline{X} - LSL}{3s_{LT}}$
$C_{pk} = \min\{C_{pu}, C_{pl}\}$	$P_{pk} = \min\{P_{pu}, P_{pl}\}$

Takes targeting into account

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Sigma Performance Level

Sigma Performance Level

- Sigma performance level is an all-inclusive process/product performance indicator figure
  - Includes capability and shift
  - Covers discrete and continuous variables
- Sigma performance level = 3*Cpk
- Sigma short-term performance level = Z-score + 1.5
- Even if dealing with discrete variables, we use the Z-score that corresponds with the yield
  - This gives us the capability if there were no shift
- Add 1.5 to the Z-score as a “standard amount of shift”

Calculating Process Performance

- All of these calculations have been automated for convenience
- Open the Excel file: ***PrCapCal***
- Go to the sheet: Method 1: Yield and Sigma

Interpreting the Excel Spreadsheet

Method 1: Yield and Sigma

1. Determine number of defect opportunities per unit	**O** =	10
2. Determine number of units processed	**N** =	453
3. Determine total number of defects made (include defects made and later fixed)	**D** =	4
4. Calculate Defects Per Opportunity	**DPO** $= \frac{D}{N \times O}$ =	0.00088
5. Calculate Yield	**Yield** = (1 – DPO) x 100 =	99.912%
6. Look up Sigma in the Process Sigma Table	**Process Sigma** =	4.63

1. Enter the number of opportunities per unit (O)

2. Enter the number of units fully inspected (N)

3. Enter the number of defects found in the inspections (D)

4. Spreadsheet returns the opportunity-based yield…

5. … and the sigma performance level

Interpreting the Excel Spreadsheet, cont.

Method 2: Process Capability

	Enter			
Xbar	10			
S_{ST}	4			
S_{LT}	5			
Target			Delete if no Target	
USL	14		Delete if no USL	
LSL	5		Delete if no LSL	
	1.83	sigma		
	370511	ppm	264305	ppm
	62.949%	LT yld	73.569%	Pot yld
	0.27	Ppk	0.33	Cpk
	0.33	Z LT	0.63	Z ST
	0.3	shift		

1. Enter the process mean, X-bar

2. Enter the *short*-term st. dev.

3. Enter the *long*-term st. dev.

4. Enter the specification limits, as appropriate.
NOTE: Be sure to delete entries if there is no limit or target

Interpreting the Excel Spreadsheet, cont.

Method 2: Process Capability

	Enter		
Xbar	10		
SST	4		
SLT	5		
Target		Delete if no Target	
USL	14	Delete if no USL	
LSL	5	Delete if no LSL	
	1.83 sigma		
	370511 ppm	264305 ppm	
	62.949% LT yld	3.569% Pot yld	
	0.27 Ppk	0.33 Cpk	
	0.33 Z LT	0.63 Z ST	
	0.3 shift		

5. Sigma performance level

6. Defectives in ppm

7. Long-term yield, based on performance

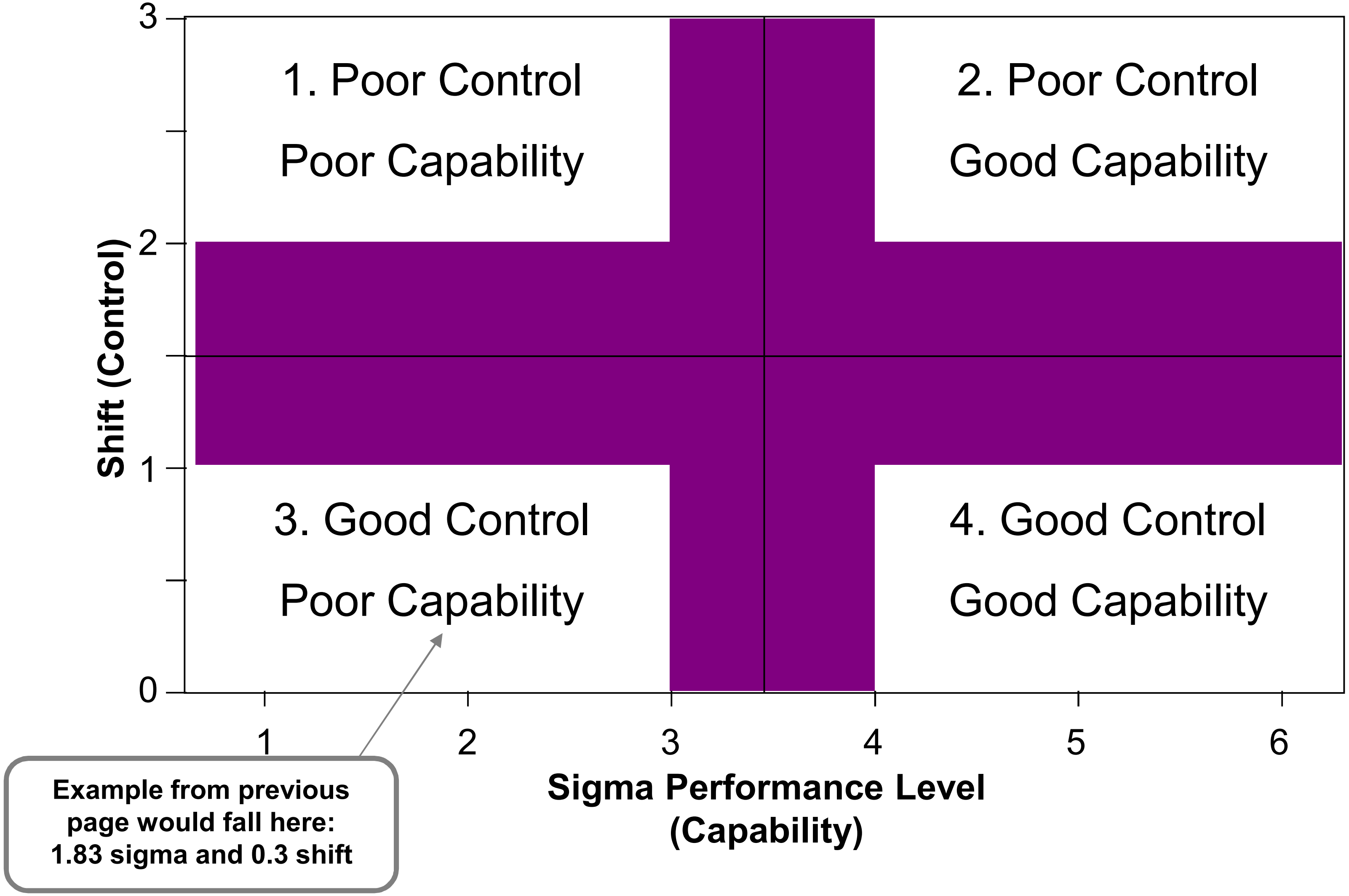
8. Ppk, the long-term performance

9. Z-score for long-term variation

10. Amount of shift (Zst – Zlt)

11. Potential yields and capabilities, if the process were in perfect control

Looking at Sigma and Shift



Exercise: Calculating Yield

Objective: Practice using Method 1 to calculate yield:

- Open ***PrCapCal*** Excel Spreadsheet
- Go to Method 1: Yield & Sigma

Instructions:

- Compute the yield for each of the following situations:
  - 5000 units, 1 opportunity per unit, 250 defects
  - 187 units, 3 opportunities per unit, 209 defects
  - 1000 units, 21 opportunities per unit, 15 defects
- A table has been provided below to aid in your calculations

Time: 5 minutes

Exercise: Calculating Yield, cont.

Objective: Practice using Method 2 to calculate yield:

- Open ***PrCapCal*** Excel Spreadsheet
- Go to Method 2: Process Capability

Instructions:

- Calculate yield for the situations described below
- Data are roughly Normally distributed:

$\overline{X} = 28$	s = 2.9	USL = 30	LSL = 25
$\overline{X} = 50$	s = 10	USL = 35	LSL = none
$\overline{X} = -4.7$	s = 13	USL = 15	LSL = -15

Time: 5 minutes

Summary

- Yield: Actual count method: 1 – p:
  - Difficulty: Multiple defects in a unit
- DPU: D/N:
  - Difficulty: Comparing processes with different complexities
- Opportunity-based yield: 1 – D/(N*O):
  - Difficulty: Small sample sizes typical of continuous variables
- Yield: Normal approximation method: Cp:
  - Difficulty: Non-Normal data (transformations not covered)
  - Difficulty: Process is off-centered

Summary, cont.

- Capability index: Cpk:
  - Difficulty: Process shift
- Performance index: Ppk:
  - Difficulty: Combining discrete and continuous
- Sigma performance level

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Process/Product Performance Indicators for Efficiency

Cycle Time

Overall Equipment Effectiveness

Cycle Time: Little's Law

$$\textbf{Cycle Time} = \frac{\textbf{Work in Process}}{\textbf{Exit Rate}}$$

- **Exit rate** is the count of how many units leave the system in a given time
- **Work in process** is the count of how many units are in the process at a given time
- **Cycle time** should match the "heartbeat" of the process:
  - Called **takt time**
  - This enables one-piece flow, just-in-time, and other benefits

Example of Little's Law

- The Procurement Department processes 14 orders per hour:
  - There is a backlog of 74 unprocessed orders
  - A 75th order is put into the queue
  - How long must the 75th order wait to be processed?

$$\textbf{5.4 Hours} = \frac{\textbf{75 Orders}}{\textbf{14 Orders per Hour}}$$

Overall Equipment Effectiveness (OEE)

- OEE measures three main equipment production process components:
  - Availability of equipment:
    - Breakdown loss
    - Setup and adjustment loss
  - Performance efficiency:
    - Minor stoppage loss
    - Idling loss
    - Reduced speed loss
  - Rate of quality products:
    - Quality defect and rework loss

Calculating Availability

$$\textbf{Availability} = \frac{\text{Actual operating time}}{\text{Planned operating time}} \times 100$$

- Planned operating time:
  - The daily or monthly time available for operation minus all forms of scheduled stops (e.g., breaks in the production schedule, lunch, rest breaks, stoppage for routine maintenance, team meetings, training, etc.)
- Downtime:
  - The total time taken for unscheduled stoppages (e.g., breakdowns, retooling, changeover, adjustments, changes, etc.)
- Actual operating time:
  - The amount of time the machine is not idle
  - Equals: Planned operating time – Downtime

Calculating Performance Efficiency

$$\textbf{Performance efficiency} = \frac{\text{Actual amount processed}}{\text{Ideal amount processed}} \times 100$$

- Ideal amount processed:
  - The ideal amount that can be processed per time unit (minute, hour, etc.) as determined by equipment design specifications
  - Times the operating time (in minutes, hours, etc.)
- Processed amount:
  - The actual amount processed

Calculating Rate of Quality Products

Rate of quality products

$$= \frac{\text{(Actual amount processed} - \text{Amount defective)}}{\text{Actual amount processed}} \times 100$$

- Amount processed:
  - The total amount of product, good **or** bad, produced in a given amount of time
- Amount defective:
  - The total processed amount that contains defects
- Notice that this is the **first-time yield** for that equipment

OEE: Establishing the Baseline

OEE = Availability

× Performance efficiency

× Rate of quality products

Why Do We Need to Measure OEE?

- Calculates actual effectiveness of equipment
- Accounts for loss factors
- Provides data for improvement
- Makes work easier
- Helps to understand actual plant capacity
- Helps to develop accurate capacity plans
- Helps to attain a world-class benchmark and beyond

Calculating OEE

1. Enter data as required

1a. Use the calculator to convert to minutes or units/min

1. AVAILABILITY	
Total Shift Time (in minutes)	480
a) Scheduled Stops *(in minutes)*	
Scheduled lunch break	20
Scheduled rest breaks	10
Routine/preventive maintenance	10
Other:	15
Other:	5
TOTAL (Scheduled Stops)	60
Planned Operating Time (in minutes)	420
b) Unscheduled Stops (Downtime)	
Equipment/die changeover	35
Breakdown	10
Readjustment	45
Stop and inspect	10
Other:	
Other:	
Total (Unscheduled Stops/Downtime)	100
c) Actual Operating Time	320
% AVAILABILITY	**76.2%**

2. PERFORMANCE EFFICIENCY	
Actual Amount Processed	5
Equipment Capacity (Ideal Units per Minute)	0.025
Ideal Amount Processed	8
PERFORMANCE EFFICIENCY	**62.5%**

3. RATE OF QUALITY PRODUCTS (FTY)	
Amount Defective	1
RATE OF QUALITY PRODUCTS	**80.0%**

4. OVERALL EQUIPMENT EFFECTIVENESS
38.1%

The Calculator	
Enter Hours	To get Minutes
1	60
Enter seconds	To get Minutes
60	1
Enter Sec./Unit	To get Units/Min
60	1
Enter Minutes/Unit	To get Units/Min.
40	0.025
Enter Hours/Unit	To get Units/Min.
1	0.016666667

2. Spreadsheet returns

1. **Percentage availability**
2. **Performance efficiency**
3. **Rate of quality products**
4. **OEE**

Exercise: Calculating OEE

Objective: Practice calculating overall equipment effectiveness

Instructions:

- Work in pairs or trios
- Using the data provided below, calculate the OEE

Time: 10 minutes

Answer: Calculating OEE

1. AVAILABILITY	
Total Shift Time (in minutes)	480
a) Scheduled Stops *(in minutes)*	
Scheduled lunch break	30
Scheduled rest breaks	20
Routine/preventive maintenance	30
Other:	
Other:	
TOTAL (Scheduled Stops)	80
Planned Operating Time (in minutes)	400
b) Unscheduled Stops (Downtime)	
Equipment/die changeover	65
Breakdown	50
Readjustment	40
Stop and inspect	
Other:	
Other:	
Total (Unscheduled Stops/Downtime)	155
c) Actual Operating Time	245
% AVAILABILITY	**61.3%**

2. PERFORMANCE EFFICIENCY	
Actual Amount Processed	25
Equipment Capacity (Ideal Units per Minute)	0.2
Ideal Amount Processed	49
PERFORMANCE EFFICIENCY	**51.0%**

3. RATE OF QUALITY PRODUCTS (FTY)	
Amount Defective	5
RATE OF QUALITY PRODUCTS	**80.0%**

4. OVERALL EQUIPMENT EFFECTIVENESS
25.0%

Note: Good units *plus* bad units

The Calculator	
Enter Hours	To get Minutes
1	60
Enter seconds	To get Minutes
60	1
Enter Sec./Unit	To get Units/Min.
60	1
Enter Minutes/Unit	To get Units/Min.
5	0.2
Enter Hours/Unit	To get Units/Min.
1	0.016666667

Summary

- Measures of effectiveness:
  - FTY: First-time yield
  - Cpk: Capability index
  - Sigma performance level
- Measures of efficiency:
  - PCT: Process cycle time
  - OEE: Overall equipment effectiveness

Goals Achieved in this Module

- Explain the value of measuring process performance
- Understand the various ways to measure process performance
- Calculation of Sigma level using DPMO method
- Automated Sigma level calculator

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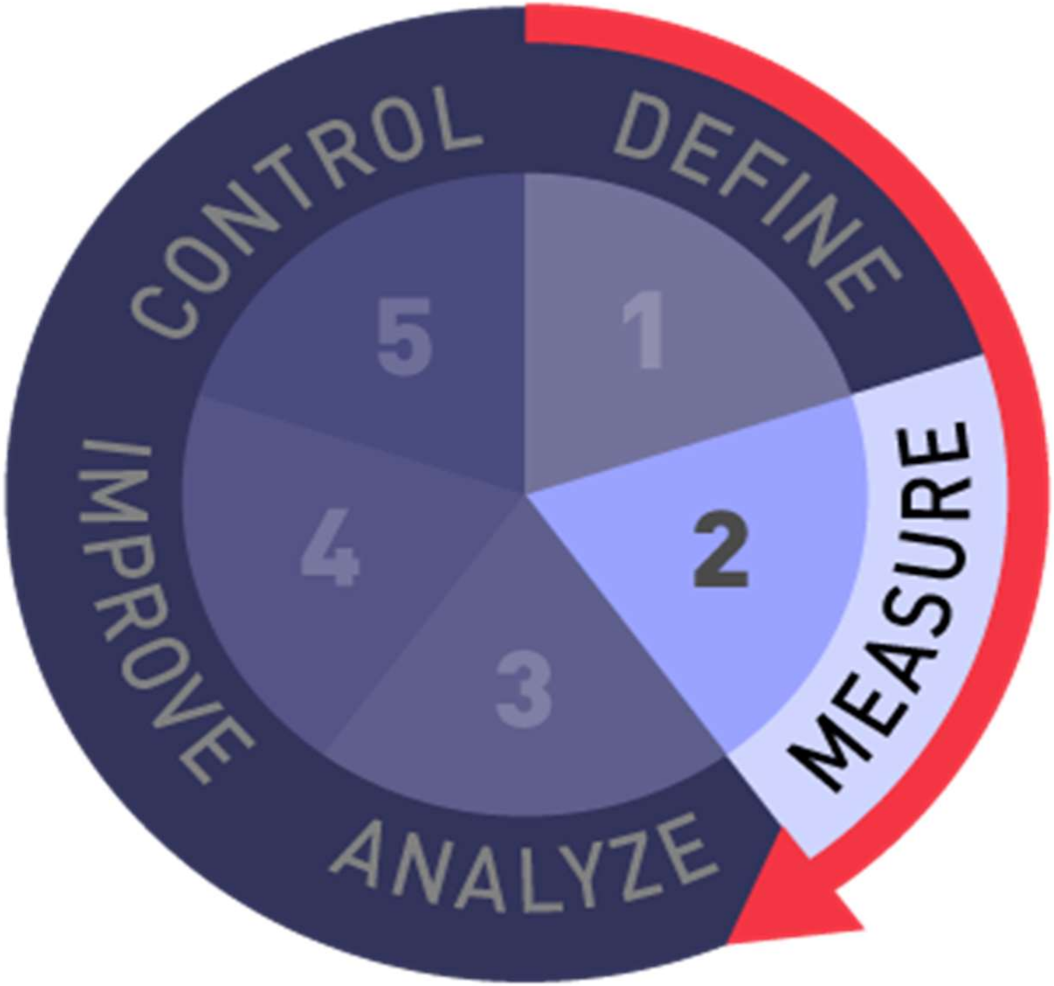
MEASURE: The Current Situation

Review

You Were Here—MEASURE



MEASURE Checklist

- By the end of the MEASURE phase, you should have answered the following questions and have data to demonstrate the following points—please check to be sure that you do:
  - What problems are occurring?
    - Under what conditions do these problems occur?
  - What specifically is the main problem or problems?
    - Focused problem statement
  - What time-related patterns did you see?
  - What special causes of variation were uncovered?
    - Have they been addressed?

MEASURE Checklist, cont.

- By the end of the MEASURE phase, you should have answered the following questions and have data to demonstrate the following points—please check to be sure that you do, cont.:
  - What patterns appeared in the plots of the data?
  - What is the current process sigma for your process?
  - What did the process map of the process reveal?
  - Which bottlenecks appeared?
  - What are the current process parameters?
    - Cycle time, output, etc.

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ANALYZE: Analyze to Identify Causes

Overview

You Are Here—ANALYZE

ANALYZE: Analyze to Identify Causes

- Goal:
  - Identify root causes and confirm them with data
- Output:
  - A theory that has been tested and confirmed

Approach to ANALYZE

Develop a focused problem statement	Brainstorm potential causes	Organize potential causes	Collect data	Statistical methods to quantify cause-effect relationship

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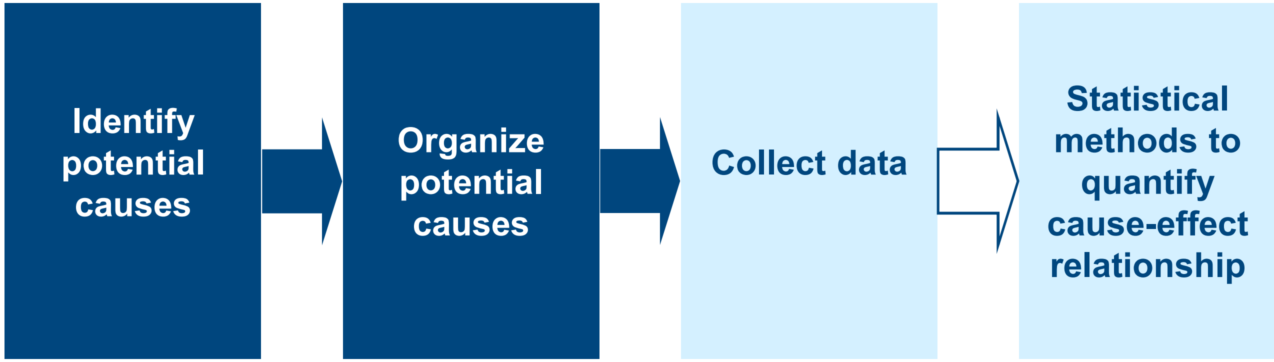
Identifying Potential Causes

You Are Here


Identify potential causes
Organize potential causes
Collect data
Statistical methods to quantify cause-effect relationship

Goals

- Given a focused problem (the output of the MEASURE phase), construct a cause-and-effect diagram that demonstrates causal thinking
- Given a focused problem, create a tree diagram with at least four levels of depth for at least one path

The Why-Why Technique

- To push for root causes, start with your focused problem and then ask "Why" several times
- Example:
  - Focused problem: Customers complain about waiting too long to get connected to staff during lunch hours

Why does this problem happen?
Backup operators take longer to connect callers.

→ **Why** does it take backup operators longer?
Backup operators don't know the job as well as the regular operator/receptionists do.

→ **Why** don't operators know the job as well?
There is no special training; no job aids make up for the gap in experience and on-the-job learning for the backups.

→ **Why** don't they have special training or job aids?
In the past, the organization has not recognized this need.

→ **Why** hasn't the organization recognized the need?
The organization has no system to identify training needs.

Verify each assumption on the spot—where the activity in question is taking place

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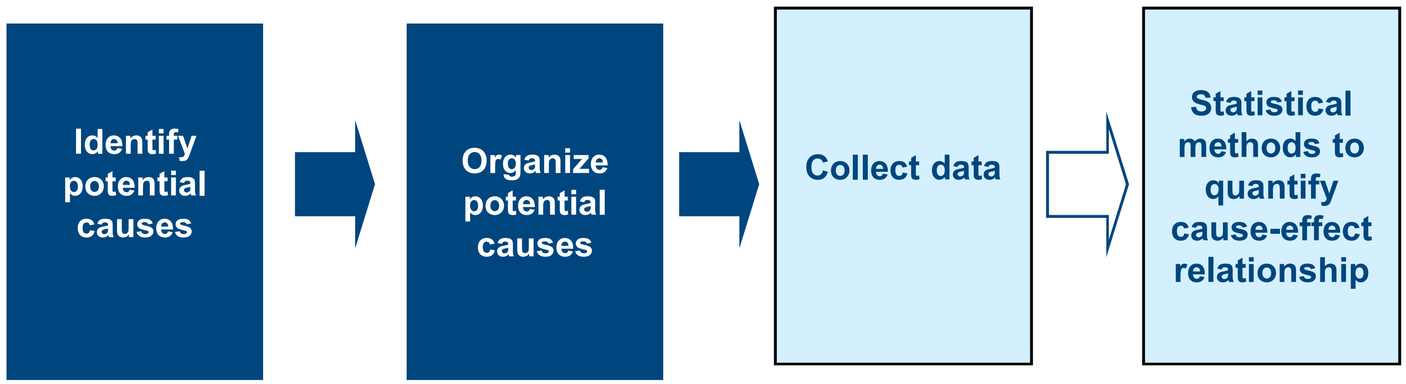
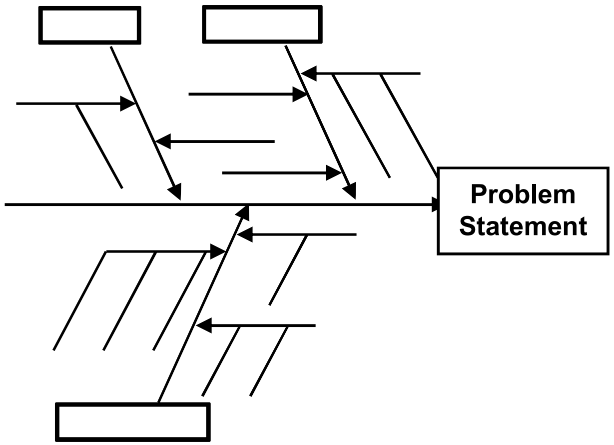
Organizing and Prioritizing Potential Causes



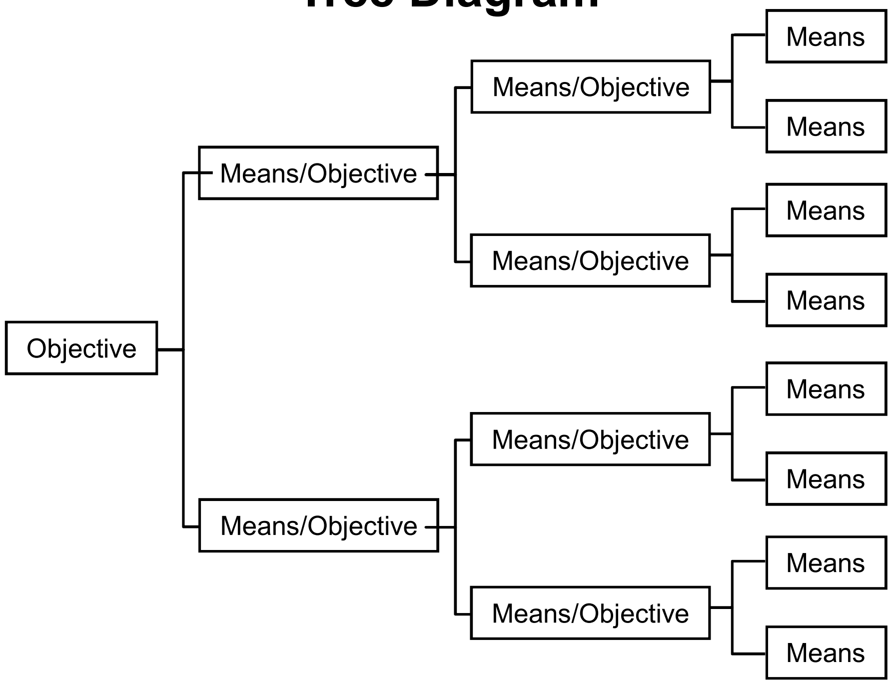
Looking for Relationships

- Graphic displays can help you structure possible causes to find relationships that will shed new light on your problem

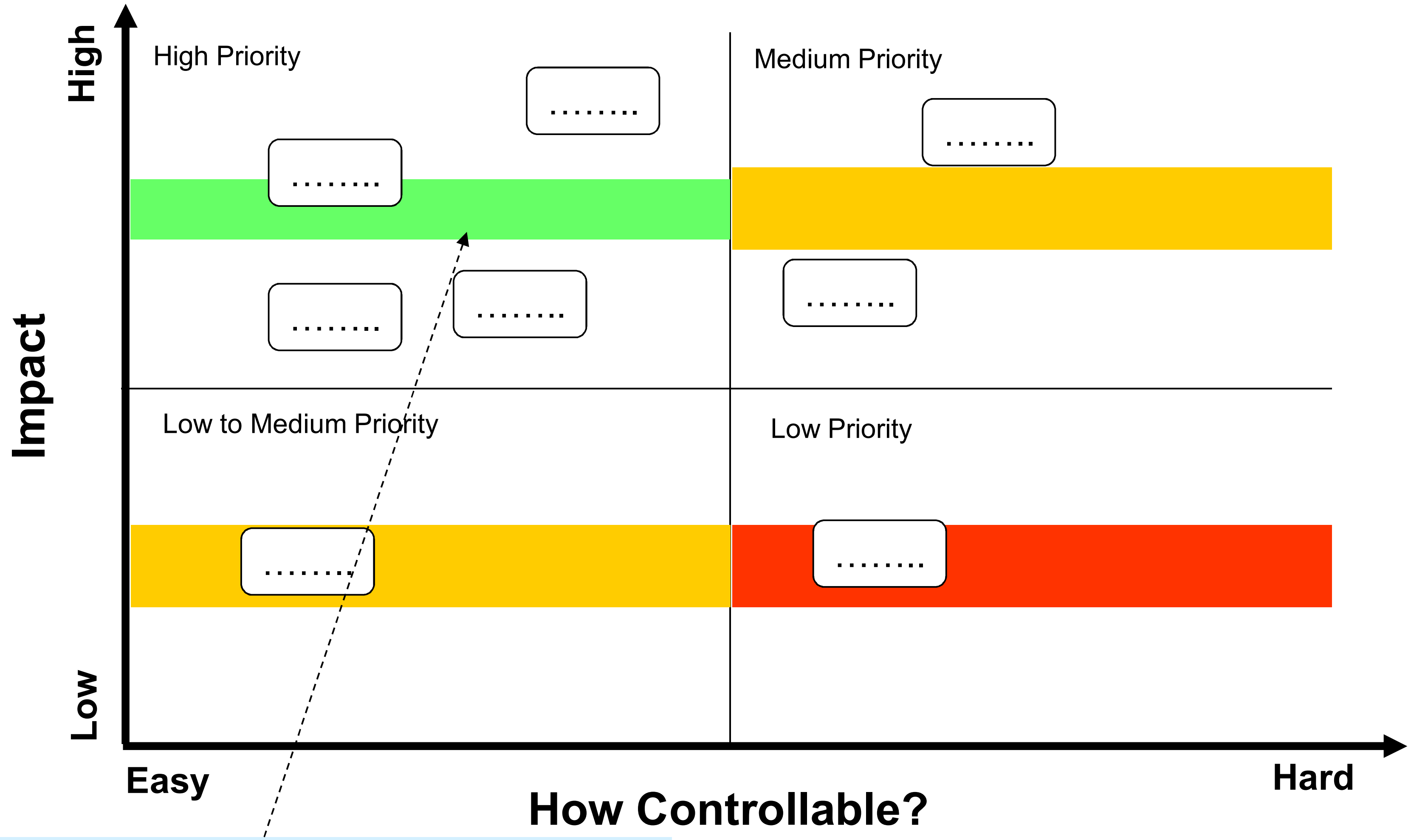
Cause-and-Effect Diagram



Tree Diagram



Prioritizing Input Variables



Focus on low-effort high-impact items

Identifying Potential Causes: Review

- Start with a narrow problem definition
- Brainstorm ideas
- Arrange ideas on a cause-and-effect or tree diagram
- Use the Effort × Impact diagram to narrow the scope of your investigation

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Introduction to Hypothesis Testing

Why Learn Hypothesis Testing?

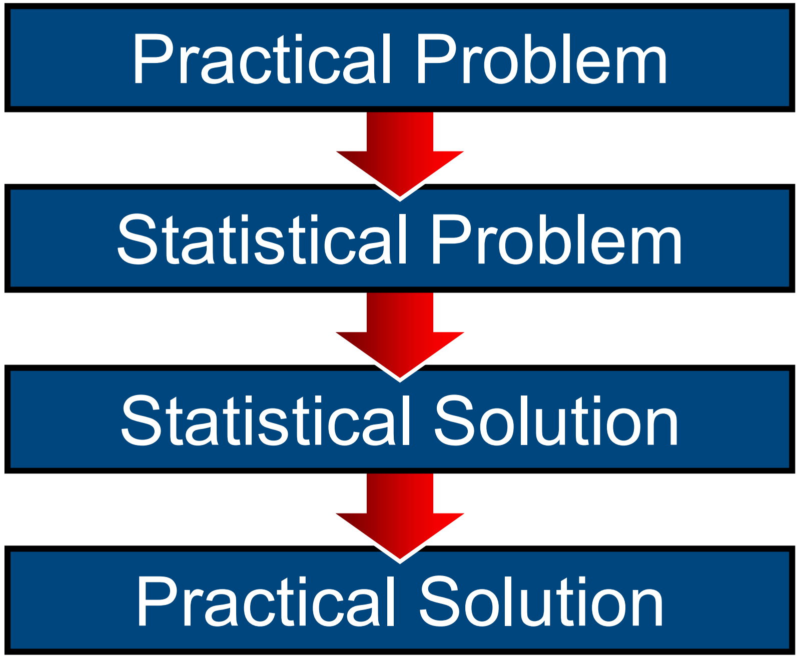
To identify sources of variability using historical or current data:

- Passive: a process is sampled or historic sample data is obtained
- Active: a modification is made to a process and then sample data is obtained

Provides objective solutions to questions which are traditionally answered subjectively

What is Hypothesis Testing?

- A procedure for testing a claim about a population parameter
- Answers practical questions such as:
  - "Is there a real difference between ______ and ______ ?"



What is Hypothesis Testing?

Example:

Practical Problem

Is there a real difference between production costs of Server 1 and Server 2?

Statistical Problem

$H_o: \mu_T = \mu_A$

$H_a: \mu_T \neq \mu_A$

Statistical Solution

T-Test of difference = 0 (vs. not =): T-Value = -0.88 p-Value = 0.390 DF = 17
Fail to reject the null hypothesis

Practical Solution

There is no evidence of significant difference between production costs of Server 1 and Server 2

What is Hypothesis Testing?

- In hypothesis testing, relatively small samples are used to answer questions about population parameters (inferential statistics)
- There is always a chance that the selected sample is not representative of the population; therefore, there is always a chance that the conclusion obtained is wrong
- With some assumptions, inferential statistics allows the estimation of the probability of getting an “odd” sample and quantifies the probability (p-value) of a wrong conclusion

Parameters Versus Statistics

	Population Parameters	Sample Statistics
Mean	μ	x
Standard Deviation	σ	s
Proportion	P	p

- Population parameters (values) are fixed, but unknown
- Sample statistics are used to estimate or infer population values

Hypotheses are statements about population parameters, not sample statistics

Hypothesis Tests

Y	X	Hypothesis Test
Continuous / Variable Data	Attribute / Discrete Data	1-z, 1-t, 2-t, paired t, ANOVA
Attribute / Discrete Data	Attribute / Discrete Data	1-p, 2-p, Chi Square
Continuos / Variable Data	Continuos / Variable Data	Correlation, Regression, Multiple Regression
Attribute / Discrete Data	Continuous / Variable Data	Logistic Regression

Significance Level

Goal: show observed values are so unlikely to come from the same population, that H_o must be wrong

However, even if the values are unlikely there is still a chance that they may occur. The chance they may occur is α.

This is called the significance level (α)

There is an α % chance that we are wrong when we say that Server 1 is more efficient than Server 2

α (Alpha) - Simplified Perspective

Null Hypothesis (H_o) assumed true

e.g., defendant assumed innocent

Prosecuting attorney must provide evidence beyond reasonable doubt that assumption is not true

Reasonable doubt = α

Alpha (α) & Beta (β) Risk

- α-risk
- Risk of finding a difference when there really isn't one

  Type I error or Producers' risk
- β-risk
- Risk of not finding a difference when there really is one

  Type II error or Consumers' risk

Truth Table: α and β Risk

Decision

		Fail to reject H_o	Reject H_o	
Truth	H_o true	Correct Decision CI = 1- α	Type I Error (α-Risk or *false positive)*	→ Producers' Risk
	H_a true	Type II Error (β -Risk or *false negative)*	Correct Decision Power = 1- β	

→ Consumers' Risk

What is p - value?

- The probability of getting sample statistics like the one we observed if our null hypothesis is true
- The chance you will be wrong if you rejected null hypothesis
- Based on an assumed or reference distribution (Z, t, F, etc.)

Decision Criteria

$p < \alpha$, reject the null hypothesis

$p > \alpha$, fail to reject the null hypothesis

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Hypothesis Tests

Hypothesis Tests

Y	X	Hypothesis Test
Continuous / Variable Data	Attribute / Discrete Data	1-z, 1-t, 2-t, paired t, ANOVA
Attribute / Discrete Data	Attribute / Discrete Data	1-p, 2-p, Chi Square
Continuos / Variable Data	Continuos / Variable Data	Correlation, Regression, Multiple Regression
Attribute / Discrete Data	Continuous / Variable Data	Logistic Regression

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Hypothesis Testing of Mean

Steps

Steps in Hypothesis tests:

1. State the null hypothesis (Ho)

   Null Hypothesis is:

   All means are equal (1-z, 1-t, 2-t, paired t, ANOVA) [Cont- Att]

   Y is independent of X (Regression) [Cont –Cont]

   Y is not related to X (1 p, 2p, Chi Square) [Att-Att]

   Y is not related to X (Binary Logistic Regression) [Att-Cont]

2. State the alternative hypothesis (Ha)

   At least one mean is different(1-z, 1-t, 2-t, paired t, ANOVA)

   Y is dependent on X (Regression)

   Y is related to X (1 p, 2p, Chi Square)

   Y is related to X (Binary Logistic Regression) [Att-Cont]

3. Choose alpha value (α = .05). Also known as level of significance. Confidence Level = 1-α

4. Collect data

Steps

Steps in Hypothesis tests:

5. Choose appropriate hypothesis test
6. Get p value
7. If p is < 0.05 , Reject Ho

   If p is > 0.05, Accept Ho

Remember :

If p is low Ho must go

If p is high, Ho must fly

Why Learn Hypothesis Tests of Mean?

Make data driven decisions with defined confidence

Determine if a statistically significant difference of means exists between:

- A sample and a target
- Two independent samples
- Paired samples

What are Hypothesis Tests of Mean?

Test	**Method for analyzing the differences between:**
1 Sample Z	a sample mean and a target value when population standard deviation is known
1 Sample t	a sample mean and a target value when population standard deviation is not known
2 Sample t	means obtained from two independent sample
Paired t	mean differences obtained from paired samples

Note: Above tests are used when the dependent variable (response) is continuous and the independent variable (factor) is discrete

Anexas Consultancy Services

1 Sample z Test

Single Mean Comparison

μ

vs

target value

σ known

Practical Question
(example)

"Is the population statistically different from the target value?"

Statistical Question

H_o: μ = target value

H_a: $\mu \neq$ target value

Business Process Example: Rising Transaction Costs

A financial institution is concerned about rising costs per teller transaction. Leadership of the institution wants to take appropriate action if the population average cost per teller transaction is greater than $1.40.

A random sample of 45 costs per teller transaction produced an average value of $1.45. It is known from previous experience that the population standard deviation of the transaction cost is approximately $0.32.

Analyze the sample data from the file ***Tellercost.mtw*** and determine if we have evidence to show that the population mean cost per teller transaction cost is greater than $1.40.

Example: Rising Transaction Costs

- **Practical Problem**
  - ✓ Did the average cost per transaction increase?
  - ✓ Is the average cost per transaction greater than $1.40?
- **Statistical Problem**
  - ✓ Is there a shift in the mean cost per transaction from the historical average?
  - ✓ Null hypothesis: Average cost is $1.40
  - ✓ Alternate hypothesis: Average cost is greater than $1.40
  - ✓ Is there evidence (at a significance level of 5%) to show that the average cost per transaction has increased? Otherwise we maintain the current belief - i.e., the null hypothesis

Example: Rising Transaction Costs

- State the hypotheses and significance level

  H_o: μ = \$1.40

  H_a: μ > \$1.40

  α = 0.05

- What hypothesis test is appropriate?

  These hypotheses deal with mean values

  Only one factor for examination – rising transaction cost

  Comparing population mean against a target value using one sample data

  Data follows a normal distribution

  σ known, \$0.32

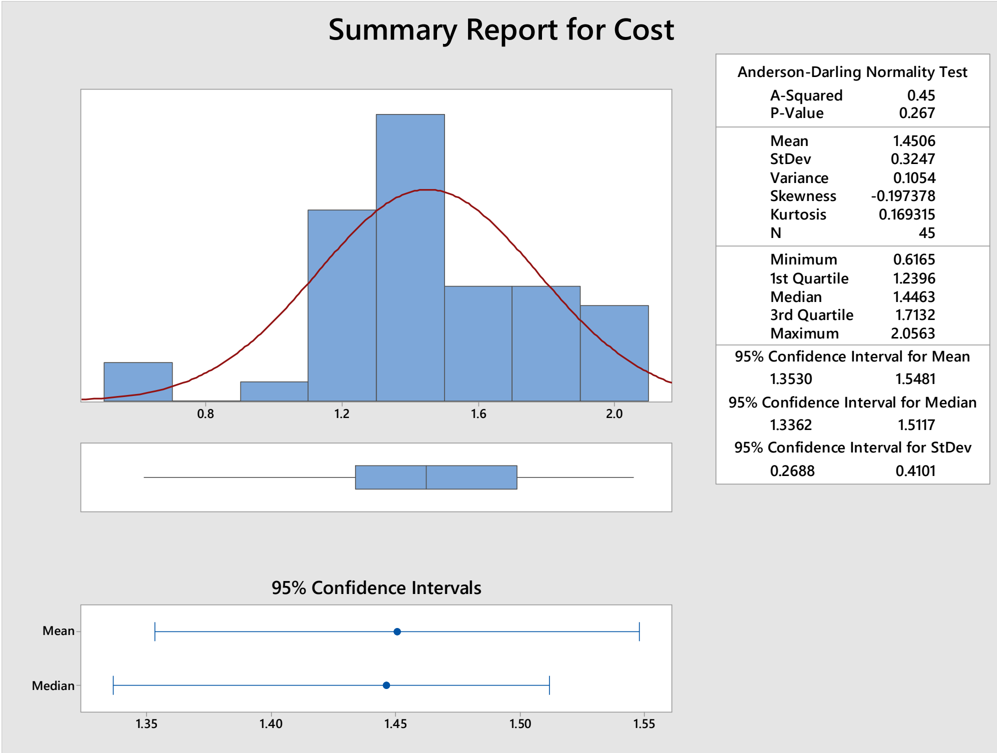
  Use 1-Sample Z-Test

Example: Rising Packing Costs

Practical and Graphical

- Open the file ***Tellercost.mtw***
- What practical questions do you have about this data?
- Evaluate descriptive statistics

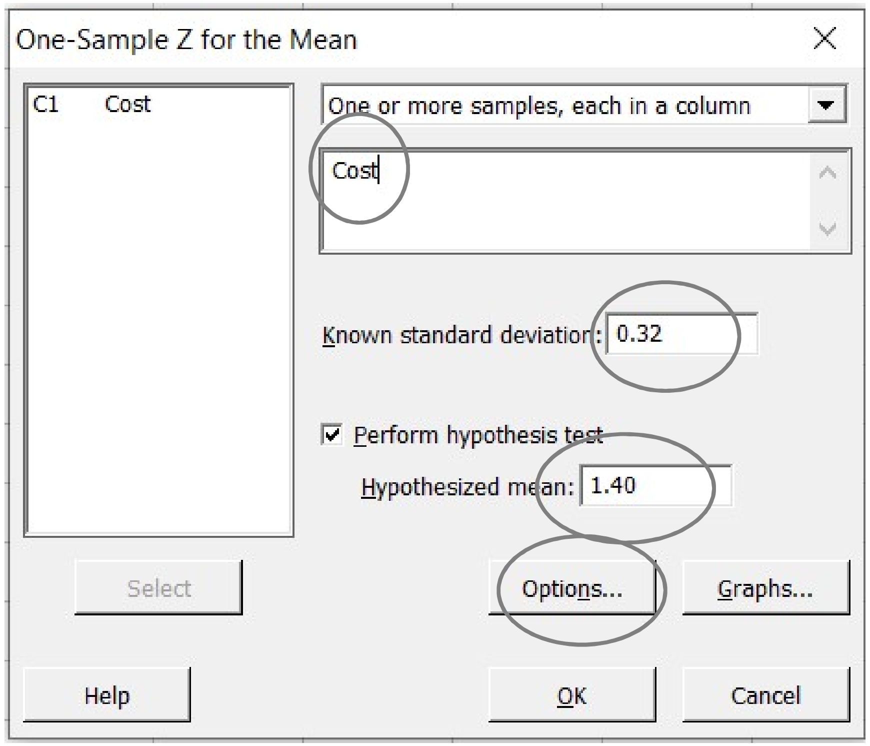
Descriptive Statistics



Example: Rising Packing Costs

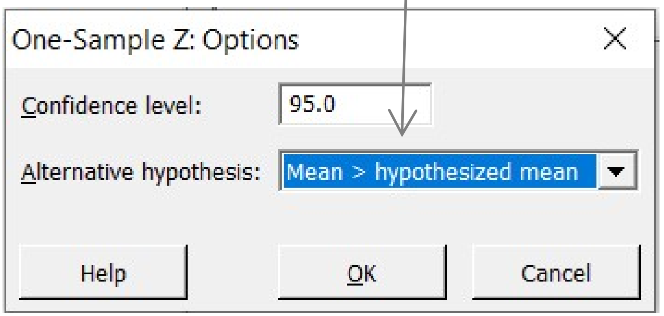
Tool Bar Menu > Stat > Basic Statistics > 1-Sample Z

Analysis through Minitab



Choose *greater than* for Alternative

(H_a: μ > \$1.40)



Example: Rising Transaction Costs

One-Sample Z: Cost

```
Test of mu = 1.4 vs mu > 1.4
The assumed sigma = 0.32

Variable           N      Mean     StDev   SE Mean
Cost              45    1.4506    0.3247    0.0477

Variable      95.0% Lower Bound        Z        P
Cost                     1.3721     1.06    0.145
```

Interpretation:

p-value = 0.145

Since p-value > α-value (0.05) fail to reject H_o

Infer H_o true: not enough evidence that average teller transaction cost is greater than $1.40

1-Sample Z test Exercise: Projector Lamps

A company that manufactures lamps for computer projectors, Sigma Lamps, Inc. (SLI), has received numerous complaints from customers concerning the quality of recently purchased lamps.

Specifically, the average life of new lamps is said to be less than previous purchases. Historical data shows that the measure of lamp life is approximately normally distributed with a mean of 1000 hours and standard deviation of 40 hours. Life information from a random sample of 25 lamps from a recent production batch is given in ***Lamps.mtw.***

Are the concerns of SLI's customers valid?

1-Sample Z-Test Exercise: Ohms

A customer believes that the resistors they purchased and installed in their instrument have higher average resistance values than required. They sent a representative sample of 10 resistors back for testing.

The resistor data (ohms) are included in file ***Ohms.mtw***

The resistors are supposed to be 60.5 ohms. Does the customer have a legitimate complaint? The population standard deviation (σ) of resistors is 0.81 ohms.

Anexas Consultancy Services

1 Sample t Test

Single Mean Comparison

μ

vs

target
value

σ Not known

Practical Question
(example)

"Is the population statistically different from the target value?"

Statistical Question

H_o: μ = target value

H_a: $\mu \neq$ target value

1-Sample t-Test

- Hypothesis test about the unknown population mean using information from one sample
- Population standard deviation not known and distribution is normal

Note: Normality assumptions relaxed when the number of sample observations is large (generally true when sample size >30).

Business Process Example: Delinquent Mortgages

A bank holds 1432 delinquent mortgages on residential properties. The Black Belt investigating the loan process wants to know if the mean appraised value (current) of the properties is greater than $175,000.

A preliminary random sample of 38 delinquent properties were appraised. The sample produced a mean appraised value of $181,769.

Use the data in ***mortgage.mtw*** to determine if there is enough evidence that population mean appraised value is greater than $175,000?

Example: Delinquent Mortgages

- **Practical Problem**
  - Is the mean appraised value of all 1432 properties higher than $175,000 in spite of the sample mean value of $181,769?
- **Statistical Problem**
  - Is the population mean of appraised value greater than $175,000?
  - Null hypothesis: mean appraised value of properties = $175,000
  - Alternate hypothesis: population average value is greater than $175,000
  - Is there sufficient evidence to show that the population average of properties is greater than the $175,000 at a significance level of 5%? Otherwise we will maintain the current belief - i.e., the null hypothesis

Example: Delinquent Mortgages

- **State the hypotheses and significance level**

$$H_o: \mu = \$175{,}000$$

$$H_a: \mu > \$175{,}000$$

$$\alpha = 0.05$$

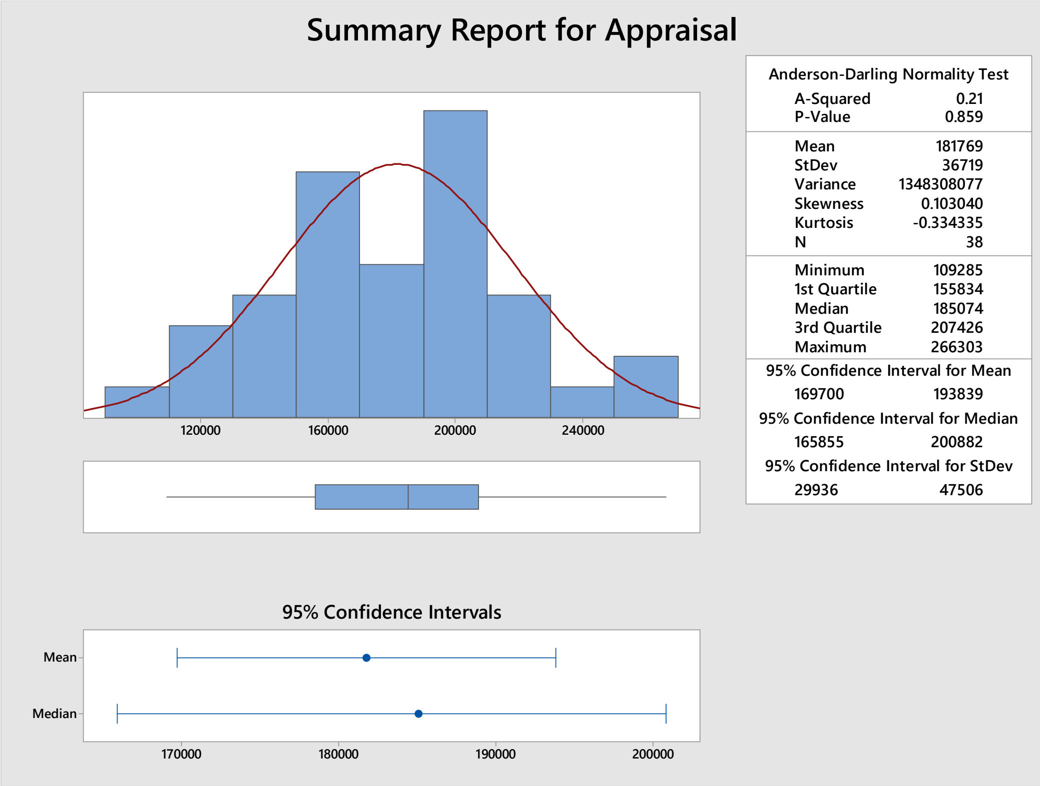
- **What hypothesis test is appropriate?**
  - These hypotheses deal with mean values
  - Only one factor for examination - appraised value
  - Comparing population mean against a target value using one sample data
  - Data follows a normal distribution
  - Population standard deviation NOT known
  - Use 1-sample t-test

Example: Delinquent Mortgages

Practical and Graphical

- Open the file ***Mortgage.mtw***
- What practical questions do you have about this data?
- Evaluate descriptive statistics

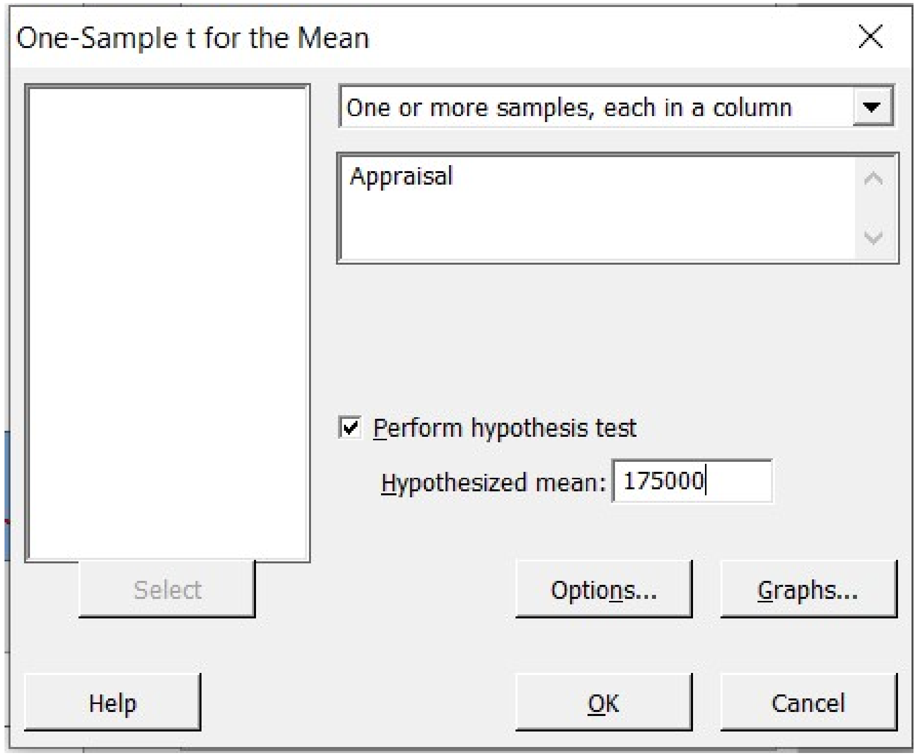
Descriptive Statistics



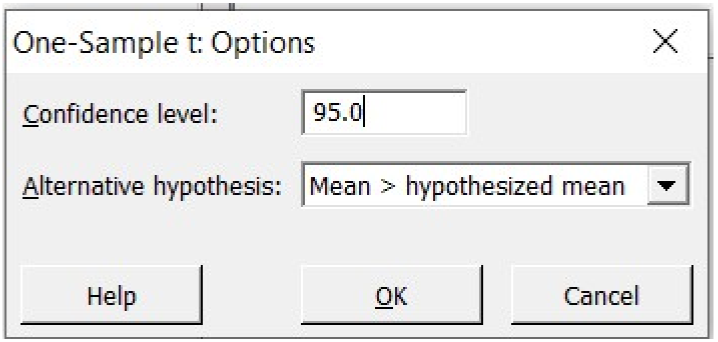
Example: Delinquent Mortgages

Tool Bar Menu > Stat > Basic Statistics > 1-Sample t

Analysis through Minitab



Choose *greater than* for Alternative (H_a: μ > $175,000)



Example: Delinquent Mortgages

One-Sample T: Appraisal

```
Test of mu = 175000 vs mu > 175000

Variable           N      Mean     StDev   SE Mean
Appraisal         38    181769     36719      5957

Variable       95.0% Lower Bound        T        P
Appraisal                 171720     1.14    0.132
```

Interpretation:

- p-value = 0.132
- Since p-value > α-value (0.05) fail to reject H_o
- Infer H_o true: not enough evidence that average appraised value of properties with delinquent mortgages is higher than $175,000

Industrial Process Exercise: Fuel Additive

An oil company has advertised that their new product, a fuel additive, can significantly enhance automobile fuel economy. They claim that on average automobiles can improve fuel economy by 2.3 miles per gallon. You are asked to investigate their claim.

As part of your investigation you have collected fuel economy information from 112 random samples of automobiles and found that on average the mileage enhancement for this sample was 2.03 miles per gallon (mpg) with a standard deviation of 1.125 mpg. You are concerned that the average value for your sample is less than the manufacturer's claim. The data is given in ***mileage.mtw.***

Is the sample average of 2.03 mpg enough evidence to show that the manufacturer's claim is invalid?

Perform a statistical test at 5% significance level.

Answer to exercise: Fuel Additive

```
One-Sample T: mpg change
Test of mu = 2.3 vs mu < 2.3

Variable            N    Mean         StDev        SE Mean
mpg change        112    2.031         1.125           0.106

Variable       95.0% Upper Bound        T              P
mpg change              2.207        - 2.53          0.006
```

Interpretation:

– p-value is 0.006, suggesting that if the true average was still 2.3 mpg, only about 0.6% of the time we would expect to see a sample average of 2.31 mpg or less

– Since p- value < α-value (0.05), reject H_o

– Infer H_a true: additive does not increase fuel economy by 2.3 mpg

– We have evidence against the manufacturer's claim

Business Process
1-Sample t-Test Exercise

A rental car company is concerned that its annual repair costs per car on its fleet of full size cars are increasing. To get an understanding of where the costs are, a random sample of 28 full size cars were selected and its repair costs analyzed.

The sample data ***Carrepair.mtw*** contains repair costs per car for last year.

Test the hypothesis that the mean repair costs per car for last year is greater than $1275.

Industrial Process
1-Sample t-Test Exercise

A customer believes that the resistors they purchased and installed in their instrument have higher average resistance values than required. They sent a representative sample of 10 resistors back for testing.

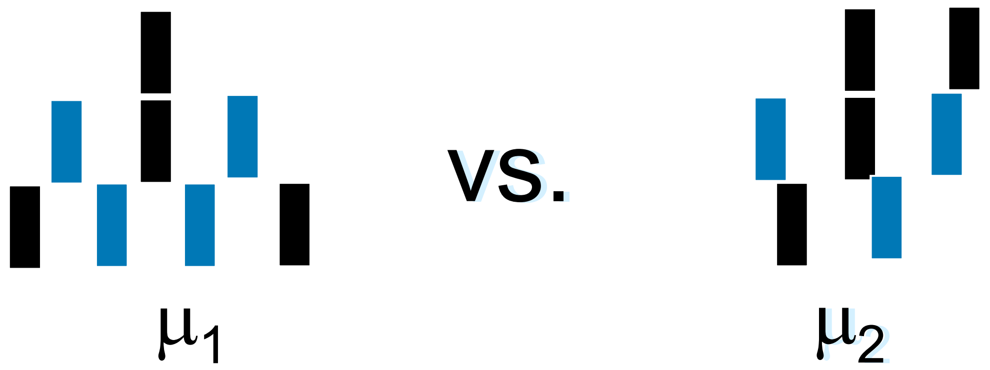
The resistor data (ohms) are included in file ***Ohms.mtw***.

The resistors are supposed to be 60.5 ohms. Does the customer have a legitimate complaint? The population standard deviation (σ) of resistors is not known.

Anexas Consultancy Services

2 Sample t Test

Two Sample Comparison



Practical Question (example)

"Are the two populations statistically different?"

Statistical Question

$H_o: \mu_1 = \mu_2$

$H_\alpha: \mu_1 \neq \mu_2$

2-Sample t-Test

- Hypothesis test about the difference between two population means using two samples
- Distributions are normal
- Two independent samples
  - Can be of different size

Business Process Example: Teller vs. ATM Costs

(A) As part of an investigation to study the transaction costs of tellers versus ATMs, a bank has collected a random sample of 45 teller transaction costs and 53 ATM transaction costs.

The data is given in file ***ATMTeller.mtw***.

Perform a hypothesis test to determine if average value teller transaction cost is higher than ATM transaction cost.

(B) Solve the same problem and perform a hypothesis test to determine if average value teller transaction cost is higher than ATM transaction costs by at least $0.35.

Example: Teller vs. ATM Costs (Part B Solution)

- Practical problem
  - Is average cost of teller transactions higher than average cost of ATM transactions by at least $0.35?
- Statistical problem
  - Is the population mean for teller transaction cost higher than the population mean of ATM transaction costs by at least $0.35?
  - Null hypothesis: difference between mean value of teller transaction costs and mean value of ATM transaction costs is equal to $0.35
  - Alternate hypothesis: difference between mean value of teller transaction costs and mean value of ATM transaction costs is greater than $0.35

Example: Teller vs. ATM Costs

- State the hypotheses and significance level

$$H_o: \mu_{Teller} - \mu_{ATM} = \$0.35$$

$$H_a: \mu_{Teller} - \mu_{ATM} > \$0.35$$

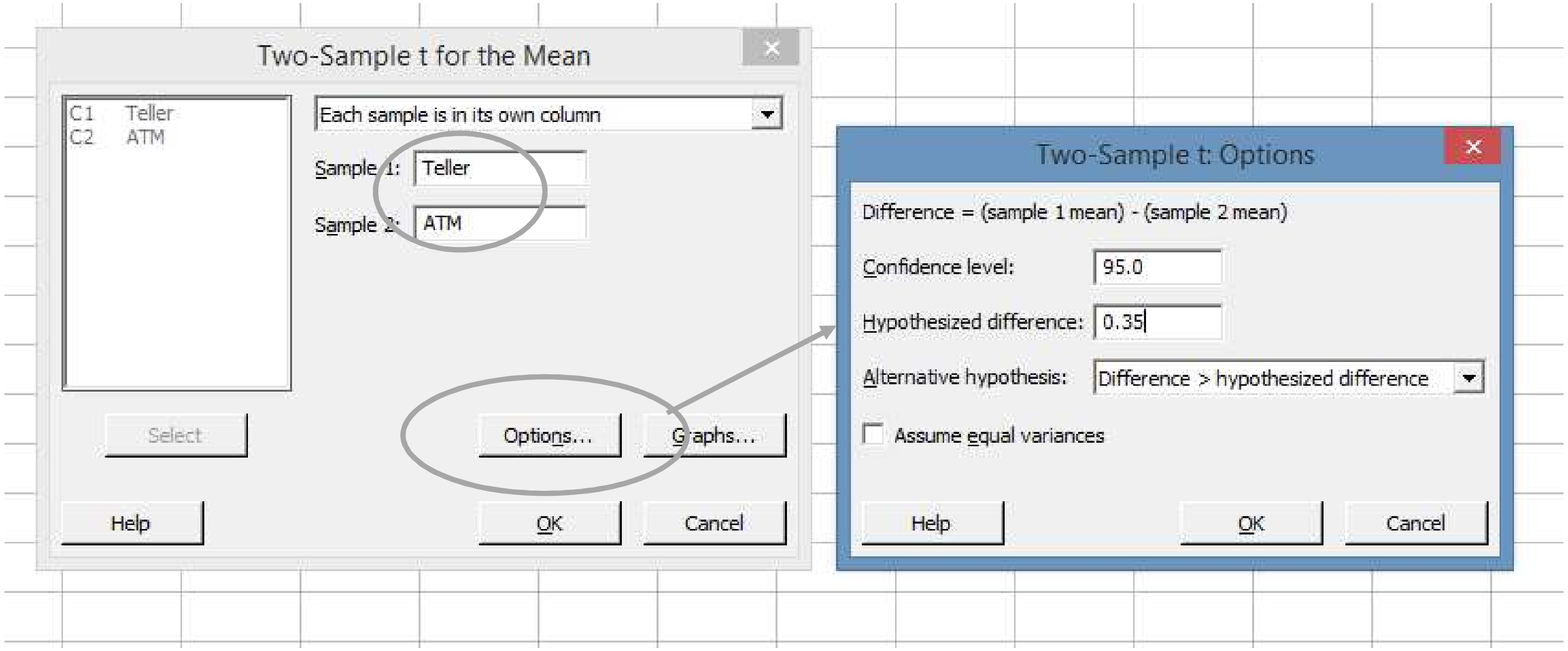
$$\alpha = 0.05$$

- What hypothesis test is appropriate?
  - These hypotheses deal with mean values
  - Only one factor for examination - transaction cost
  - Comparing population means based on two independent sets of sample data
  - Samples are normally distributed
  - Use 2-Sample t-Test

Example: Teller vs. ATM Costs

Tool Bar Menu > Stat > Basic Statistics > 2-Sample t

Analysis through Minitab



Example: Teller vs. ATM Costs

```
Two-sample T for Teller vs ATM

         N      Mean     StDev   SE Mean
Teller  45     1.451     0.325     0.048
ATM     53     0.985     0.210     0.029

Difference = mu Teller - mu ATM
Estimate for difference:  0.4654
95% lower bound for difference: 0.3716
T-Test of difference = 0.35 (vs >): T-Value = 2.05  P-Value = 0.022  DF = 72
```

Interpretation:

-p-value 0.022

-Since p-value < α-risk (0.05), reject the null hypothesis

-The difference between Teller cost and ATM costs is greater than $0.35

Industrial Process Exercise
Alloy Tensile Strength

Your Purchasing department is faced with a dilemma in choosing between two suppliers of alloy bars for your manufacturing operation.

Decisions must be made based on the average tensile strength and price of the supplied alloy bars. Your potential supplier B claims that the tensile strength of their bars is comparable to your current supplier A.

Moreover, bars from supplier B are cheaper than those from supplier A. If there is no difference between the tensile strength of alloy bars from the two companies you would consider switching to supplier B based on price.

Industrial Process Example
Alloy Tensile Strength

To help make decisions you have measured the tensile strength of 50 samples of alloy bars from each supplier. The results are given in the file ***Alloy.mtw.*** Summary of sample statistics are as follows: Supplier A: average tensile strength = 42.07 ksi, standard deviation = 2.91 ksi; Supplier B: average tensile strength = 41.38 ksi, standard deviation = 2.41 ksi

Is there a difference in average tensile strength of alloy bars from Supplier A and B? Would you recommend switching to Supplier B? What other questions do you have about the decision making process?

Note: Other things being equal, higher tensile strength is preferred.

Example: Alloy Tensile Strength

- Practical problem
  - Is there a difference in alloy tensile strength between suppliers?
  - If there is a difference, is it statistically significant?
- Statistical problem
  - Is the population mean for alloy tensile strength from Supplier A different from Supplier B?
  - Null hypothesis: average value of tensile strength for A and B are equal
  - Alternate hypothesis: average value of tensile strength for A and B are not equal
  - Is there evidence to show that the difference between the population average of tensile strength for A and B is not zero when tested at a significance level of 5%? Otherwise we will maintain the current belief - i.e., the null hypothesis

Solution: Alloy Tensile Strength

```
Two-sample T for SupplyA vs SupplyB

          N      Mean     StDev   SE Mean
SupplyA  50     42.07      2.91      0.41
SupplyB  50     41.70      2.72      0.38

Difference = mu SupplyA - mu SupplyB
Estimate for difference:  0.373
95% CI for difference: (-0.745, 1.490)
T-Test of difference = 0 (vs not =):T-Value = 0.66  P-Value = 0.510  DF = 97
```

Interpretation:

p-value 0.510

If the difference between population averages was still zero, about 51% of the time expect to see a sample average difference as high as 0.373 ksi. In other words, if we reject the null hypothesis we would be wrong about 51%. This is more than the risk we are willing to take.

Example: Alloy Tensile Strength

- Interpretation (continued):

  Since p-value is higher than the α-risk (0.05), fail to reject the null hypothesis in favor of the alternative

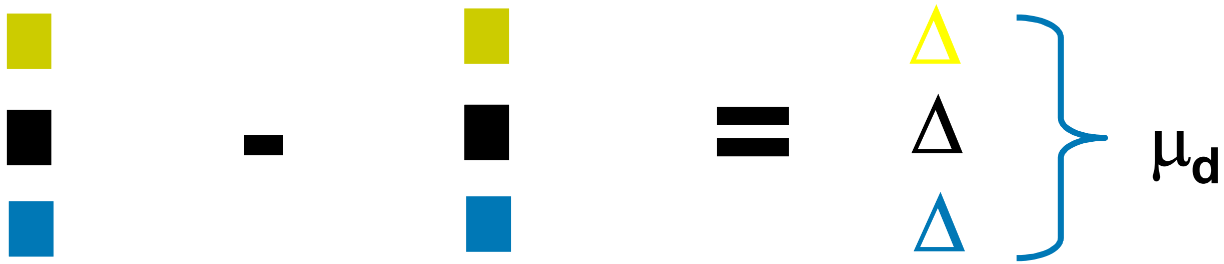
  The difference between tensile strength of alloys from Supplier A and B is not statistically significant

  95% Confidence interval for difference between average alloy tensile strength from A and B is -0.745 and 1.490; since interval contains zero, insufficient evidence that the alloys are different

Anexas Consultancy Services

Paired t Test

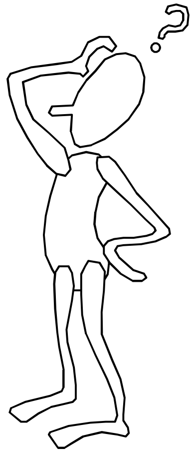
Paired Comparison



Group 1 **Group 2** ***(paired difference between the two groups)***

Practical Question
(example)

Is the difference between matched pairs greater than zero?"



Statistical Question

H_o: $\mu_d = 0$

H_a: $\mu_d > 0$

Paired t-Test

- Test for mean difference between pairs of samples
- Differences between matched pairs is normally distributed
- Each datum has a dependent mate
- Increased sensitivity over 2-Sample t-Test
- Effectively used to block out excess variability

Paired t-Test - Procedure

- State the practical problem
- State the statistical problem
  - Generate the null and alternative hypotheses

    For example, H_o: $\mu_d = D_0$ or $\mu_d \leq D_0$

    vs

    H_a: $\mu_d > D_0$

D_0 represents hypothesized mean difference of pairs

- Calculate the test statistic $t_{observed}$
- $\bar{d}$ and s_d are sample mean and standard deviation of 'n' differences

$$t_{obs} = \frac{\bar{d} - D_0}{s_d/\sqrt{n}}$$

Paired t-Test - Procedure

- Determine the critical value (tn-1, α) of test statistic
- To test H_a: $\mu_d > D_0$, reject H_o if $t_{observed} > t_{n-1, \alpha}$
- To test H_a: $\mu_d < D_0$, reject H_o if $t_{observed} < - t_{n-1, \alpha}$
- To test H_a: $\mu_d \neq D_0$, reject H_o if $t_{observed} < - t_{n-1, \alpha/2}$ or $t_{observed} > t_{n-1, \alpha/2}$
- Reject the null hypothesis if p-value < α-value
- Ensure that none of the assumptions for test are violated
- Translate statistical conclusion into practical solution

Industrial Process Example: High Performance Tires

R&D department of Sigma Tires, Inc. has invented a new brand of tires (Brand X) that can potentially offer superior fuel economy. Based on tests performed under laboratory conditions the Engineering department believes that use of Brand X tires on the average improves the fuel economy by 0.3 mpg.

As part of the next phase of development, Sigma Tires has decided to do further field trials on a fleet of 42 taxis. The test to evaluate fuel economy obtained for Brand X tires as well as regular brand tires is as follows:

Industrial Process Exercise: High Performance Tires

First, all 42 taxis were fitted with Brand X tires and driven over a prescribed course collecting fuel economy information. Then the same taxis were fitted with regular tires and driven once again over the same test course without changing drivers. The results obtained from the test are recorded in the file ***Tirebrandx.mtw.***

Sigma Tires would like to know if these tests are consistent with the Engineering department's previous finding that cars equipped with Brand X tires give better fuel economy than those equipped with regular brand tires?

Solution: High Performance Tires

```
Paired T-Test and CI: BrandX, Regular
Paired T for BrandX - Regular

              N       Mean      StDev    SE Mean
BrandX       42     14.420      2.621      0.404
Regular      42     14.072      2.758      0.426
Difference   42     0.3478     0.5327     0.0822

95% lower bound for mean difference: 0.2095
T-Test of mean difference = 0 (vs > 0): T-Value = 4.23  P-Value = 0.000
```

Interpretation:

- p-value 0.000
- p-value < α-value (0.05), reject H_o
- Infer H_a: Improvement in fuel economy due to Brand X compared to regular brand is statistically significant

Example contd.: High Performance Tires

- Having seen an improvement, Engineering also wants to know if they can say that Brand X tires, on average, improve the fuel economy by 0.3 mpg?
- Practical problem
  - Is the improvement at least 0.3 mpg?
- Statistical problem
  - Is the difference in paired fuel economy greater than 0.3?
  - Null hypothesis: Average value of paired difference is equal to 0.3
  - Alternate hypothesis: average value of paired difference is greater than 0.3
  - Is there evidence to show that population average of paired difference between fuel economy for Brand X and Regular tires is greater than 0.3 when tested at a significance level of 5%? If not we will maintain the current belief - i.e., the null hypothesis

Example: High Performance Tires

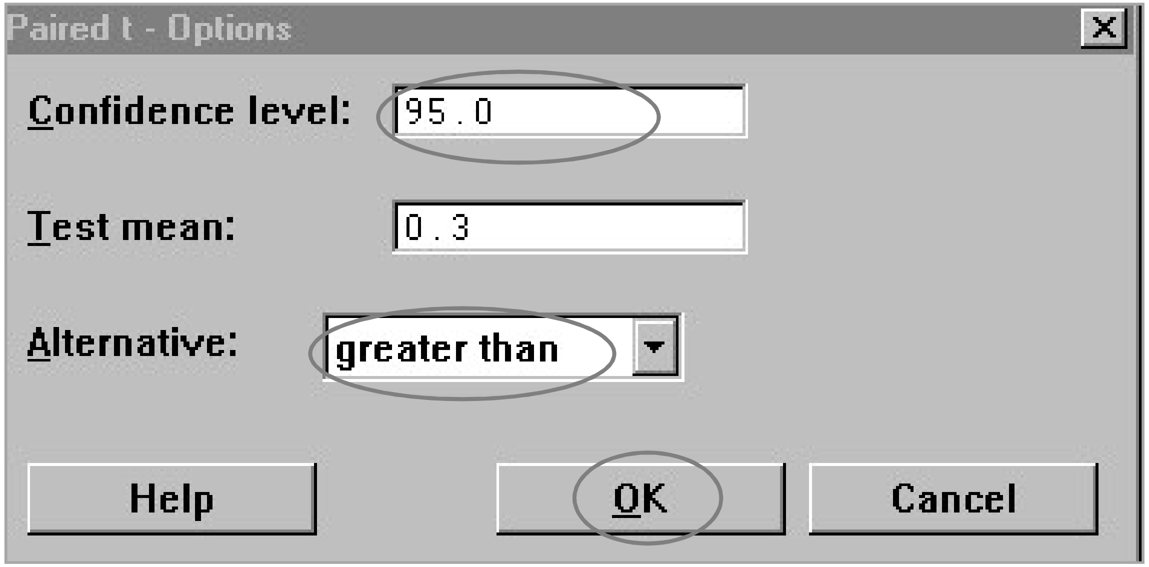
Question: Does Brand X improve the fuel economy by more than 0.3 mpg?

State the Hypotheses and Risk

$H_o: \mu_d = 0.3$

$H_a: \mu_d > 0.3$

$\alpha = 0.05$



Example: High Performance Tires

```
Paired T-Test and CI: Brand X, Regular
Paired T for Brand X - Regular

              N       Mean      StDev     SE Mean
Brand X       42      14.420    2.621     0.404
Regular       42      14.072    2.758     0.426
Difference    42      0.3478    0.5327    0.0822

95% lower bound for mean difference: 0.2095
T-Test of mean difference = 0.3 (vs >0.3): T-Value = 0.58 P-Value = 0.282
```

Interpretation:

- p-value = 0.282
- p-value > α-value (0.05), fail to reject H_o
- Infer H_a: insufficient evidence to prove Brand X improves the fuel economy by more than 0.3 mpg

Business Process Example: Comparing Analysts

A financial institution wants to compare the predictions of earnings per share (EPS) by two different financial analysts, George and Lisa. The two financial analysts' EPS forecasts for a random sample of 18 fortune 500 corporations are recorded in ***FaEPS.mtw.*** Financial institution wants to know if there is a difference between the forecasts produced by George and Lisa.

Perform a hypothesis test at 5% significance level to determine if there is a statistically significant difference between the predictions by these analysts.

Example: Comparing Analysts

- Practical problem
  - Is there a difference between the EPS forecasts of two analysts?
  - Is the average value of prediction by one analyst different from the other?
- Statistical problem
  - Is the difference in paired EPS predictions greater than zero?
  - Null hypothesis: mean value of paired difference is zero
  - Alternate hypothesis: mean value of paired difference is not equal to zero
  - Is there evidence to show that population average of paired difference between EPS forecasts by George and Lisa is not zero when tested at a significance level of 5%? If not, we will maintain the current belief - i.e., the null hypothesis

Example: Comparing Analysts

- State the hypotheses and significance level

$$H_o: \mu_d = 0$$

$$H_a: \mu_d \neq 0$$

$$\alpha = 0.05$$

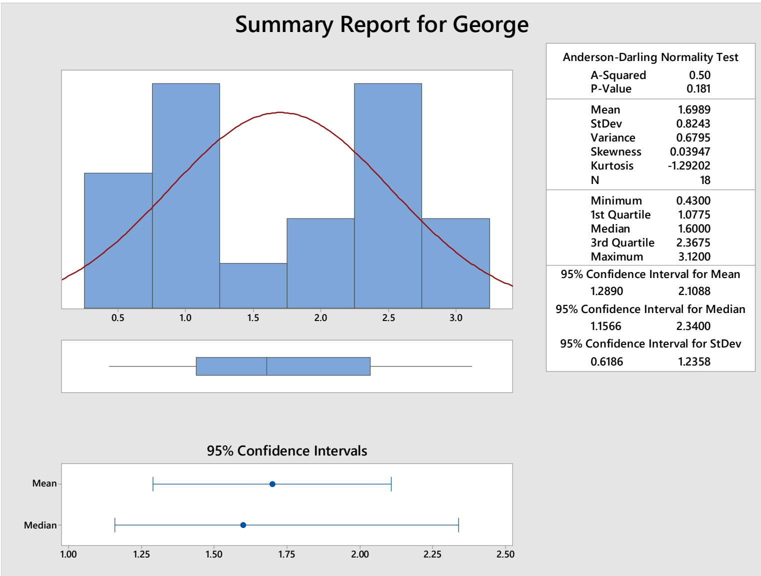
- What hypothesis test is appropriate?
  - These hypotheses deal with mean values
  - Only one factor for examination - EPS forecasts
  - Comparing mean differences of paired sample data
  - Difference between paired data follows a normal distribution
  - Use Paired t-Test

Example: Comparing Analysts

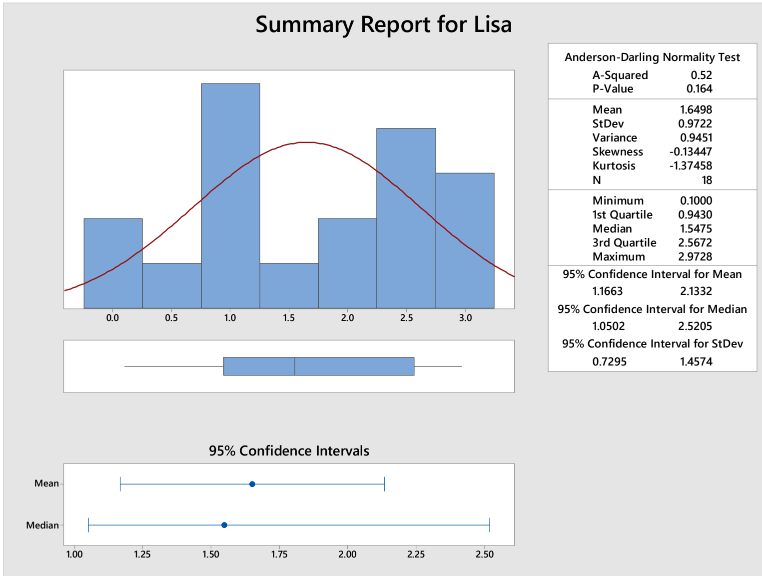
Practical and Graphical

- Open *FAEps.mtw* in Minitab
- What practical questions do you have about this data?
- What assumptions are used in a Paired t-Test?

Descriptive Statistics



Descriptive Statistics

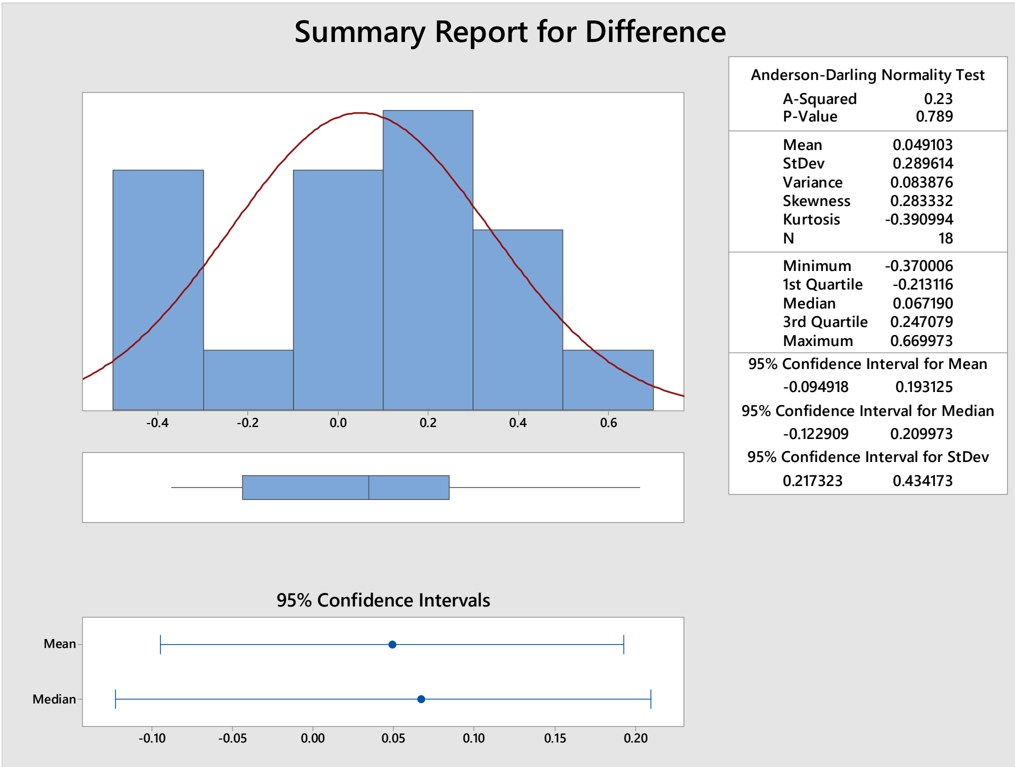


Example: Comparing Analysts

Practical and Graphical

- Review descriptive statistics of the difference between paired data

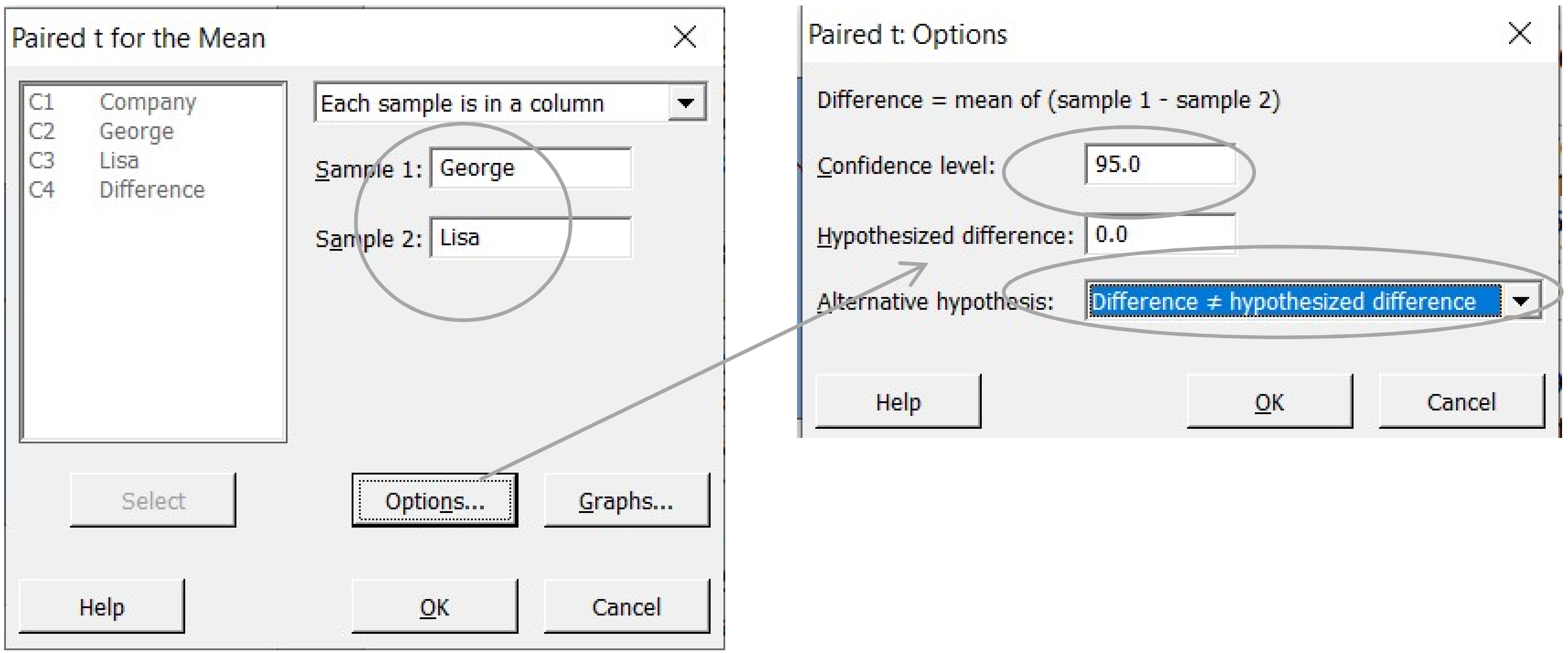
Descriptive Statistics



Example: Comparing Analysts

Tool Bar Menu > Stat > Basic Statistics > Paired t

Analysis through Minitab



Example: Comparing Analysts

Paired T-Test and CI: George, Lisa

```
Paired T for George - Lisa

                  N       Mean      StDev    SE Mean
George           18      1.699      0.824      0.194
Lisa             18      1.650      0.972      0.229
Difference       18     0.0491     0.2896     0.0683

95% CI for mean difference: (-0.0949, 0.1931)
T-Test of mean difference = 0 (vs not = 0): T-Value = 0.72  P-Value = 0.482
```

Interpretation:

- p-value 0.482
- p-value > α-value (0.05), fail to reject H_o
- Infer H_o: Difference in EPS forecasts by Lisa and George are not statistically significant

Paired t-Test Exercise

A customer believes that the resistors they purchased and installed in their instrument have higher average resistance values than ordered. They tested a representative sample of 10 resistors and data recorded in column1 (Customer) of file ***CSresist.mtw.***

The sample of 10 resistors were sent back to a supplier testing facility. These resistors were tested at the supplier facility and recorded in column2 (Supplier of the file ***CSresist.mtw***).

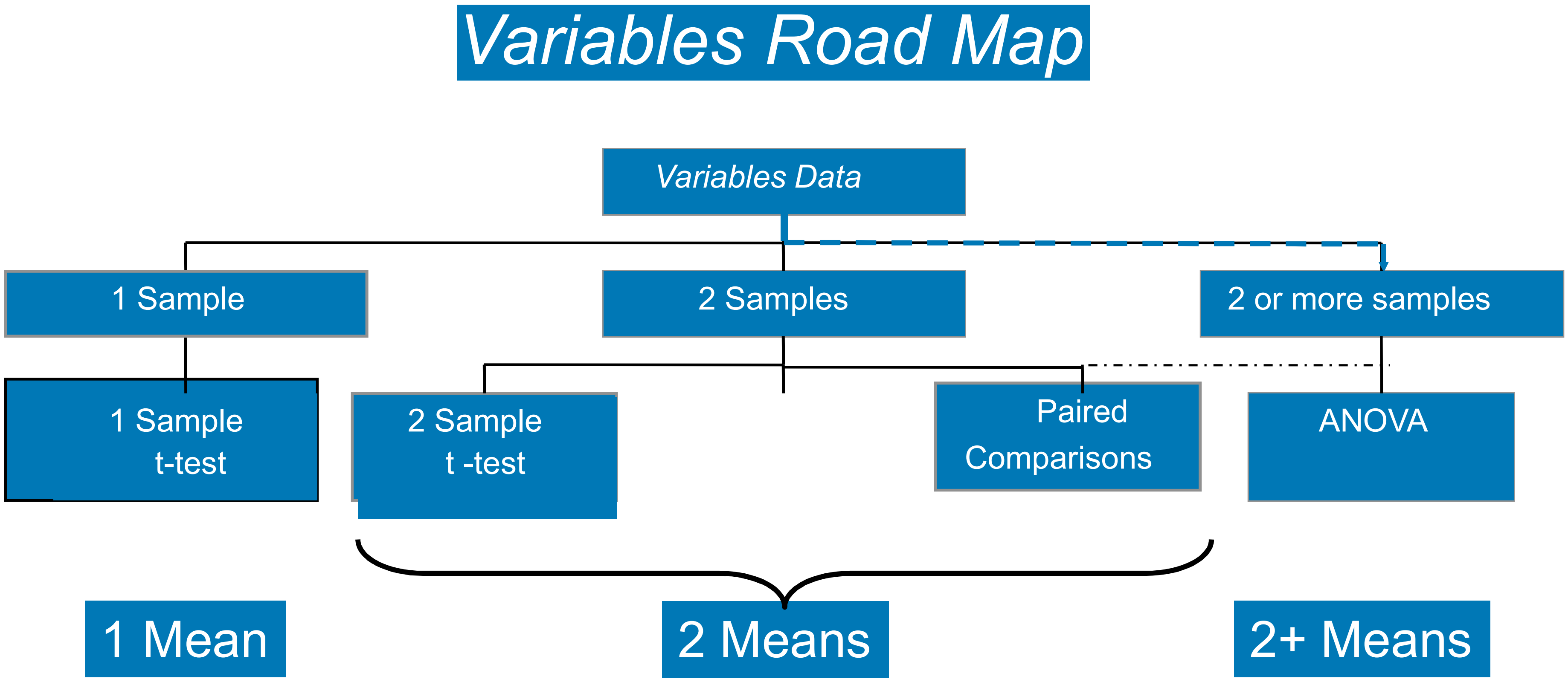
Is the customer’s test method comparable to the testing facility? Assume the resistors were tested in the same order, such that 61.3 and 62.1 are the resistance for resistor1, etc.

Anexas Consultancy Services

Comparing Two or More Group Averages

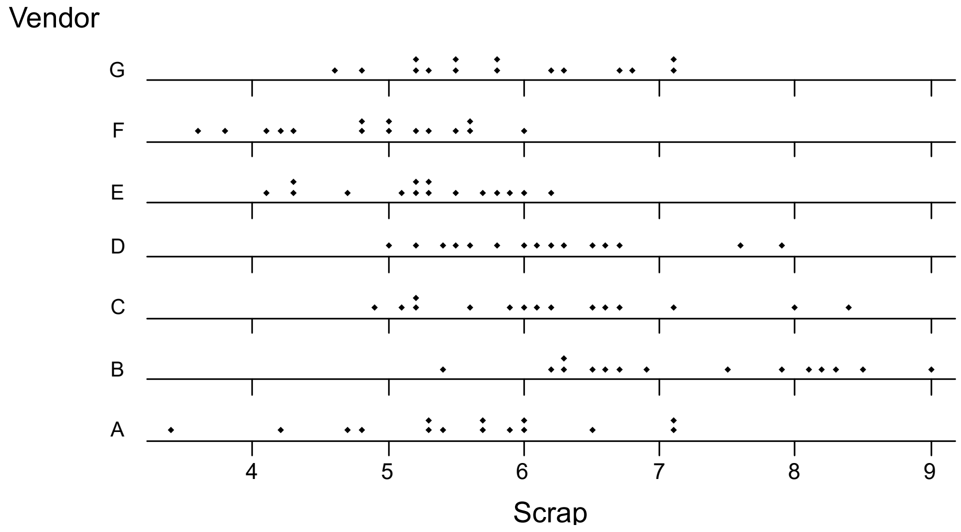
ANOVA

When to Use ANOVA



ANOVA is used to test two or more means

Discussion: How Would You Compare Seven Groups?



An improvement team wants to compare seven packaging material vendors to see whether there are any significant differences in the average amount of scrap produced among the different materials:

- How would you make seven comparisons?
- Can you find the difference of seven items at the same time?

Answers: How Would You Compare Seven Groups?

- Although a dot plot helps us compare seven groups visually, mathematically you can take the difference only between two numbers at a time, not among seven
- If you make pairwise comparisons, two at a time, you would end up doing 21 *t-test*s:
  - This is an inefficient use of time as well as data (to estimate the variance)
  - You also increase the chance of making a Type I error (on at least one of the comparisons)*
- We must find a better way:
  - To compare the groups simultaneously
  - To use all the data efficiently

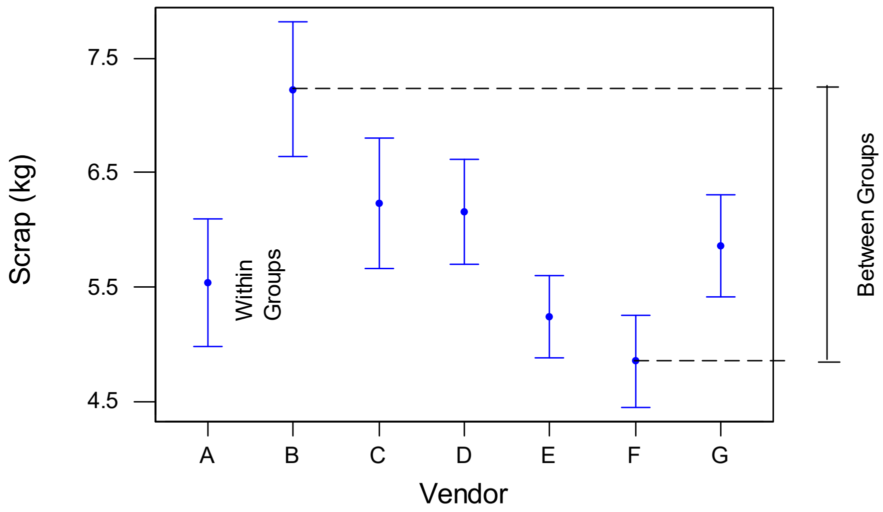
Analyze Variances Instead of Averages

- There is a statistical test that uses variances to compare multiple group averages simultaneously:
  - ANOVA: Analysis of Variance
- Instead of comparing pairwise averages, it compares the variance **between** groups with the variance **within** groups:
  - The between group variance is obtained from the variance s^2 of the **group averages**
  - The within group variance is obtained from the variance s^2 among values within each group and then **pooled** (or averaged with appropriate degrees of freedom) **across the groups**
- If the variance between groups is the same as the variance within groups, we say there is no difference among the group averages

$$\frac{S^2_{between}}{S^2_{within}}$$

Analyze Variances Instead of Averages, cont.

- Here is a plot to help you visualize “between” and “within” variance for seven groups (think of a Normal distribution centered over each line shown)



- In this diagram, the within group variation appears smaller than the between group variation, so the test will probably show that at least one of the groups is different from the rest

Analysis of Variance (ANOVA)

- Obtain the variance between groups: S_B^2
- Obtain the variance within groups: S_W^2
- If they are about the same, conclude there is no significant difference between groups:
  - Take a ratio: if $\frac{S_B^2}{S_W^2} = 1$ then say there is no difference between group averages
- The ratio of two variances = F-statistic
- We can get a P-value from the F distribution
- Minitab menu:

  Stat > ANOVA > One-way

ANOVA Hypothesis

- The null hypothesis:
  - H_0: Average A = Average B = Average C = . . .

    (or)

    No difference among the group averages

    (or)

$$S^2_{Between} = S^2_{Within}$$

- The alternative hypothesis:
  - H_a: At least one group average is significantly different from the others

ANOVA Hypothesis, cont.

- If $P \geq 0.05$:
  - Do not reject the H_0
  - There is not enough evidence to say there is a statistically significant difference between any two of the groups
  - If there is a true difference, either the variation is too large or the sample size is too small to detect it
- If $P < 0.05$:
  - Reject the H_0, and conclude the H_a
  - At least one of the groups is statistically different from the others
  - Examine confidence intervals to find which of the groups are different (non overlapping)
  - Actions: evaluate importance or size of the difference (is it enough to warrant further action?)

ANOVA

- Analysis of variance (ANOVA):
  - Used to **compare averages** of two or more groups:
    - Assumes variances of each group are the same
  - Also used to **compare variances** of two or more groups:
    - Called the **test for equal variances**
    - Use this test to check the assumption that variances are the same when comparing averages

Prerequisites for ANOVA

- Every subgroup has a normal distribution
- Subgroups have statistically equal variances
- Residuals are independent and normally distributed about the mean

Anexas Consultancy Services

Hypothesis Testing Exercise

ANOVA

Normality Check

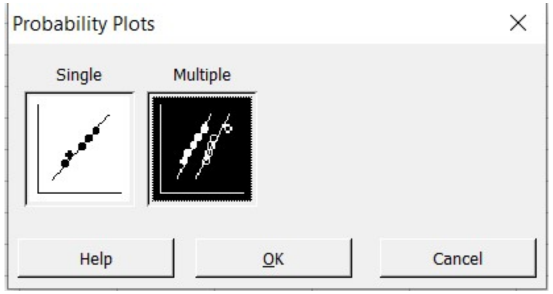
ANOVA – Exercise

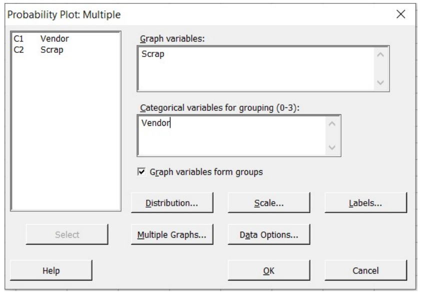
- Data: ***ScrapAnova.MTW***
- Background: The data set contains the amount of scrap (kg) from 15 pieces of material from each of the seven vendors (identified as AG) for a total of 105 production runs on Process X
- An improvement team wants to compare seven packaging material vendors to see whether there are any significant differences in the average amount of scrap produced among the different materials:
  - ❑ How would you make seven comparisons?
  - ❑ Can you find the difference of seven items at the same time?

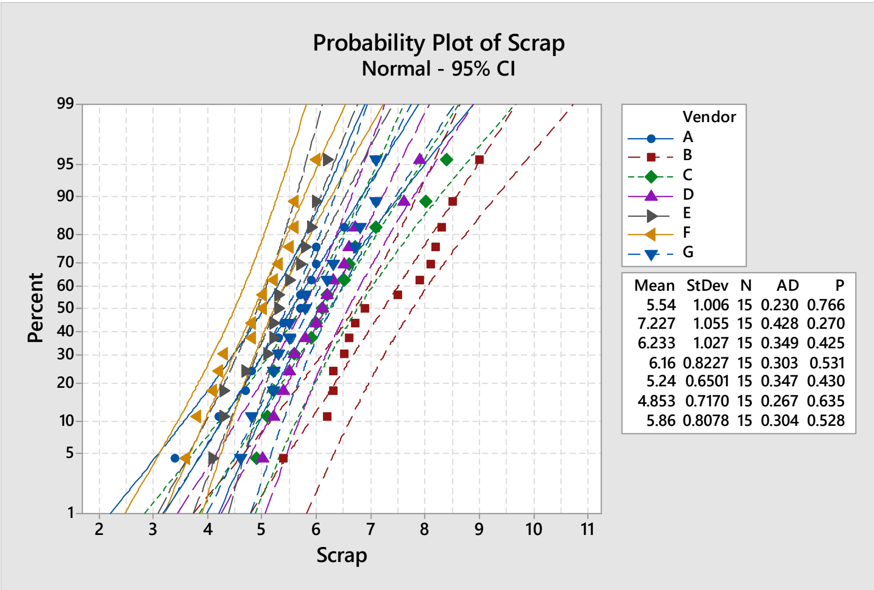
Prerequisites for ANOVA

Normality Check

Graph > Probability plot > (By Vendor)







P-values of all Scrap vendors is more than 0.05,

Data is considered as Normal.

Anexas Consultancy Services

Hypothesis Testing Exercise

ANOVA

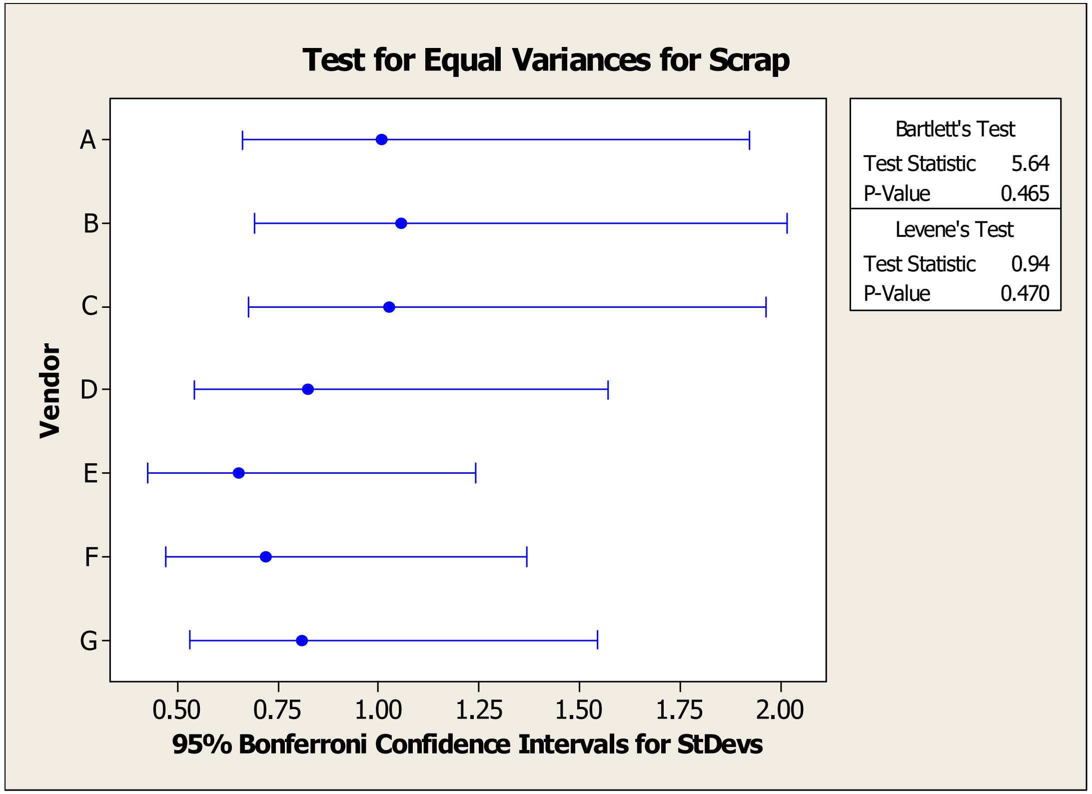
Test of Equal Variances

Exercise: Test for Equal Variances

- **Objective:** Practice using Minitab to check whether the variances of several groups are the same
- **Time:** 5 minutes
- **Data:** ***ScrapAnova.MTW***
- **Background:**
  - Recall the ANOVA test we did to determine whether material from seven vendors was associated with significantly different average scrap amounts
  - We made an assumption that the variances in the scrap were the same for each vendor when we did the ANOVA
- **Instructions:** Working alone:
  1. Check the assumption of same variances
  2. Be prepared to report your conclusions

Answers: Test for Equal Variances

Test for equal variances:



Conclusion: No significant difference in variances

Anexas Consultancy Services

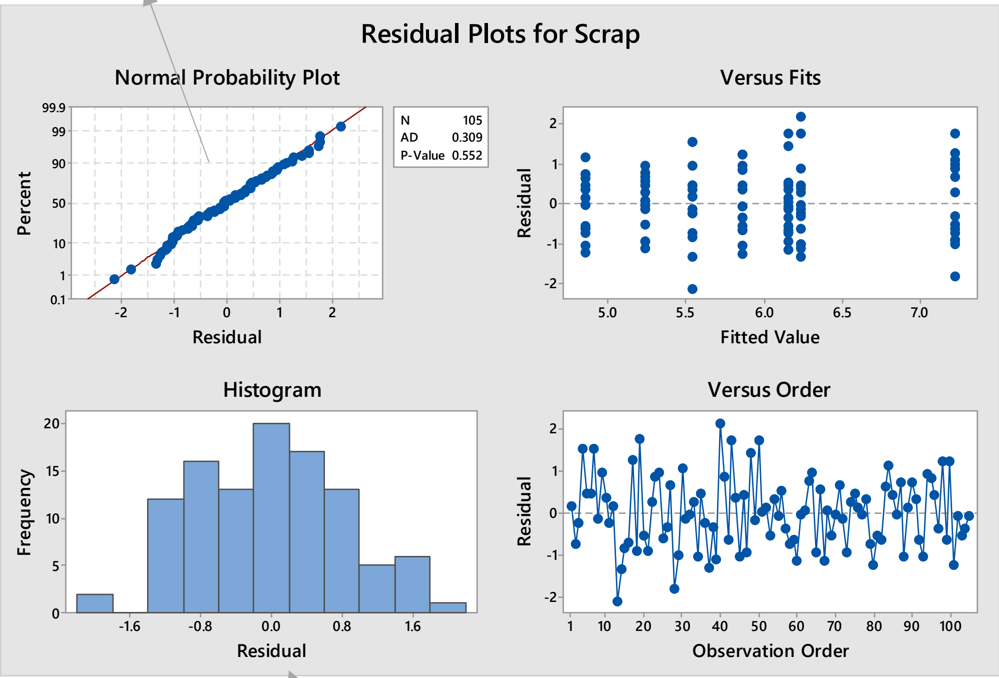
Hypothesis Testing Exercise

ANOVA

Residuals for Violations

Answers: Residuals for Violations

There is a straight line through nearly all the points, indicating the residuals are Normal. Examine the extreme points closely. Decide whether to leave them in or take them out.



Residuals vs. fits should not have patterns or extreme outliers. This plot should show a random pattern of residuals on both sides of 0. If a point lies far from the majority of points, it may be an outlier. There should not be any recognizable patterns in the residual plot. For instance, if the spread of residual values tend to increase as the fitted values increase, then this may violate the constant variance assumption.

2. Here again, with the exception of outliers, the residuals look Normal (good).

4. Residuals vs order should be scattered with no pattern. There seems to be a slight pattern (wave or cycle). What variable related to time may be causing this? Try to discover it and add it to the regression analysis. We'll demonstrate how to do this later.

Anexas Consultancy Services

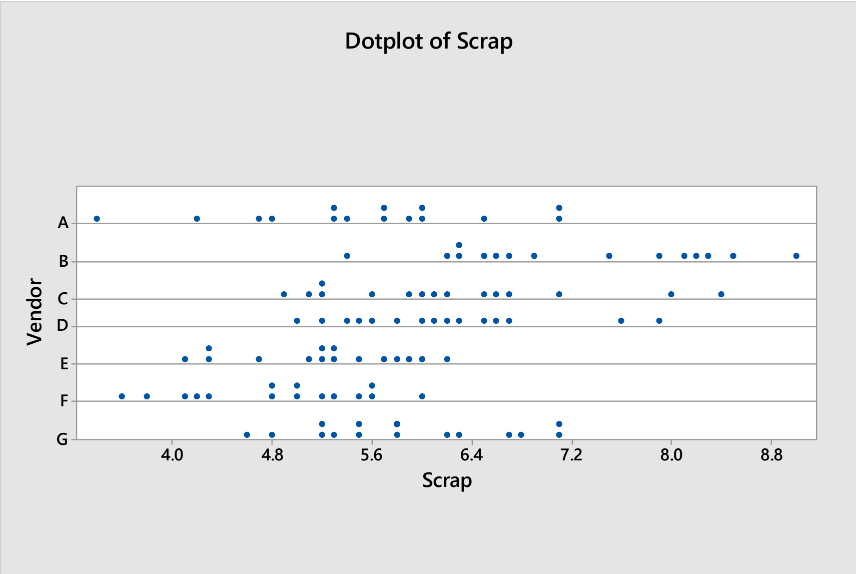
Hypothesis Testing
Exercise

ANOVA

Minitab Follow-Along: ANOVA

1. Make a stratified dot plot of the face amount by vendor:

   Graph > Dotplot > (By Vendor)



Minitab Follow-Along: ANOVA, cont.

2. Get a summary of the data:

Stat > Basic Statistics > Display Descriptive Statistics > (Scrap by Vendor)

Descriptive Statistics: Scrap by Vendor

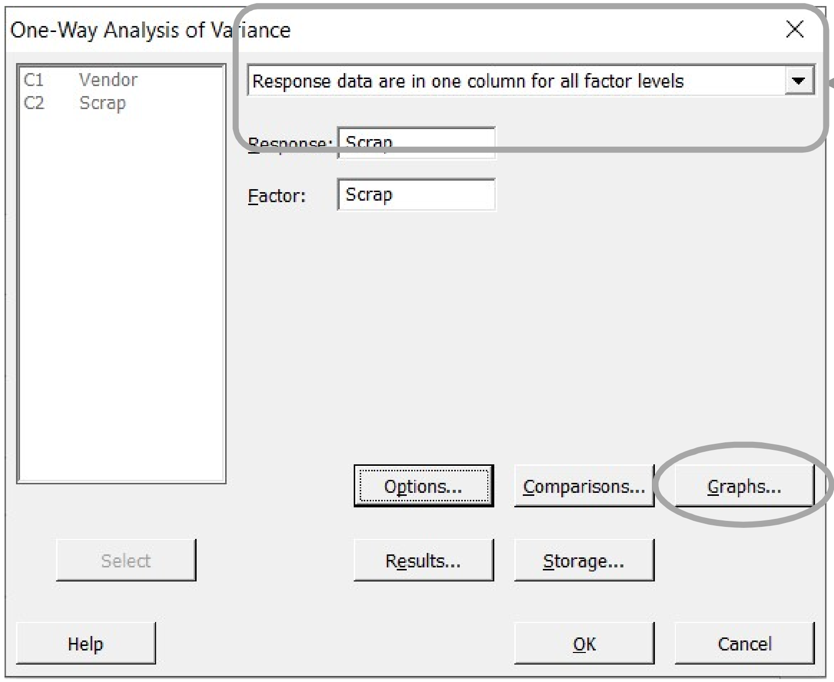
Variable	Vendor	N	Mean	Median	TrMean	StDev
Scrap	A	15	5.540	5.700	5.585	1.006
	B	15	7.227	6.900	7.231	1.055
	C	15	6.233	6.100	6.169	1.027
	D	15	6.160	6.100	6.115	0.823
	E	15	5.240	5.300	5.254	0.650
	F	15	4.853	5.000	4.862	0.717
	G	15	5.860	5.800	5.862	0.808

Variable	Vendor	SE Mean	Minimum	Maximum	Q1	Q3
Scrap	A	0.260	3.400	7.100	4.800	6.000
	B	0.272	5.400	9.000	6.300	8.200
	C	0.265	4.900	8.400	5.200	6.700
	D	0.212	5.000	7.900	5.500	6.600
	E	0.168	4.100	6.200	4.700	5.800
	F	0.185	3.600	6.000	4.200	5.500
	G	0.209	4.600	7.100	5.200	6.700

Minitab Follow-Along: ANOVA, cont.

3. Do an analysis of variance (ANOVA) or F-test:

   Stat > ANOVA > Oneway



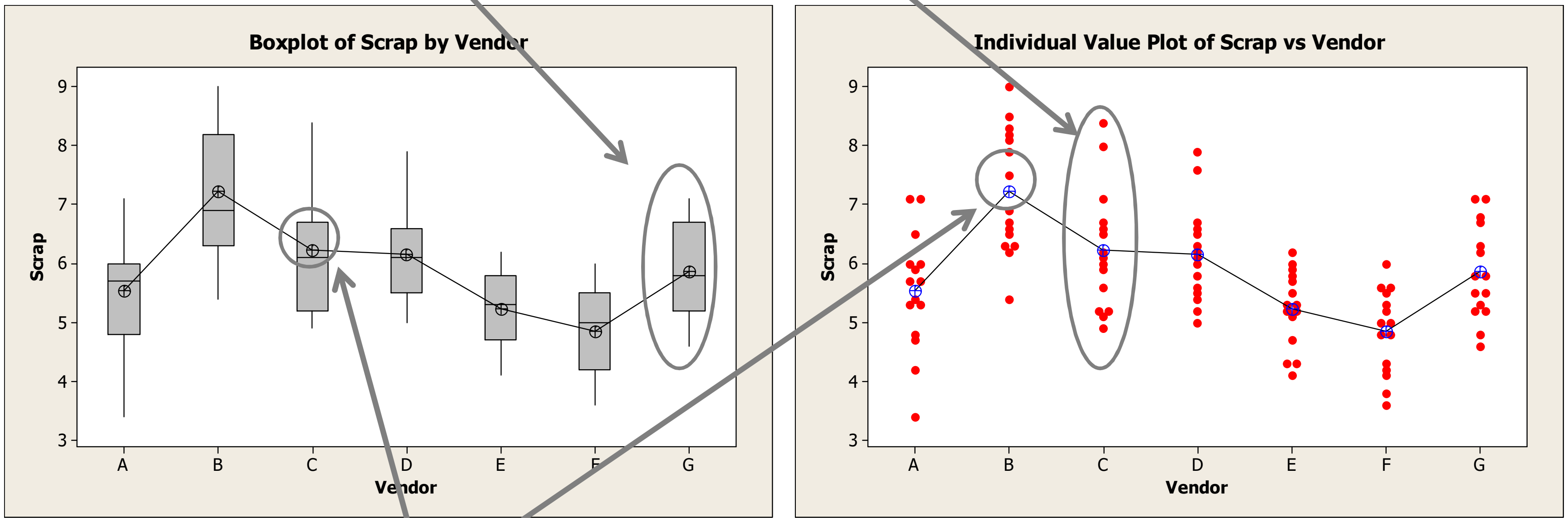
Use this menu if the Y data are in one column and the group labels are in another column

If each group is in its own column, use the "Oneway (Unstacked)" menu

Check box plots and individual values plot

Minitab Follow-Along: ANOVA, cont.

Extreme points provide a “visual” of the “within-vendor” variation



Mean values provide a “visual” of the “between-vendor” variation

Minitab Follow-Along: ANOVA, cont.

Question 3: Minitab output

“Sum of Squares”

“Mean Squares” is another name for variance

The variance between groups is 11.5 times bigger than the variance within groups

Draw conclusion from P-value

Between

Within

Oneway ANOVA: Scrap versus Vendor

```
Analysis of Variance for Scrap
Source     DF        SS        MS         F        P
Vendor      6    53.941     8.990     11.56    0.000
Error      98    76.224     0.778
Total     104   130.165

                                     Individual 95% CIs For Mean
                                     Based on Pooled StDev
Level       N      Mean     StDev    ++++
A          15    5.5400    1.0056           (*)
B          15    7.2267    1.0546                            (*)
C          15    6.2333    1.0272                     (*)
D          15    6.1600    0.8227                    (*)
E          15    5.2400    0.6501         (*)
F          15    4.8533    0.7170    (*)
G          15    5.8600    0.8078                  (*)
                                     ++++

Pooled StDev =    0.8819                5.0       6.0       7.0       8.0
```

The parentheses represent confidence intervals for *group averages* (not individual values)

We assume the variances for all groups are the same

Minitab Follow-Along: ANOVA, cont.

Conclusions:

- Because $p < 0.05$, reject the H_0 and conclude that at least one group is significantly different from another
- Based on the confidence intervals:
  - Average scrap associated with Vendor B's material is significantly higher than all other vendors
  - Average scrap associated with Vendor F is significantly lower than that associated with Vendors B, C, D, and G, but not significantly lower than that associated with Vendors A or E
- The ANOVA shows the scrap will be significantly lower if you use materials from Vendors F, E, or A
- Use other criteria (e.g., cost, ease of use, or other aspects) to choose among these three materials

Setting Up the Data in Minitab

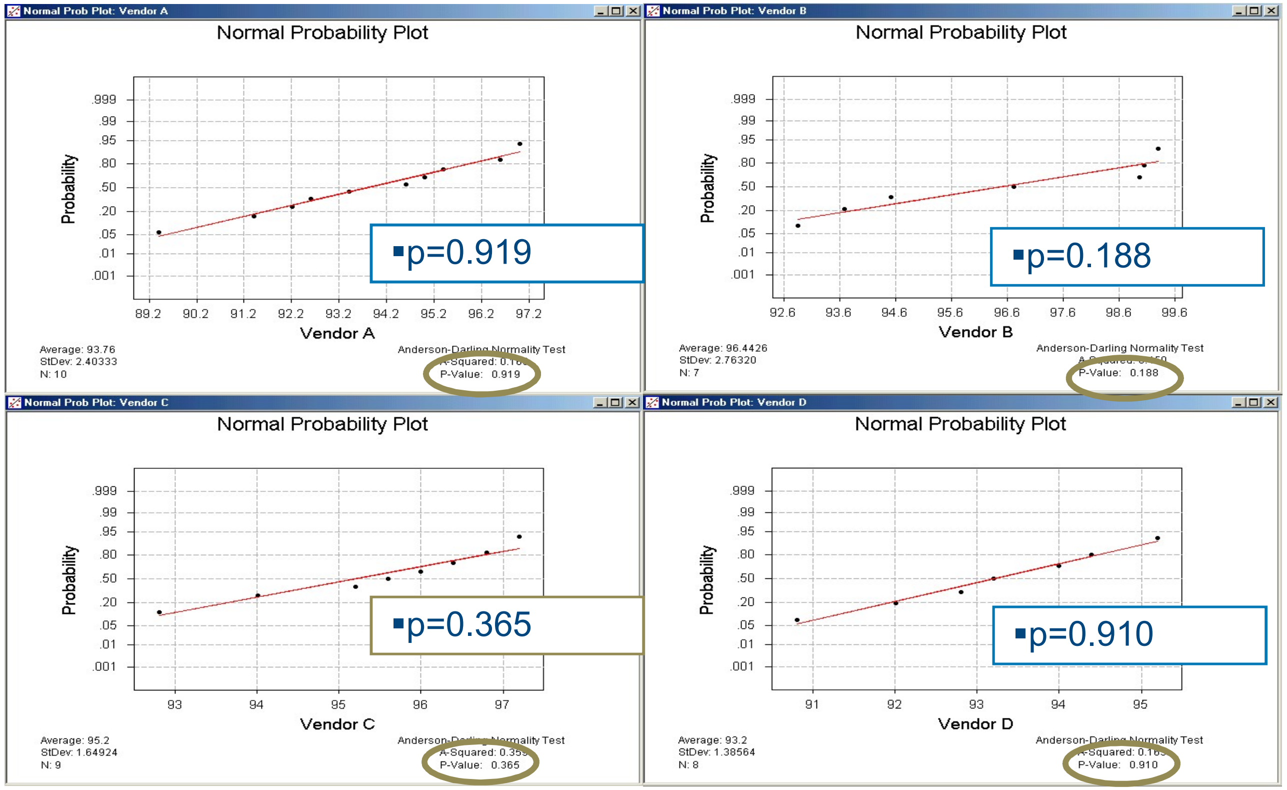
Open worksheet ***Vendor Yield.mtw***

Vendor Yield.MTW ***

↓	C1	C2	C3	C4	C5-T	C6
	Vendor A	Vendor B	Vendor C	Vendor D	Vendor	Yield
1	91.4	99.3	92.8	94.4	Vendor A	91.4000
2	94.6	93.7	96.4	92.8	Vendor A	94.6000
3	92.6	99.1	96.0	90.8	Vendor A	92.6000
4	95.0	99.0	94.0	93.2	Vendor A	95.0000
5	92.2	92.8	92.8	95.2	Vendor A	92.2000
6	97.0	96.7	95.6	93.2	Vendor A	97.0000
7	89.4	94.5	96.8	92.0	Vendor A	89.4000
8	95.4		97.2	94.0	Vendor A	95.4000
9	93.4		95.2		Vendor A	93.4000
10	96.6				Vendor A	96.6000

Sorted data is in columns C1-C4. Stacked data is in column C5-T and C6

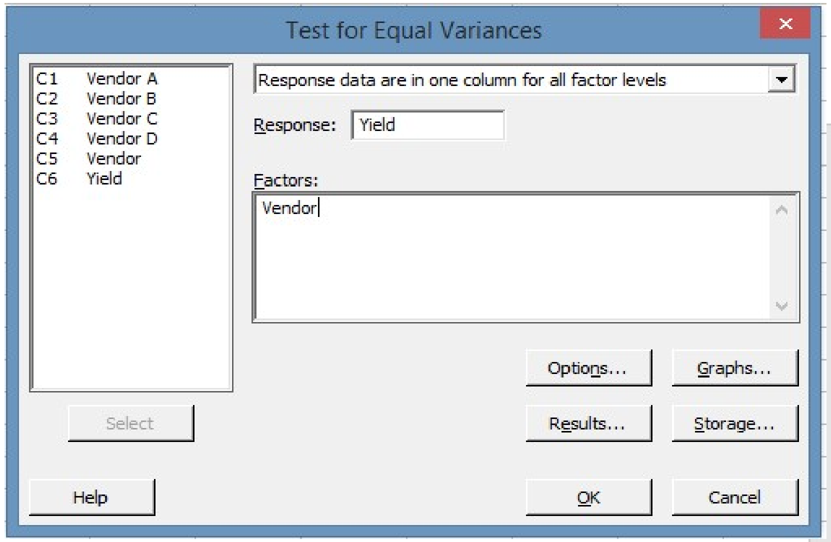
Testing Data for Normality

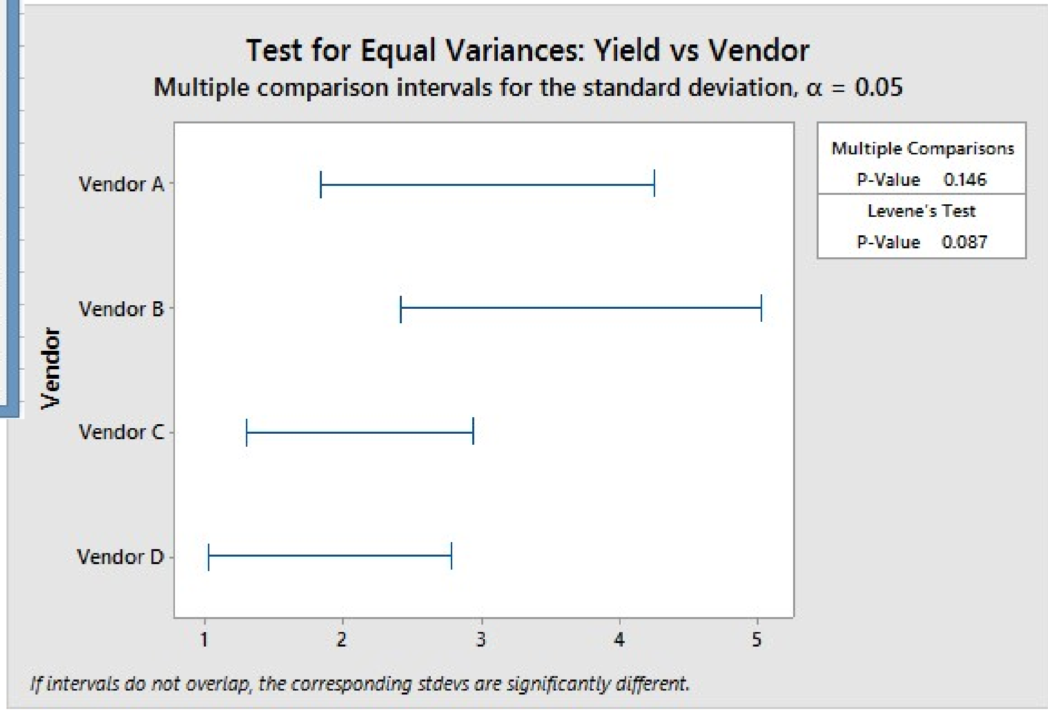


All subgroups have a normal distribution

Testing Data for Equal Variances

Tool Bar Menu > Stat > ANOVA > Test for Equal Variances

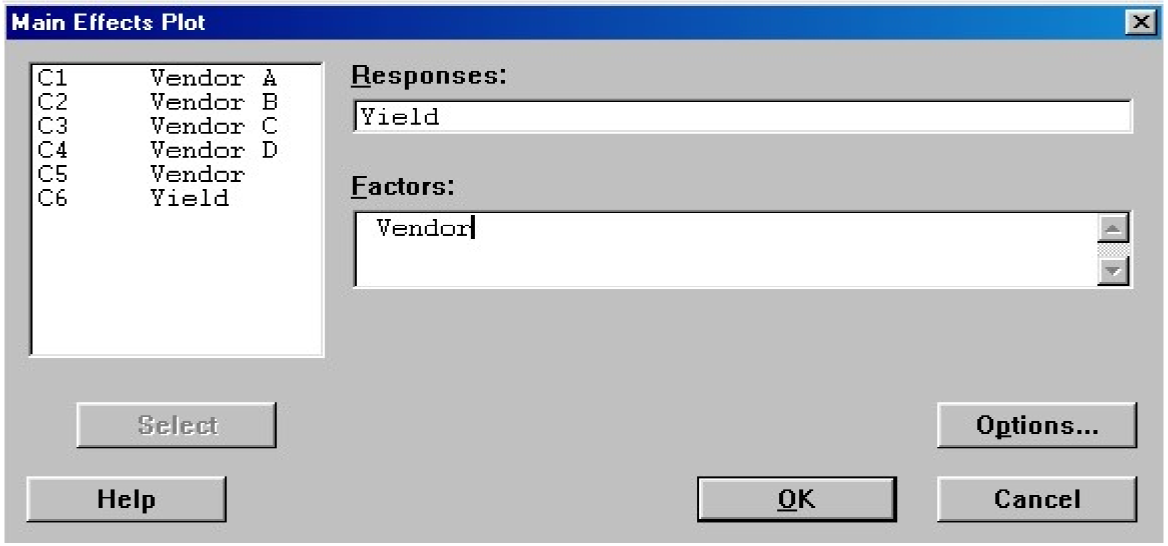




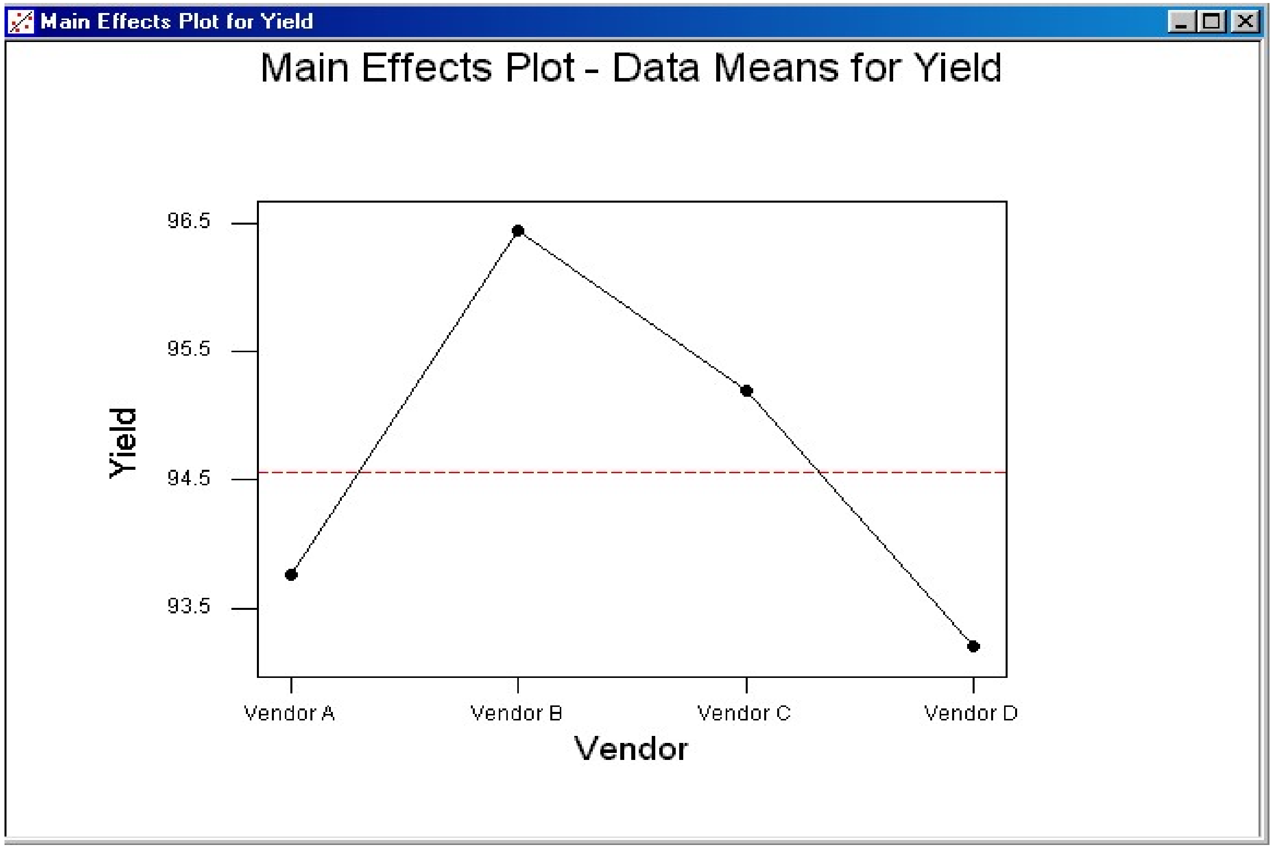
P=0.146 indicates variances are equal

Running a Main Effects Plot

Tool Bar Menu > Stat > ANOVA > Main Effects Plot



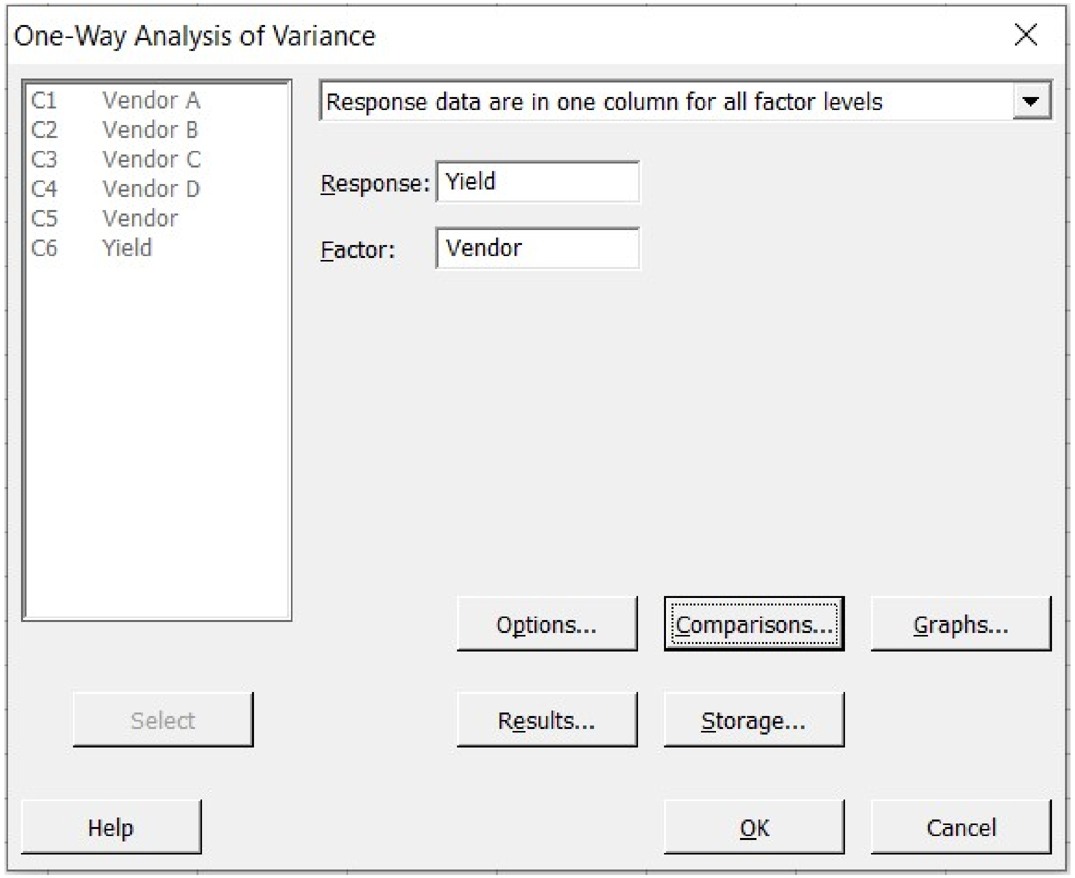
The Main Effects Plot



The plot shows the output vs. the factor

Running a One Way ANOVA

Tool Bar Menu > Stat > ANOVA > One Way…



The One Way ANOVA

One-way ANOVA: Yield versus Vendor

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Vendor	4	Vendor A, Vendor B, Vendor C, Vendor D

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Vendor	3	49.69	16.564	3.74	0.022
Error	30	133.00	4.433		
Total	33	182.69			

P < 0.05: source is significant!

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
2.10551	27.20%	19.92%	6.05%

Means

Vendor	N	Mean	StDev	95% CI
Vendor A	10	93.760	2.403	(92.400, 95.120)
Vendor B	7	96.44	2.76	(94.82, 98.07)
Vendor C	9	95.200	1.649	(93.767, 96.633)
Vendor D	8	93.200	1.386	(91.680, 94.720)

Pooled StDev = 2.10551

Tests of Significance (Non- Parametric)

Tests of Significance (Non- Parametric)

	Test of Mean/ Median	Test of Variance	Test of Proportion
1 Sample	▪ 1 sample Z Test ▪ 1 Sample t Test ▪ 1 sample Sign ▪ 1 Sample Wilcoxon	Descriptive Statistics Bartlett's test Levene's test	1 Proportion Test
2 Sample	▪ 2 Sample t Test ▪ Mann-Whitney ▪ Paired T Test		2 Proportion Test
2 or more Samples	▪ ANOVA ▪ Mood's Median/ ▪ Kruskal Wallis Test		Chi Square

1 Sample Sign Test - Overview

1 sample sign tests allow you to compare the median of just one sample against a known median value, such as an industry benchmark or well established historical mean.

Example:-

A recruitment consultancy has recently implemented a new salary negotiation process and a project team is trying to verify that it has improved (increased) the salaries that are being achieved. The salaries of the first 20 placements made using the new negotiation process have been recorded and the project team want to compare these results against the benchmark.

1 Sample Sign Test

Because the sample of salaries is not Normally distributed and there is only one sample to compare against the benchmark.

The median salary of the sample is 60K and the historical salary median was 48K, and so it appears that there has been an increase in the median of 12K. however its quite a small sample and there is lots of variation within the sample and it is difficult to be sure.

The data file for this example can be found in ***Salaries.mpj***

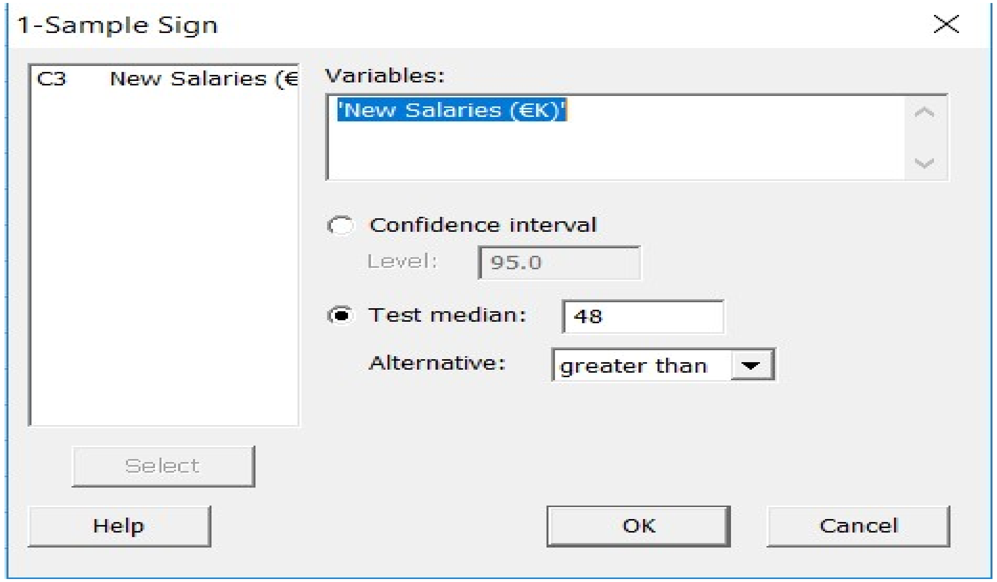
In this example, the sample median is being tested against a historical benchmark (the test median). Enter 48 (the historical benchmark level)

Alternate Hypothesis: Less than / Not equal / Greater than):

In this example because it appears that the sample median is greater than test median, the alternative greater than has been selected.

1 Sample Sign Test - Interpreting the Results

Stat > Nonparametrics > 1-Sample Sign



Sign Test for Median: New Salaries (€K)

```
Sign test of median =  48.00 versus > 48.00

                    N  Below  Equal  Above       P  Median
New Salaries (€K)  20      5      1     14  0.0318   60.00
```

Session Window Results:

The first line provides a summery of the Null and Alternate Hypothesis, in a technical shorthand. Translated into day-to-day language, this line says: These are the results of a Sign Test for the sample median being equal to 48 (median = 48.00) versus it being greater than 48 (versus > 48.00)

1 Sample Sign Test – Interpreting the Results

Sign Test for Median: New Salaries (€K)

```
Sign test of median =  48.00 versus > 48.00

                     N  Below  Equal  Above       P  Median
New Salaries (€K)   20      5      1     14  0.0318   60.00
```

How the Sign test works:

While the Sign test produces a p-value that can be interpreted in a similar way to other hypothesis tests, the mathematics behind the Sign Test are quite different.

The sign test works by classifying each result within the sample as either above, below or equal to the test median. If the null hypothesis were true, we would expect to see approximately half of the results above and half below, the test median

However in this case, the majority of the results (14 out od 20) were above the test median, and this was high enough for the test to indicate (with statistical confidence) that the sample median (60) is greater than test median (48)
It is interesting to note that one of the results was exactly equal to the test median as summarised in the session window output above. The row was 7 in the example data file.

1 Sample Sign Test – Interpreting the Results

Sign Test for Median: New Salaries (€K)

```
Sign test of median =  48.00 versus > 48.00

                     N  Below  Equal  Above       P  Median
New Salaries (€K)   20      5      1     14  0.0318   60.00
```

The p-value is 0.0318 (which is lower than the Alpha Level of 0.05), and so you can reject the null, and conclude (with 95% confidence) than the median salary in the sample is greater than the historical median of 48, So the new negotiation process does increase placement salaries.

The I Sample Sign test menu in Minitab does not offer any additional graphs. However using a Dot plot from the graph menu, the sample results can be visually compared to the historical benchmark of 48K. As can be seen, while some of the results are below 48, most of them are above and this is enough to conclude, statistically, that the median new salary is higher than 48K

One-Sample Wilcoxon Test - Overview

Use the one-sample Wilcoxon (also called one-sample Wilcoxon signed rank) confidence interval and test procedures to make inferences about a population median based on data from a random sample.

Use the 1-Sample Wilcoxon when you are unable to assume a distribution for the population from which the sample was drawn, but you can assume the distribution is symmetric . This is a nonparametric alternative to one-sample Z and one-sample t procedures.

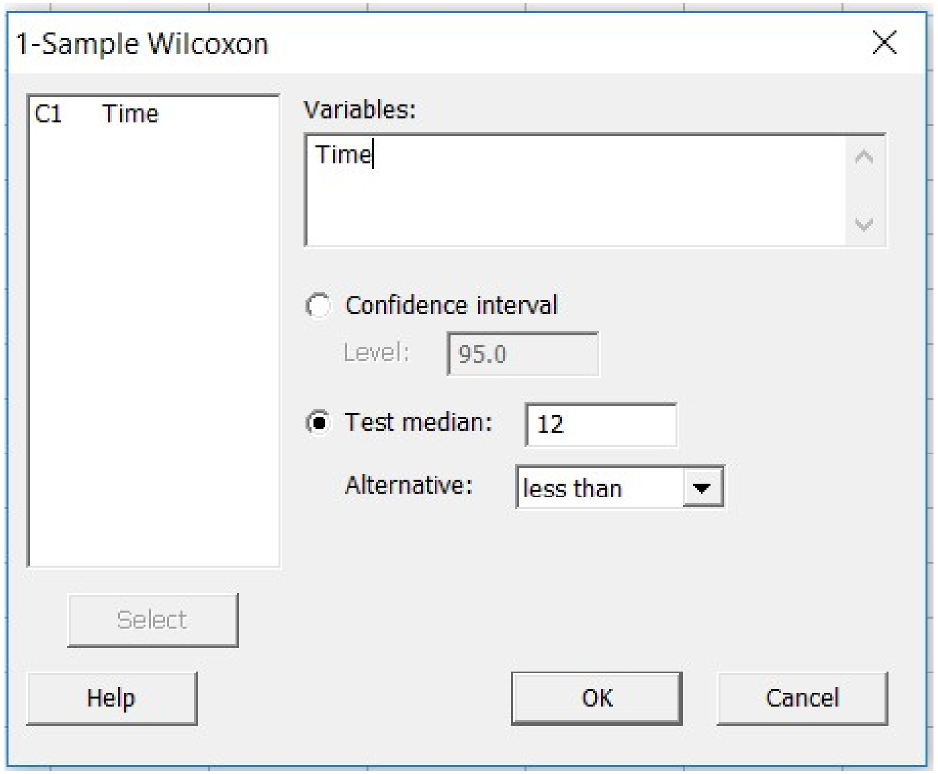
One-Sample Wilcoxon Test - Overview

Example: A chemist wants to see if a newly developed antacid relieves pain in less than 12 minutes.

Stat > Nonparametrics > One Sample Wilcoxon

The data file for this example

can be found in :
Antacid.MTW



One-Sample Wilcoxon Test – Interpreting the Results

Wilcoxon Signed Rank Test: Time

```
Test of median = 12.00 versus median < 12.00

            N for  Wilcoxon          Estimated
        N    Test  Statistic      P     Median
Time   16      16       26.5  0.017      10.05
```

Other results in the Session Window :

The Wilcoxon statistic is 26.5 and the Associated p-value is 0.017

Session Window Results:

Minitab produces only session window results for this test as follows:

Based on the sample data, you want to know if the newly developed antacid relieves pain in less than 12 minutes.

The hypotheses are

Null Hypothesis: H0: Median = 12.00 and
Alternate Hypothesis: H1: Median < 12.00

Estimated Median:

The median of the observations for each treatment. These medians provide an estimate of the population medians for each treatment.

p-value is 0.017, Since, the p-value is less than 0.05, therefore you should reject H0 and conclude that the antacid relieves pain significantly faster than 12 minutes.

Mann-Whitney Test - Overview

Use the two-sample Mann-Whitney (also called two-sample rank or two-sample Wilcoxon rank sum) confidence interval and test procedures to make inferences about the difference between two population medians based on data from two independent, random samples.

For example, you can determine whether

- The packing time of two packing machines is the same
- The time to relief is the same for two pain relievers

Assumptions:

- Samples are randomly drawn whose distributions have the same shape
- The two random samples are independent

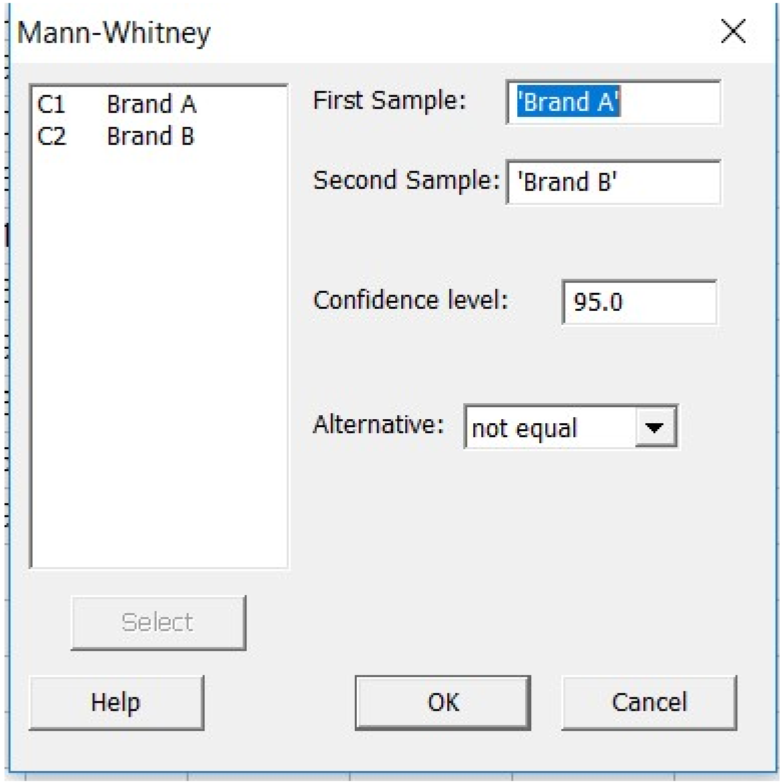
The Mann-Whitney test is a nonparametric alternative to the two-sample t test with pooled sample variances.

Mann-Whitney Test - Overview

Example: A state's highway department uses two brands of paint for striping roads. A highway official wants to know if a difference exists between the two brands of paint. To assess the problem, the official records the number of months that stripes applied with each brand of paint last on the highway.

The data file for this example can be found in : ***Srtipes.MTW***

Stat > Nonparametrics > Mann-Whitney



Mann-Whitney Test – Interpreting the Results

Mann-Whitney Test and CI: Brand A, Brand B

```
          N  Median
Brand A  11  36.000
Brand B  10  37.600


Point estimate for η1 - η2 is -1.850
95.5 Percent CI for η1 - η2 is (-3.000,-0.901)
W = 76.5
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0019
The test is significant at 0.0019 (adjusted for ties)
```

Other results in the Session Window :

The Mann-Whitney statistic is 76.5 and the associated p-value is 0.0019.

Confidence Interval:

Because you do not know the true value of the median, the confidence interval gives you a range of likely values based on the sample. In repeated sampling, the proportion of intervals that include the true value of the median is equal to 1 minus the chosen a-level.

Session Window Results:

Minitab produces only session window results for this test as follows:

Based on your sample, you want to know if the time that the paint stripes last on the highway is the same for the two brands

The hypotheses are

Null Hypothesis: H0: H0: η1 = η2 and
Alternate Hypothesis: H1: H1: η1 not = η2

Point Estimate:

The difference between the sample medians is a point estimate for the difference between population medians.

p-value is 0.0019. Because the p-value is less than 0.05, you should reject H0 and conclude that the median times are significantly different.

Kruskal-Wallis Test - Overview

The Kruskal-Wallis test compares the medians of different samples of data, and can be used where the data samples are not Normally distributed and do not have any obvious outliers.

Example:- A project is looking at the time to deliver different products (INGOT and BILLET). The box plot below shows that the INGOT product appears to be delivered quicker than BILLET, and the team are keen to validate this conclusion before other tools (such as detailed process mapping) are used to find out why.

Because the INGOT results do not appear to be normally distributed (a histogram and Box plot both indicate a skewed distribution), a Kruskal-Wallis test is being used to compare the median values of the two samples.

Kruskal-Wallis Test – Interpreting the Results

Kruskal-Wallis Test: Time to deliver versus Product

```
Kruskal-Wallis Test on Time to deliver

Product    N  Median  Ave Rank      Z
BILLET    25   7.500      29.7   0.73
INGOT     30   6.750      26.6  -0.73
Overall   55              28.0

H = 0.53  DF = 1  P = 0.467
H = 0.54  DF = 1  P = 0.463  (adjusted for ties)
```

Session Window Results:

Minitab produces only session window results for this test as follows:

Firstly the sample sizes and medians of the samples are summarised. The difference in the median values is 0.75 days (7.5-6.75), but this should be considered in combination with the following:

The size of the samples (25 for BILLET and 30 for INGOT) appears relatively low.

The resolution of the data was to the nearest 0.5 days (see previous page).

From these reasons, a hypothesis test is essential in order to decide if the difference in medians is statistically significant, as described on the left.

Kruskal-Wallis Test – Interpreting the Results

Kruskal-Wallis Test: Time to deliver versus Product

```
Kruskal-Wallis Test on Time to deliver

Product    N  Median  Ave Rank      Z
BILLET    25   7.500      29.7   0.73
INGOT     30   6.750      26.6  -0.73
Overall   55              28.0

H = 0.53  DF = 1  P = 0.467
H = 0.54  DF = 1  P = 0.463  (adjusted for ties)
```

Analysing the p-value:

The p-value from this test is 0.463. since this is higher than 0.05, we cannot say with confidence that there is a difference in the medians of the two samples.
In other words, the median delivery times of the two internet products (that the two samples of data represent) could be the same as each other.

Note: the two p-values usually very similar, but if not, use the value that is "adjusted for ties"

So, to summarise the results in day to day language:

Based on the data we have collected, we cannot say with confidence that there is a difference between the medians.
The difference of 0.75 hours between the sample medians could easily have occurred just by chance.

If there is a difference, more data will have to be collected to prove it.

Mood's Median Test - Overview

The Mood's Median test compares the medians(central position) of different samples of data, where the samples are not Normally distributed and where there are obvious outliers.in the data samples.

Example:- A project is looking at the time to deliver different products (INGOT and BILLET).
The data has been stratified into two groups INGOT and BILLETS, and the box plot below shows that the INGOT product appears to be delivered quicker than BILLET.

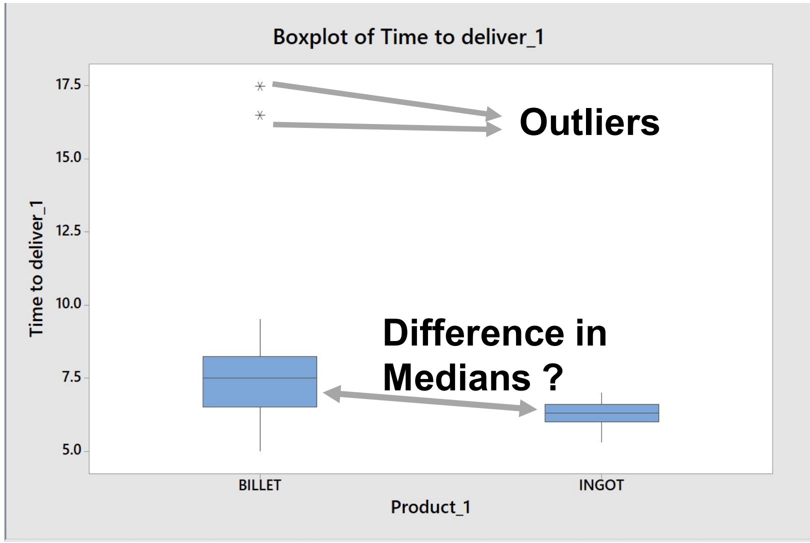
The team are keen to validate this before they set out to find and understand the root cause of this difference. Mood's Median test is being used because the Billet data appears to be skewed and also has some outliers (the asterisks)

Mood’s Median Test - Overview

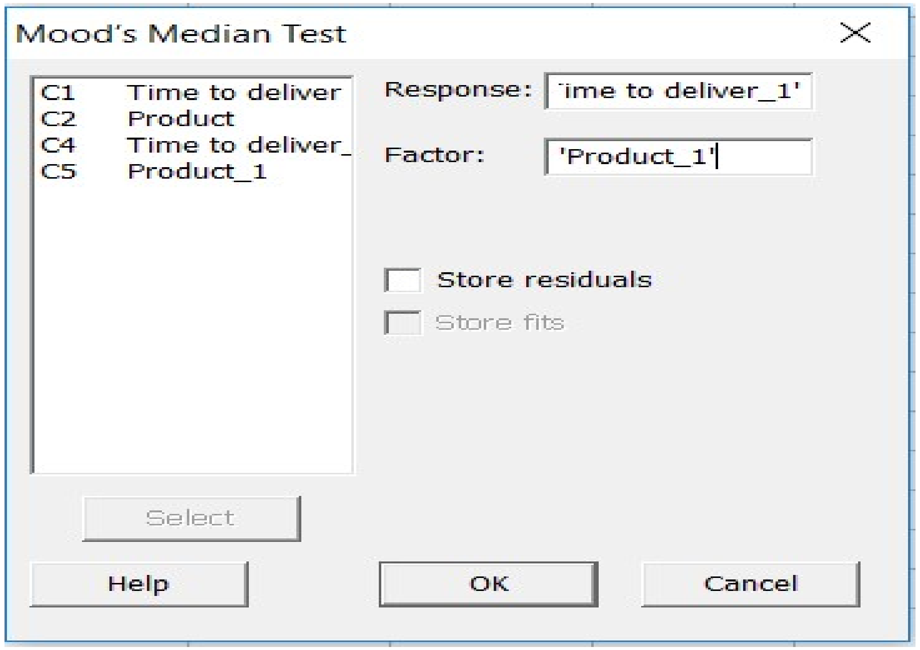
Data format:

Data for the Mood’s Median test must be stacked in one column, with the subgroup(factor) code alongside as shown on the right.

The data file for this example can be found in ***Time to deliver INGOT BILLETS.mpj and in Columns C4***



Stat > Nonparametrics > Mood’s Median



Mood’s Median Test – Interpreting the Results

Mood Median Test: Time to deliver_1 versus Product_1

```
Mood median test for Time to deliver_1
Chi-Square = 7.73    DF = 1    P = 0.005

                                      Individual 95.0% CIs
Product_1  N≤  N>  Median  Q3-Q1  +---------+---------+---------+------
BILLET      9  16    7.50   1.75          (-----------------*--------)
INGOT      22   8    6.30   0.60  (----*--)
                                  +---------+---------+---------+------
                                  6.00      6.60      7.20      7.80

Overall median = 6.50

A 95.0% CI for median(BILLET) - median(INGOT): (0.00,1.91)
```

Session Window Results:

Minitab produces only session window results for this test as follows:

The p-value for the test is 0.005, since this is less than Alpha Level of 0.05 we can say, with 95% confidence, that the medians of the subgroups are different.

A rough graph of the 95% Confidence Intervals (Cis) for the median of the subgroups is shown. Note that although the Cis are visually overlapping, the statistical conclusions is that they are different.

Other results in the Session Window :

Based on the data subgroups,
the difference between the subgroup
sub-group medians is 1.2 Days(7.50-6.30)

The confidence interval for the difference provides more detail and confirms (with 95% confidence), that the difference in medians is somewhere between 1.91 and 0.00 Days.

So, to summarise the results in day to day language:

We can be very confident that there is a difference in the median delivery time for INGOT & BILLETS.

The median delivery time of INGOTs is at least 0 days quicker than BILLETs but could be as much as 1.91 days quicker.

Anexas Consultancy Services

Proportions Tests

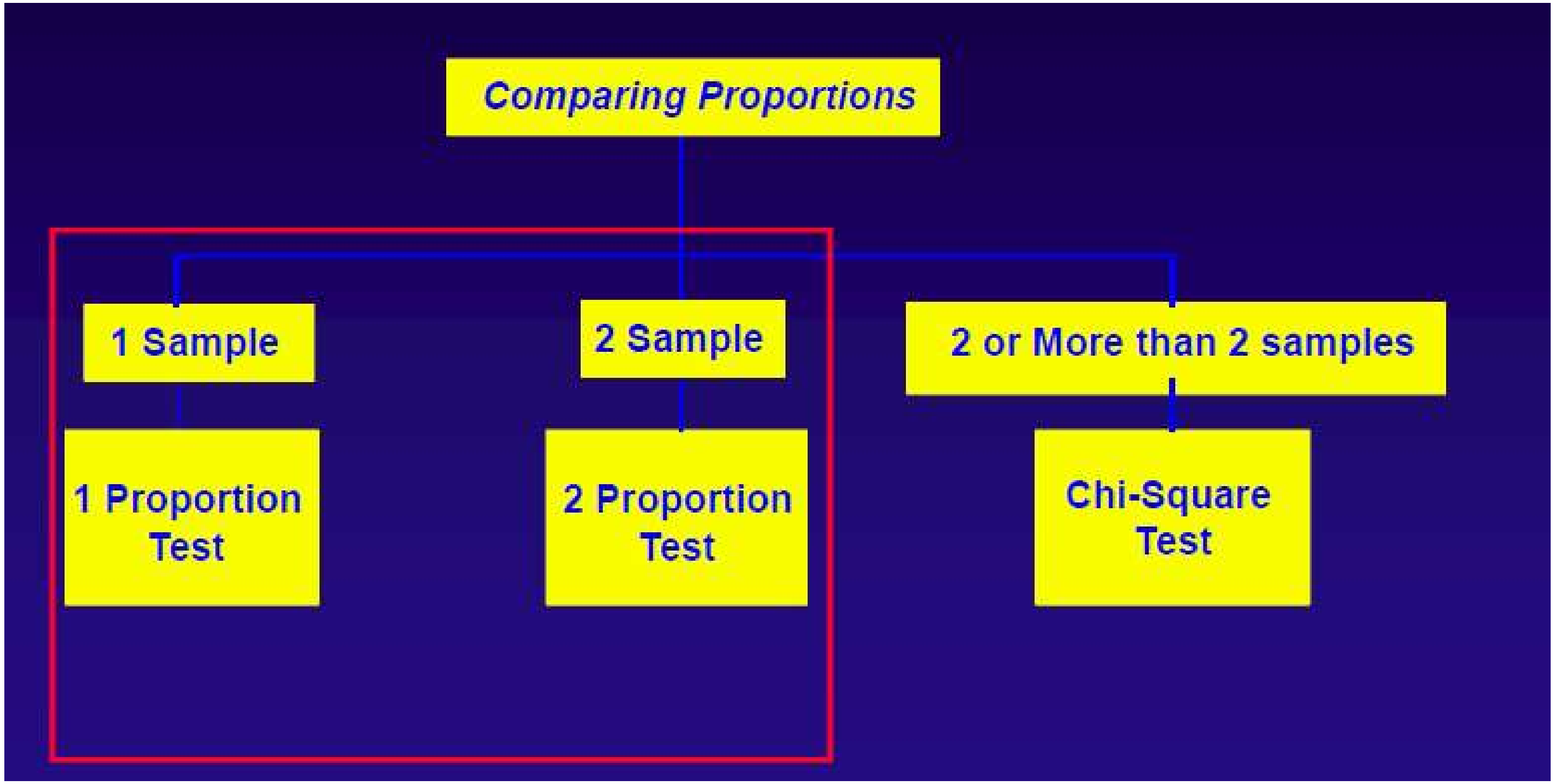
Why Learn Hypothesis Tests of Proportion?

- Make data driven decisions with defined confidence
- Determine if a statistically significant difference of proportion exists between:
  - A sample and a target
  - Two independent samples
  - More than two independent samples

What are Hypothesis Tests of Proportion?

Test	Method for analyzing the differences between:
1 Proportion	a sample proportion and a target value
2 Proportion	proportion obtained from two independent samples

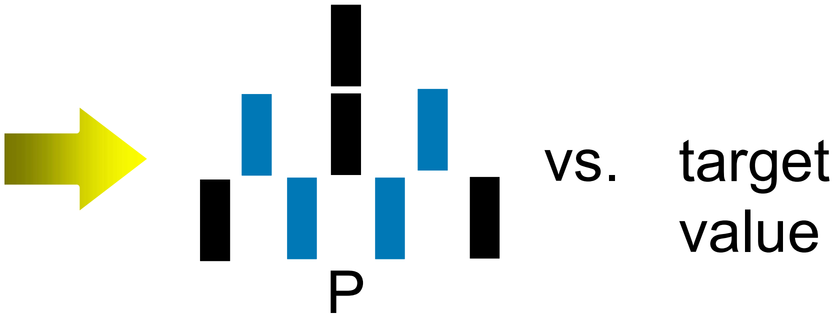
Hypothesis Testing of Proportion - Roadmap



Comparison of Proportion: 2 Scenarios

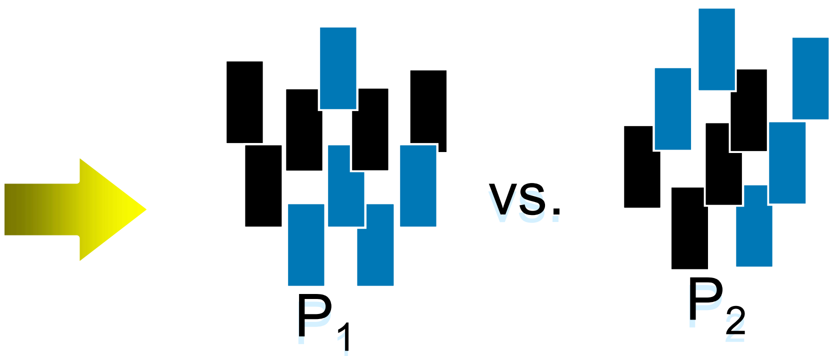
1) Single Proportion Comparison

   One population proportion compared to a target value



2) Two Sample Comparison

   Proportions of two independent populations compared to each other



Anexas Consultancy Services

1 Proportion Test

Single Proportion Comparison

P

vs.

target value

Practical Question
(example)

"Is the population proportion statistically different from the target value?"

Statistical Question

H_O: P = target value

H_a: P $\neq$ target value

1 Proportion Test

- Hypothesis test about the population proportion using information from one sample

Industrial Process Example
Migraine Medicine

A pharmaceutical company has invented a new medicine for relieving migraine headaches. The company wants to test the hypothesis that the drug is effective more than 73% of the time.

A clinical study of 111 out of 143 adults suffering from migraine headaches reported relief after using the drug. Is this sufficient evidence that the drug is effective more than 73% of the time?

Use a 5% significance level.

Industrial Process Example
Migraine Medicine

- Practical Problem
  - Is the migraine medicine effective more than 73% of the time?
- Statistical Problem
  - Is population proportion of medicine effectiveness greater than or equal to 73%?
  - Null hypothesis: population proportion is 73%
  - Alternate hypothesis: population proportion is greater than 73%

Example: Migraine Medicine

- State the hypotheses and significance level

$$H_o: P = 0.73$$

$$H_a: P > 0.73$$

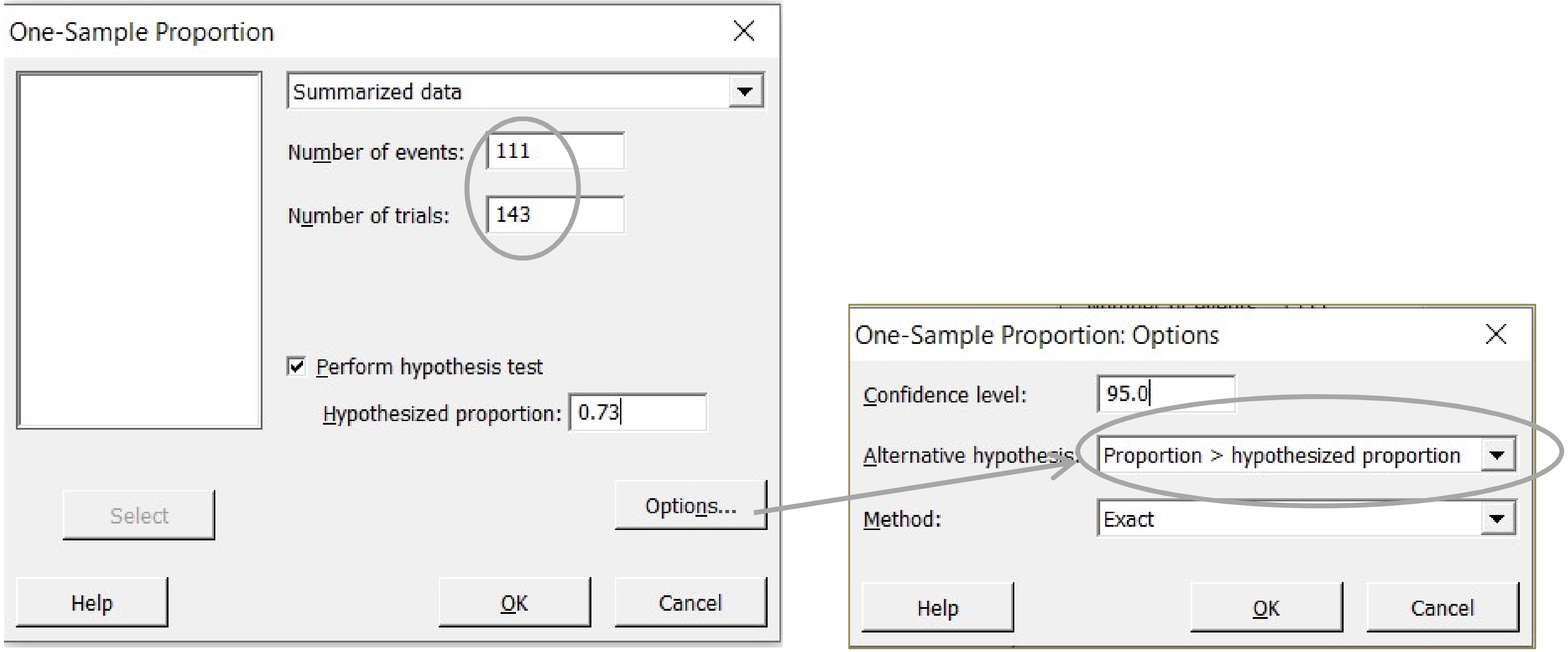
$$\alpha = 0.05$$

- What hypothesis test is appropriate?
  - These hypotheses deal with proportions
  - Comparing population proportion against a target proportion using one sample data
  - Use 1 Proportion Test

Example: Migraine Medicine

Tool Bar Menu > Stat > Basic Statistics > Proportion

Analysis through Minitab



Example: Migraine Medicine

Test and CI for One Proportion

```
Test of p = 0.73 vs p > 0.73

                                                                   Exact
Sample          X        N  Sample p   95.0% Lower Bound   P-Value
1             111      143  0.776224            0.711327     0.124
```

- Interpretation:
  - p-value = 0.124
  - p-value > α-risk (0.05): fail to reject H_o
  - Infer H_o: insufficient evidence that that the drug is more than 73% effective

Business Process Example
IPO Prospectus

A Black Belt is studying the effects of voluntary disclosure of earnings forecast in the Initial Public Offering (IPO) prospectus.

A random sample of 130 IPO prospectus revealed that 58 of them did not reveal their earnings forecast.

Test the hypothesis at 5% significance level that less than 50% of IPO prospectus do not disclose their earnings forecast.

Example: IPO Prospectus

- Practical Problem
  - Is the percentage of IPO prospectus disclosing their earnings forecast less than 50%?

- Statistical Problem
  - Is population proportion of IPO prospectus revealing their earnings forecast less than 50%?
  - Null hypothesis: population proportion is 50%
  - Alternate hypothesis: population proportion is less than 50%

Example: IPO Prospectus

State the hypotheses and significance level

H_o: P = 0.50

H_a: P < 0.50

α = 0.05

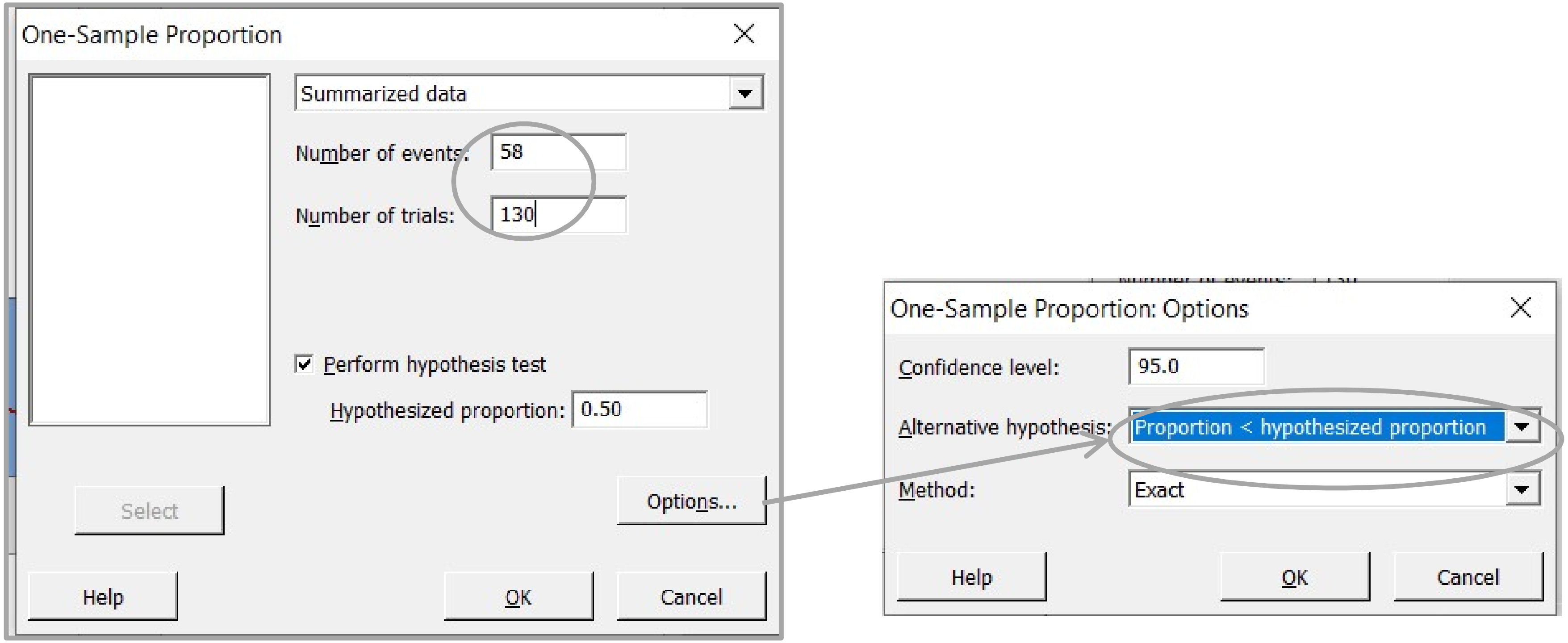
What hypothesis test is appropriate?

- These hypotheses deal with proportions
- Comparing population proportion against a target proportion using one sample data
- Use 1 Proportion Test

Example: IPO Prospectus

Tool Bar Menu > Stat > Basic Statistics > 1 Proportion

Analysis through Minitab



Example: IPO Prospectus

Test and CI for One Proportion

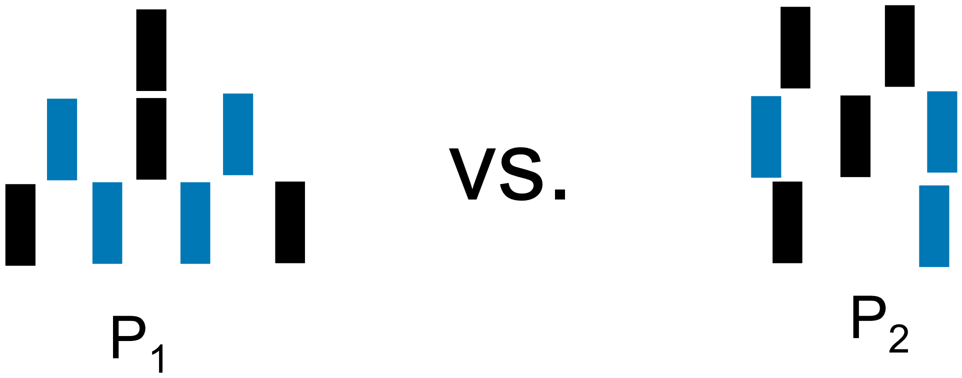
```
Test of p = 0.5 vs p < 0.5

                                                        Exact
Sample       X       N  Sample p  95.0% Upper Bound   P-Value
1           58     130  0.446154           0.522079     0.127
```

- Interpretation:
  - P-value = 0.127.
  - P-value > α-risk (0.05): Fail to reject H_o
  - Infer H_o: insufficient evidence that only less than 50% of IPO prospectus disclose their earnings forecast

Anexas Consultancy Services

2 Proportions Test

Two Sample Proportion Comparison



Practical Question (example)

Are the two populations' proportions
▪statistically different?

Statistical Question

$H_o: P_1 = P_2$

$H_a: P_1 = P_2$

2 Proportion Test

- Hypothesis test about the difference between two population proportions using information from two samples
- Two sets of samples are statistically independent

Industrial Process Example: Comparing Medicines

MedChoice, Inc. distributes two identical brands of medicine for relieving migraine headaches.

It is found from controlled studies that 145 out of 200 people suffering from migraines reported relief through use of Brand A whereas 101 out of 150 people reported relief through the use of Brand B.

The company wants to know if we can conclude at the 5% level of significance that the percentage of people getting relief through use of Brand A is higher than through Brand B?

Example: Comparing Medicines

- Practical Problem
  - Is Brand A better than Brand B in providing relief from migraine headaches?

- Statistical Problem
  - Is population proportion of relief through Brand A greater than population proportion through Brand B?
  - Null hypothesis: population proportion for Brand A = population proportion for Brand B
  - Alternate hypothesis: population proportion for Brand A is greater than that of Brand B

Example: Comparing Medicines

State the Hypotheses and Significance Level

H_o: P_A - P_B = 0

H_a: P_A - P_B > 0

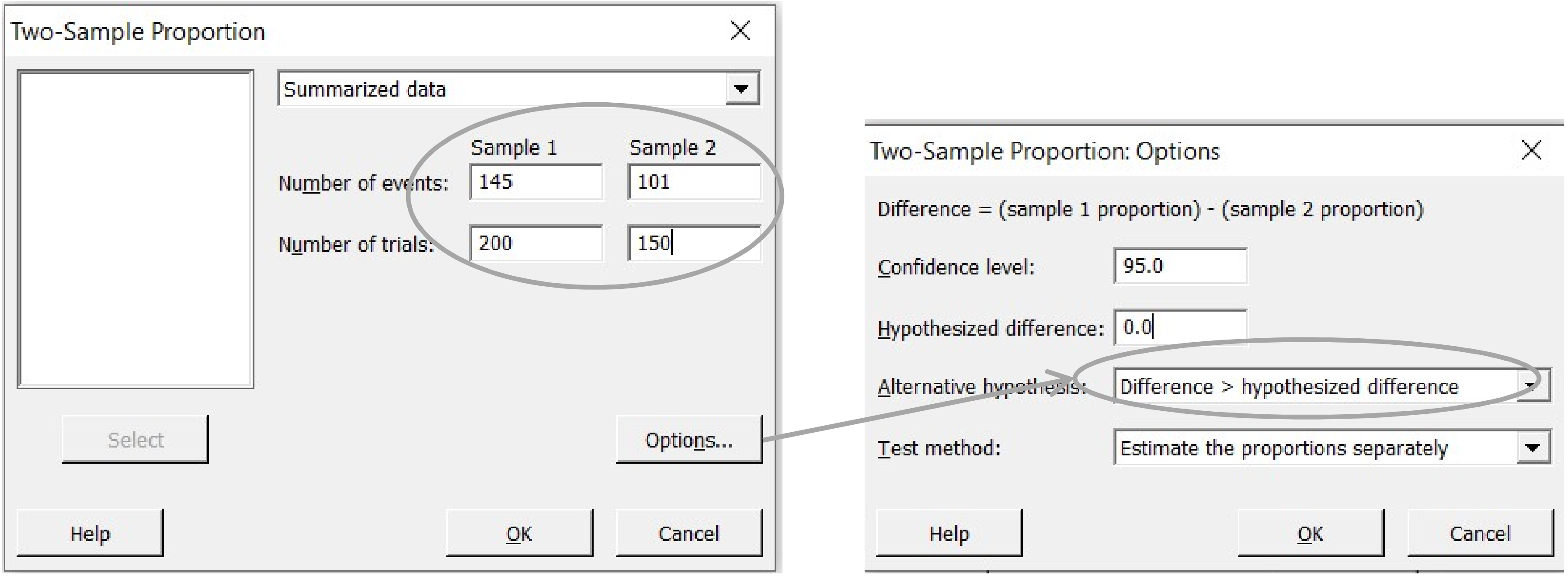
α = 0.05

- What Hypothesis Test is Appropriate?
  - These hypotheses deal with proportion values
  - Comparing population proportions using two sets of independent samples
  - Use 2 Proportion Test

Example: Comparing Medicines

Tool Bar Menu > Stat > Basic Statistics > 2 Proportion

Analysis through Minitab



Example: Comparing Medicines

```
Test and CI for Two Proportions

Sample     X    N  Sample p
1        145  200  0.725000
2        101  150  0.673333


Difference = p (1) - p (2)
Estimate for difference:  0.0516667
95% lower bound for difference:  -0.0299692
Test for difference = 0 (vs > 0):  Z = 1.04  P-Value = 0.149

Fisher's exact test: P-Value = 0.176
```

What is the Interpretation?

p-value = 0.149

p- value (0.149) > α-risk (0.05); fail to reject H_o

Infer H_o: insufficient evidence that brand A is more effective than brand B

Anexas Consultancy Services

Hypothesis Testing
Chi-Square Tests

Why Learn Chi-Square Tools?

Make data driven decisions with defined confidence

Determine if

- Two attribute variables are related
- A population fits a certain probability model (distribution)

What Are Chi-Square Tools?

Chi-Square Goodness-of-Fit Test

To test if a particular distribution (model) is a good fit for a population

Chi-Square Test for Association

To test if a relationship between two attribute variables exists

$$\chi^2 = \sum_{j=1}^{g} \frac{(f_o - f_e)^2}{f_e}$$

- *Chi-Square Statistic*

Both of these tools use the Chi-Square distribution, where f_o and f_e are the observed and expected frequencies, respectively.

Test for Association

Business Process Example: Black Belt Projects

A sample of Black Belts was asked to rate both their six sigma project performance and the average weekly hours spent with the Project Champion discussing project details. The results are shown in the following table. Test at the 5% level the null hypothesis of no association between the two sets of ratings.

Data is given in ***Chi1.mtw***

Time with Champion	PROJECT PERFORMANCE		
HOURS	Low	Medium	High
< 0.1	17	21	12
0.1 - 1	31	53	21
> 1	17	42	71

Example: Black Belt Projects

- Practical problem
  - Does the performance of Black Belt projects depend on time spent with Project Champions?
- Statistical problem
  - Is there an association between project performance and time spent with Champion?
  - Null hypothesis: project performance is independent of the time spent with Champion
  - Alternate hypothesis: project performance is dependent of the time spent with Champion
- What hypothesis test is appropriate?
  - These hypotheses deal with relationship between two attribute variables
  - Use Chi-Square Test for Association

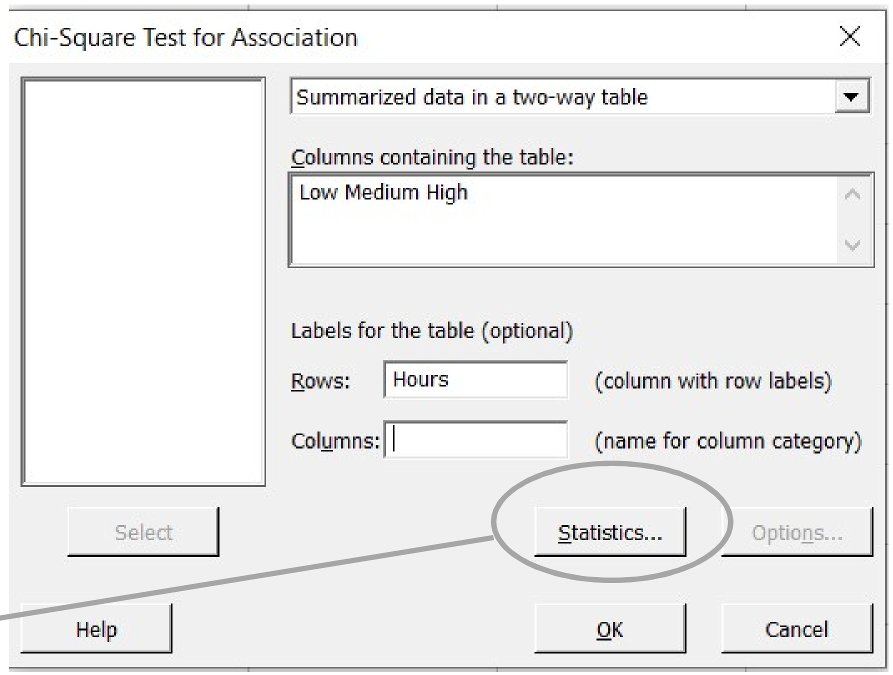
Example: Black Belt Projects

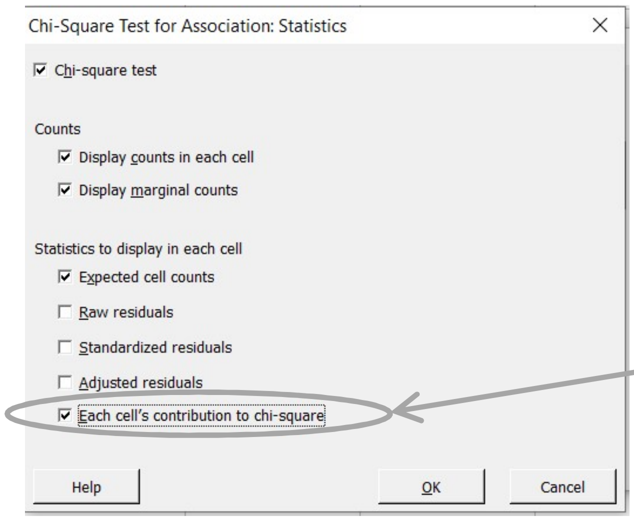
1. Open data file Chi1.mtw

C1-T	C2	C3	C4
Hours	Low	Medium	High
<0.1	17	21	12
0.1-1.0	31	53	21
>1	17	42	71

Tool Bar Menu > Stat > Tables > Chi-Square Test

2. *Stat > Tables > Chi-Square Test for Association*
3. Fill in the dialog as shown below:





4. Click Statistics and Enable Each cells' contribution to chi-square

Example: Black Belt Projects

Chi-Square Test: Low, Medium, High

Rows: Hours   Columns: Worksheet columns

	Low	Medium	High	All
<0.1	17	21	12	50
	11.40	20.35	18.25	
0.1-1.0	31	53	21	105
	23.95	42.74	38.32	
>1	17	42	71	130
	29.65	52.91	47.44	
All	65	116	104	285

Cell Contents: Count
Expected count

Pearson Chi-Square = 36.622, DF = 4, P-Value = 0.000
Likelihood Ratio Chi-Square = 37.348, DF = 4, P-Value = 0.000

- Interpret output
- What is □^{2}(calc)
- What is the p-value?
- What is its interpretation?

Example: Black Belt Projects

- Interpretation:
  - p-value = 0.000
  - p-value < a-risk (0.01): reject Ho
  - Infer Ha: sufficient evidence that Black Belt project performance and time spent with Champion are dependent

Test for Association Exercise

- **Objective:** Practice doing a Chi-square test in Minitab and interpret the results

  Data: ***Shipments.MTW***
- **Background:**
  - We have been tracking time taken to ship subassemblies between two manufacturing facilities by three carriers
    - Shipping records have been examined for 12 months
  - Deliveries are expected to be completed within 24 hours
  - The results for all shipments are summarized on the next page

Test for Association Exercise, cont.

Carrier	Within 24 Hours	24-36 Hours	36+ Hours
A	1810	679	551
B	609	219	237
C	176	85	58

Test for Association Exercise, cont.

- **Instructions:**
  1. Use the summarized table data in the worksheet
  2. Do a Chi-square test and interpret it
  3. Be prepared to report the P-value, your conclusions, and recommended next steps

Test for Association Exercise, Answers

- **Minitab output**

Chi-square Test: Within24, 2436hours, 36 + hours

```
Expected counts are printed below observed counts
Chi-Square contributions are printed below expected counts

          Within    24-36
        24 hours    hours   36+ hours  Total
    1       1810      679         551   3040
         1783.18   675.48      581.34
           0.403    0.018       1.583

    2        609      219         237   1065
          624.70   236.64      203.66
           0.395    1.315       5.458

    3        176       85          58    319
          187.12    70.88       61.00
           0.660    2.812       0.148

Total       2595      983         846   4424

Chi-Sq = 12.793, DF = 4, P-Value = 0.012
```

Row labels: 1 = A, 2 = B, 3 = C

More deliveries beyond 24 hours than expected. These cells contribute the most to the chi-square.

Significant

Conclusion: The carriers differ: Carrier C has more deliveries than expected between 24 and 36 hours and Carrier B has more deliveries than expected in 36+ hours

Test for Association Exercise

Use the following data to decide if the outcome of a surgical procedure depends on the hospital used

Condition	Hosp A	Hosp B	Hosp C	Hosp D	Hosp E
no improvement	13	5	8	21	43
partial functional restoration	18	10	36	56	29
complete functional restoration	16	16	35	51	10

Anexas Consultancy Services

Hypothesis Testing
Correlation and Regression

Hypothesis Tests

Y	X	Hypothesis Test
Continuous / Variable Data	Attribute / Discrete Data	1-z, 1-t, 2-t, paired t, ANOVA
Attribute / Discrete Data	Attribute / Discrete Data	1-p, 2-p, Chi Square
Continuos / Variable Data	Continuos / Variable Data	Correlation, Regression, Multiple Regression
Attribute / Discrete Data	Continuous / Variable Data	Logistic Regression

Why Learn Correlation and Regression?

- Explore the existence of relationship between variables with the aid of data
- Screen variables and determine which variable(s) has the biggest impact on the response(s) variable
- Describe the nature of relationship with the help of an equation and use it for prediction

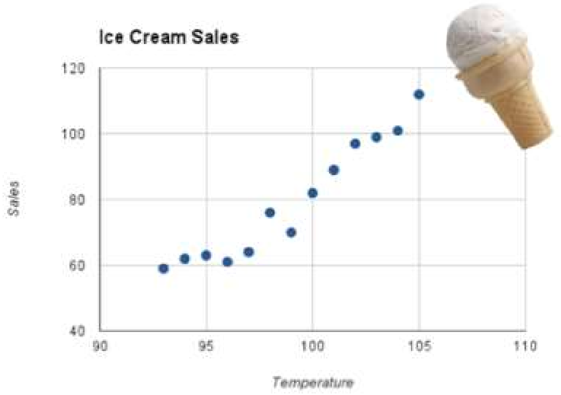
Anexas Consultancy Services

Correlation

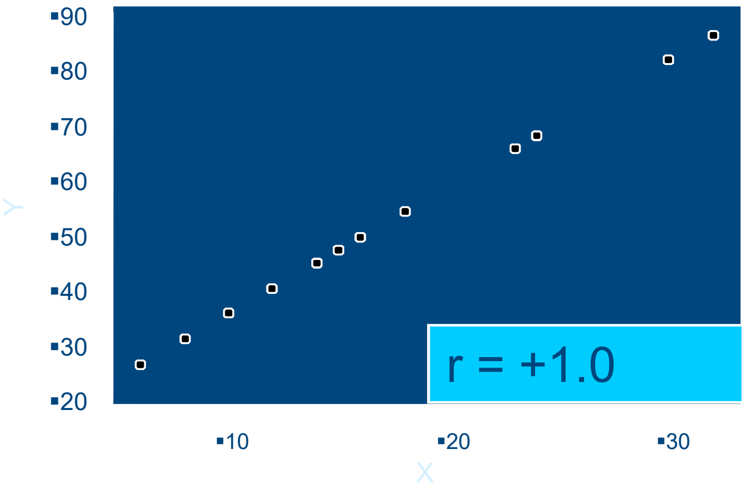
What is Correlation?

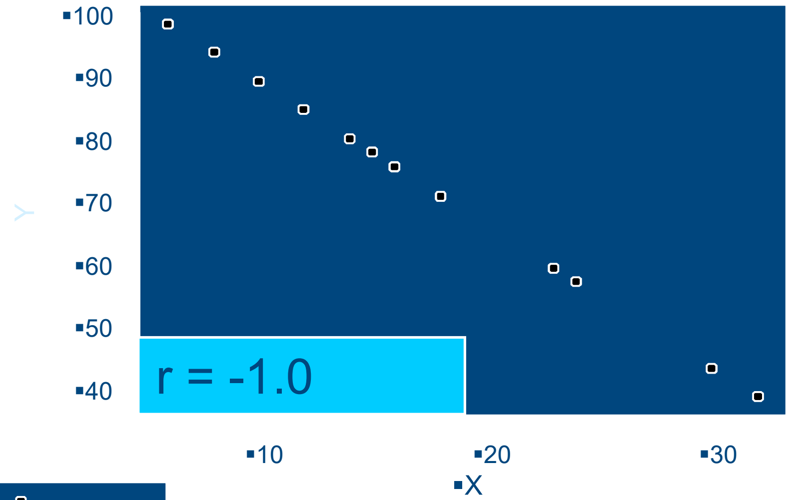
- Correlation is a measure of the strength of association between two quantitative variables
  (Ex: Pressure and Yield)
- Measures the degree of linearity between two variables assumed to be completely independent of each other

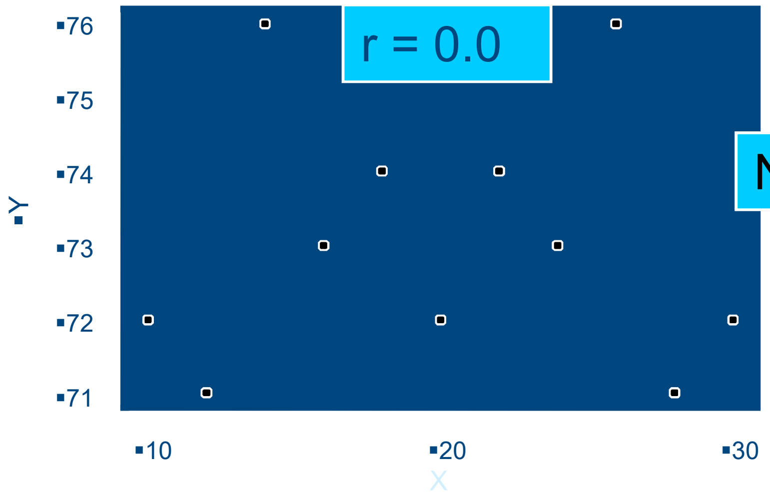
Correlation coefficient or P*earson* correlation coefficient is a way of measuring the strength of correlation



Correlation Coefficient



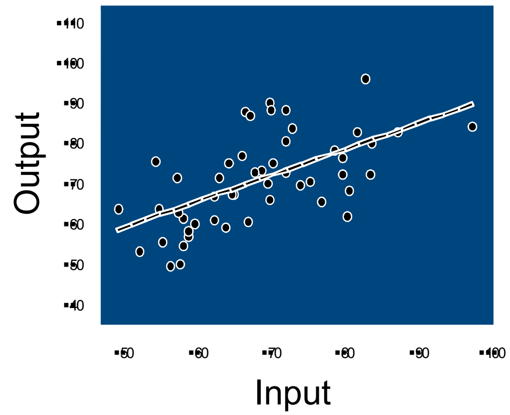




No correlation

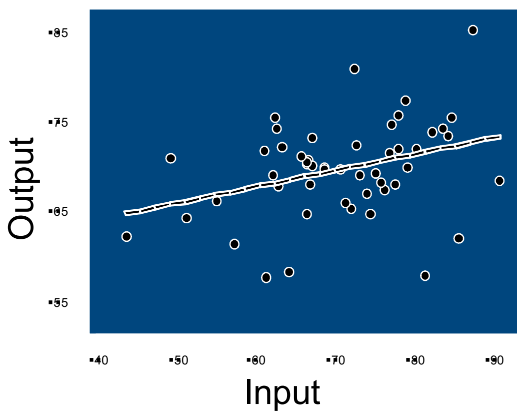
Strength and Direction of "+" Correlation

Moderate positive correlation



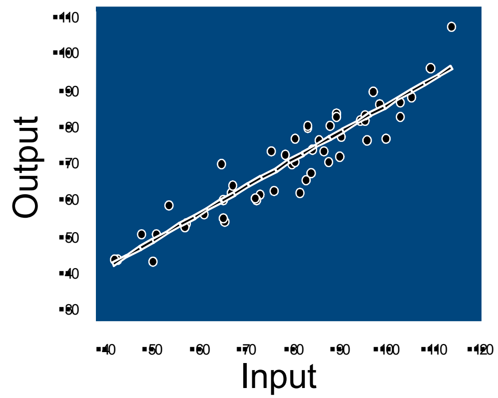
Y=25.7595+0.645418X
R Squared=0.369

Weak positive correlation



Y=56.6537+0.181987X
R Squared=0.115

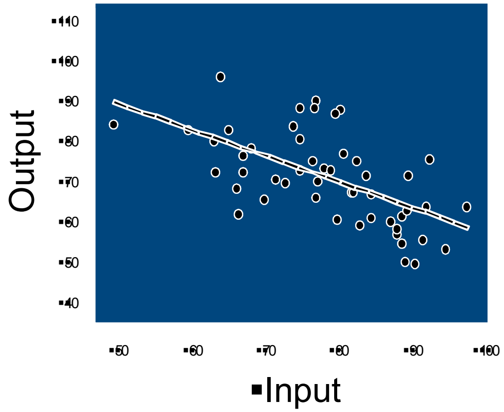
Strong positive correlation



Y=9.77271+0.745022X
R Squared=0.876

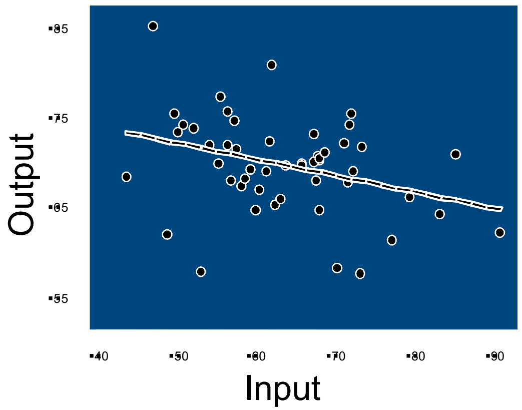
Strength and Direction of "-" Correlation

Moderate negative correlation



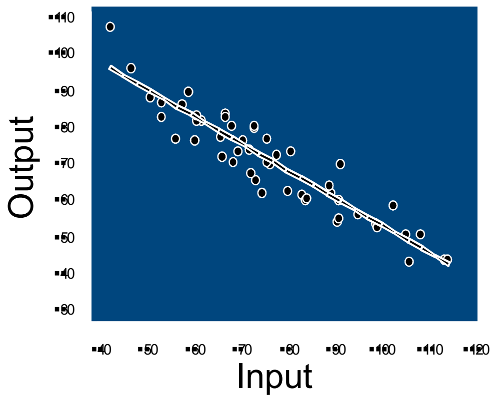
Y=90.3013-0.645418X
R Squared=0.369

Weak negative correlation



Y=74.8524-0.181987X
R Squared=0.115

Strong negative correlation

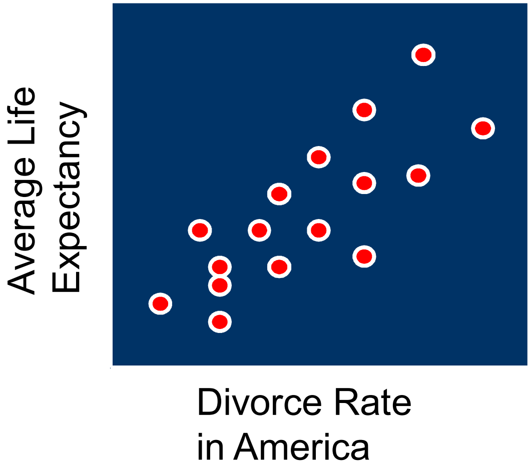


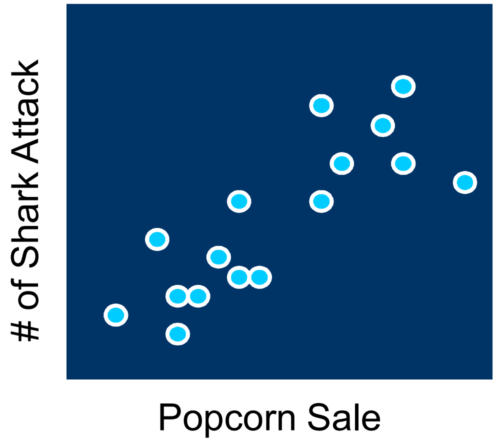
Y=99.1754-0.745022X
R Squared=0.876

Correlation vs. Causation

Data shows that average life expectancy of Americans increased when the divorce rate went up!

Is there a correlation between grass height and hair length?





Correlation does not imply causation! A third variable may be 'lurking' that causes both x and y to vary

Business Process Example: Cereal Sales

A market research analyst for a certain brand of cereal is interested in finding out if there is a relationship between the sales generated and shelf space used to display the cereal. As a result she conducted a study and collected data from 12 different stores selling this brand of cereal.

Shelf Space	Sales
574	960
635	1709
533	651
560	831
628	1460
615	1473
540	751
587	1238
656	1924
594	1370
622	1609
567	1120

The data contains sales $ generated for a certain month and the shelf space dedicated to the product.

What would you do?

What questions might you ask?

Data in ***Sales.mtw***

Example: Cereal Sales

- Practical Problem
  - Is there a relationship between sales $ from cereal and the shelf space used to display the cereal?
  - If there a relationship, how strong is that relationship?

- Statistical Problem
  - Are the variables ‘Sales’ and ‘Shelf Space’ correlated?
  - Null hypothesis: Sales and Shelf space are not correlated
  - Alternate hypothesis: Sales and Shelf space are correlated

Example: Cereal Sales

State the Hypotheses and Significance Level

H_o: $\rho = 0$

H_a: $\rho \neq 0$

$\alpha = 0.01$

Notice that the hypotheses are about a population parameter

What Hypothesis Test is Appropriate?

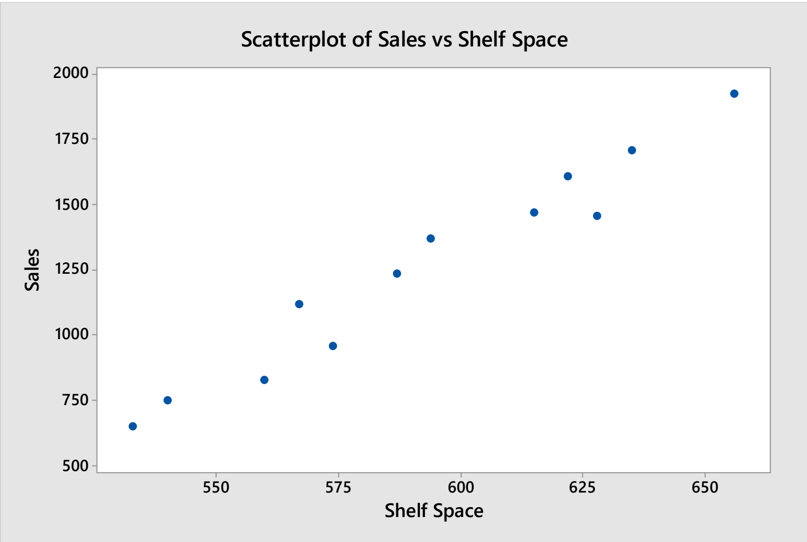
- These hypotheses deal with correlation coefficient
- Make decisions based on Pearson correlation coefficient and ‘p-value’

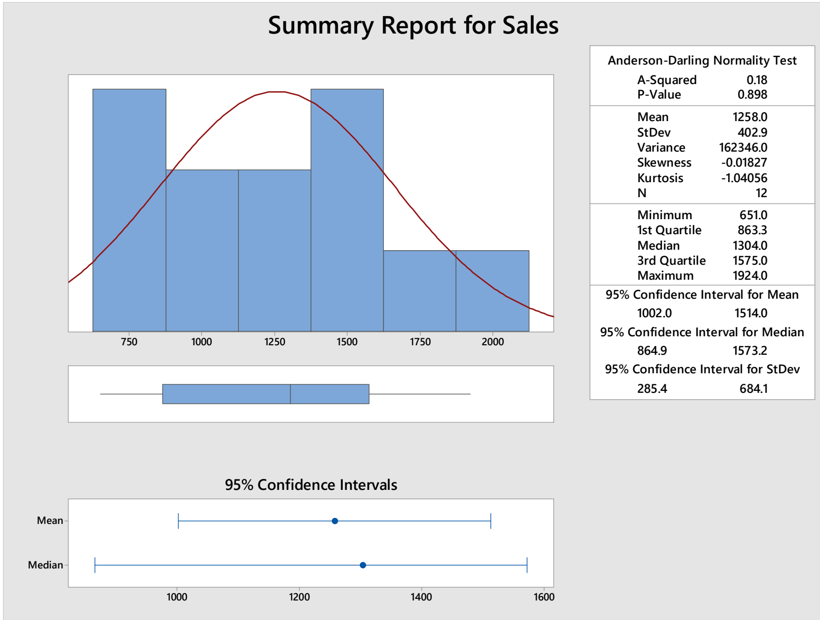
Example: Cereal Sales

Tool Bar Menu > Stat > Basic Statistics > Graphical Summary

- Practical and Graphical:
  - Practical questions about the data?
  - Plot the data using different techniques

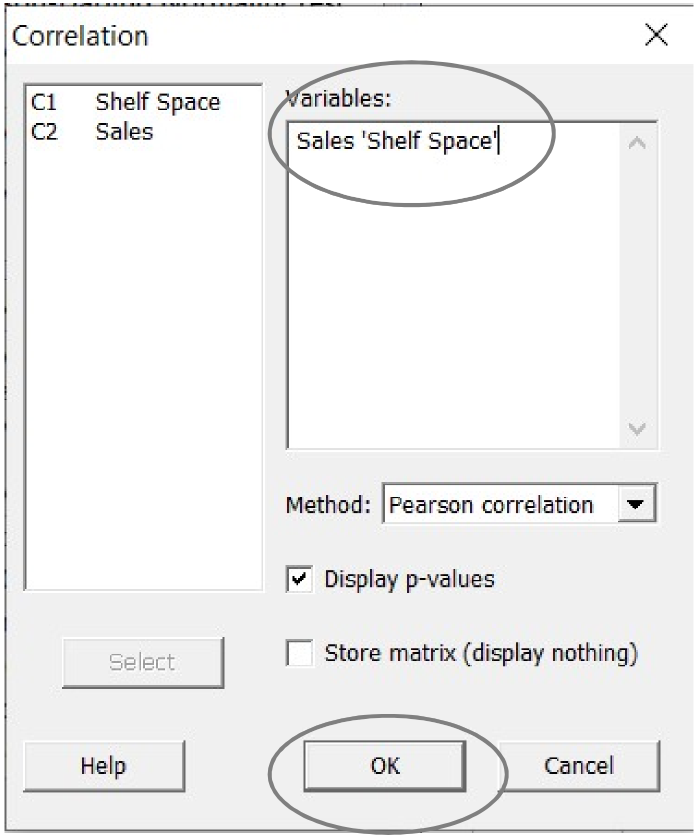
Graph > Scatter Plot





Example: Cereal Sales

Tool Bar Menu > Stat > Basic Statistics > Correlation

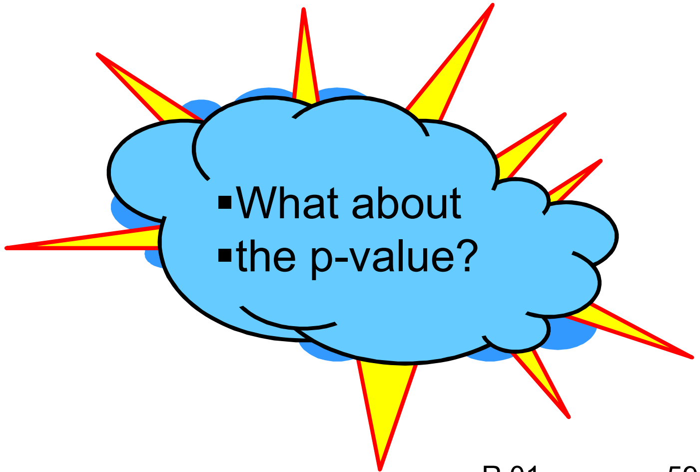


Example: Cereal Sales

Correlations: Shelf Space, Sales

Pearson correlation of Shelf Space and Sales = 0.978
p-value = 0.000

- What is the Decision?
  - Pearson correlation or correlation coefficient for the sample, r = 0.978
  - Does that mean 'ρ' is greater than zero? Or could it be that r = 0.978 due to chance variation while 'ρ' is still zero?
  - Answer this question using table next page



Example: Cereal Sales

- What is the statistical interpretation?
  - p-value (0.000) < α-risk (0.01): reject the null hypothesis
  - Infer H_a: sufficient evidence that there is a correlation between sales $ and shelf space

Regression

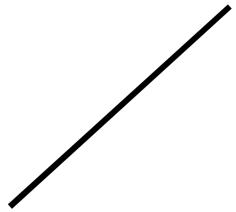
Correlation and Regression

- Correlation tells how much linear association exists between two variables
- The Regression process creates a line that best resembles the relationship between process input and output and also provides an equation describing the nature of relationship.

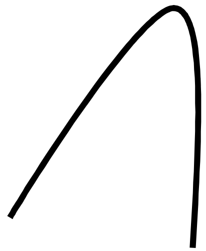
Different types of Mathematical Models

- The regression process can fit several different types of line, since the linear relationship won't be applicable to all situations. The alternatives are

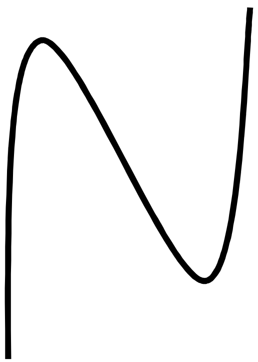
Different types of Mathematical Models



- **Linear:** A simple, common relationship that has the simplest mathematical model: Y= m(x) + c
- Where m and c are constants



- **Quadratic:** A more complex mathematical model that includes X2 term. This can be used to model process relationships that rise and then fall again.



- **Cubic:** A rarer situation, where the process relationship rises, falls, then rises again (or vice versa).

Correlation and Regression

- Correlation tells how much linear association exists between two variables
- Regression provides an equation describing the nature of relationship

Correlations: Shelf Space, Sales

Pearson correlation of Shelf Space and Sales = 0.978

p-value = 0.000

Regression Analysis: Sales versus Shelf Space

The regression equation is Sales = - 4711 + 10.1 Shelf Space

Regression Terminology

- Response Variable
  - This is the uncontrolled variable - also known as dependent variable, output variable or Y variable
- Regressor Variable
  - Response depends on these variables - also known as independent variables, input variables, or X variables
- Noise Variable
  - Input variables (X) that are not controlled in the experiment
- Regression Equation
  - Equation that describes the relationship between independent variables and dependent variable
- Residuals
  - Difference between predicted response values and observed response values

Regression Objectives

- Determination of a Model
  - Explore the existence of relationship
- Prediction
  - Describe the nature of relationship using an equation and use the equation for prediction
- Estimation
  - To assess the accuracy of prediction achieved by the regression equation
- Determination of KPIV
  - Screen variables and determine which variable has the biggest impact on the response variable

Types of Regression

Simple Linear Regression

Single regressor (x) variable such as x_1 and model linear with respect to coefficients

Example 1: $y = a_0 + a_1x + error$

Example 2: $y = a_0 + a_1x + a_2 x^2 + a_3 x^3 + error$

Note: 'Linear' refers to the coefficients a_0, a_1, a_2 , etc. It implies that each term containing a coefficient is added to the model. In example 2, the relationship between x and y are cubic polynomial in nature, but the model is linear with respect to the coefficients.

Types of Regression

Multiple Linear Regression

Multiple regressor (x) variables such as x_1, x_2, x_3 and model linear with respect to coefficients

Example: $y = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 + \text{error}$

Simple Non-Linear Regression

Single regressor (x) variable such as x and model non-linear with respect to coefficients

Example: $y = a_0 + a_1 (1-e^{-a_2 x}) + \text{error}$

Multiple Non-Linear Regression

Multiple regressor (x) variables such as x_1, x_2, x_3 and model non-linear with respect to coefficients

Example: $y = (a_0 + a_1 x_1) / a_2 x_2 + a_3 x_3 + \text{error}$

Anexas Consultancy Services

Simple Linear Regression

Simple Linear Regression

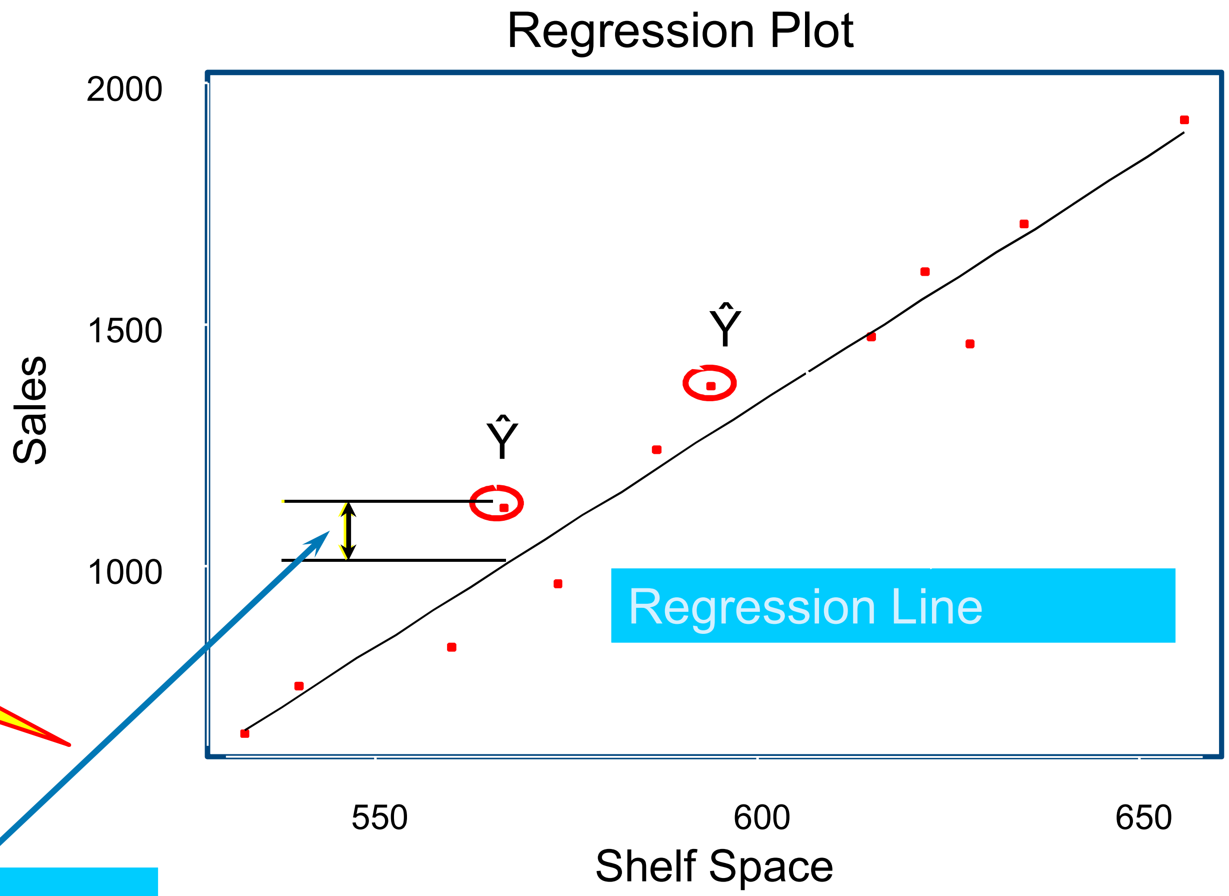
- Use one independent variable (x) to explain the variation in dependent variable (y)
  - Example 1: use shelf space to explain variation sales $
  - Example 2: amount of fertilizer applied to explain the yield of crop
- Method of Least Squares
  - Use the ‘Method of Least Squares’ to find the best fitting regression line

Method of Least Squares

Objective:

Find a line that will minimize sum of squares of residuals

Residuals are the error of prediction



Residual = $Y - \hat{Y}$

Business Process Example: Cereal Sales

A market research analyst for a certain brand of cereal is interested in predicting the sales generated from information on shelf space used to display the cereal. As a result she conducted a study and collected data from 12 different stores selling this brand of cereal

Shelf Space, Sq in	Sales, $
574	960
635	1779
533	651
560	831
628	1460
615	1370
540	851
587	1220
656	1889
594	1370
622	1609
567	1120

- The data contains sales $ generated for a certain month and the shelf space dedicated to the product
- How will we create a simple linear regression model for the two variables?
- Predict the sales $ using the regression equation when shelf space is 615 sq. in.

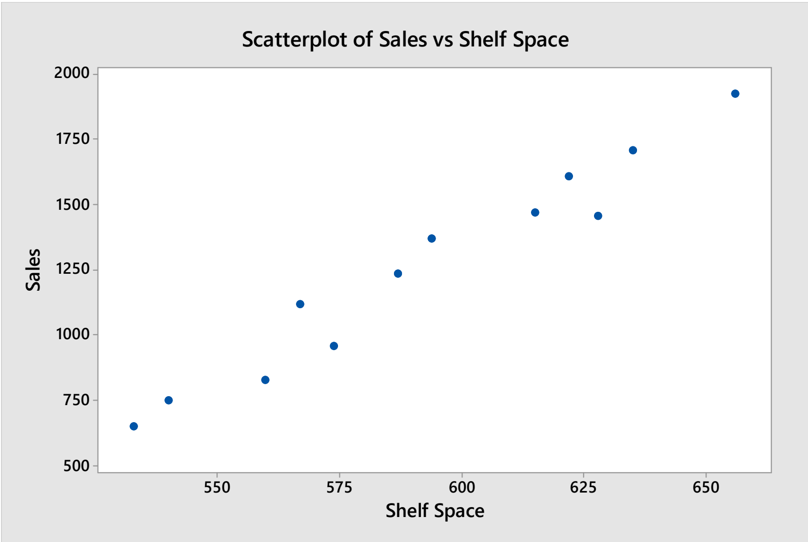
Data in Sales.mtw

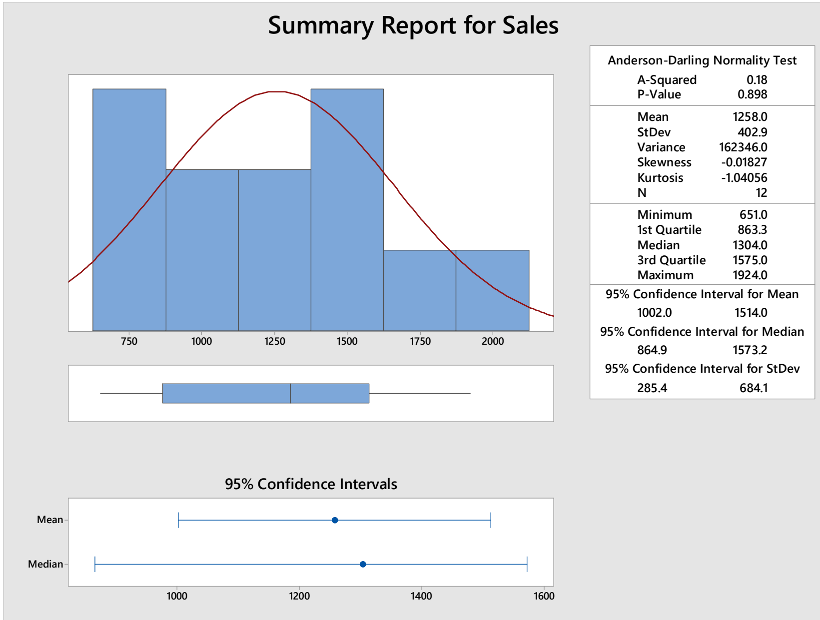
Example: Cereal Sales

Tool Bar Menu > Stat > Basic Statistics > Graphical Summery

- Practical and Graphical:
  - Practical questions about the data?
  - Plot the data using different techniques

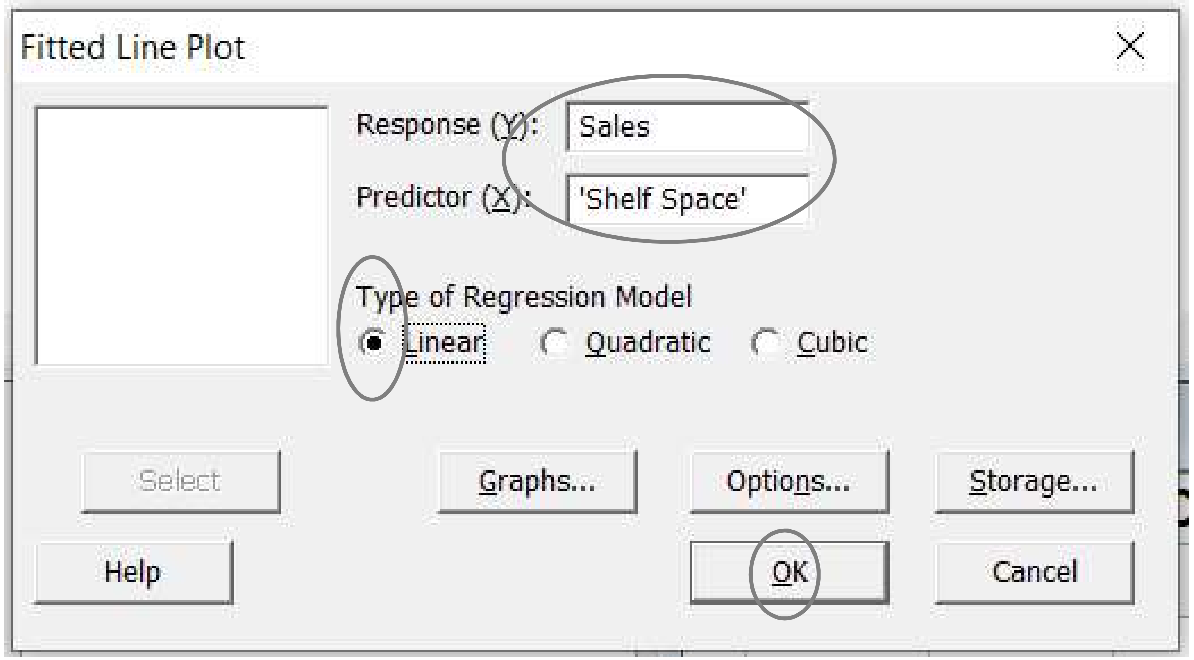
Graph > Scatter Plot





Example: Cereal Sales

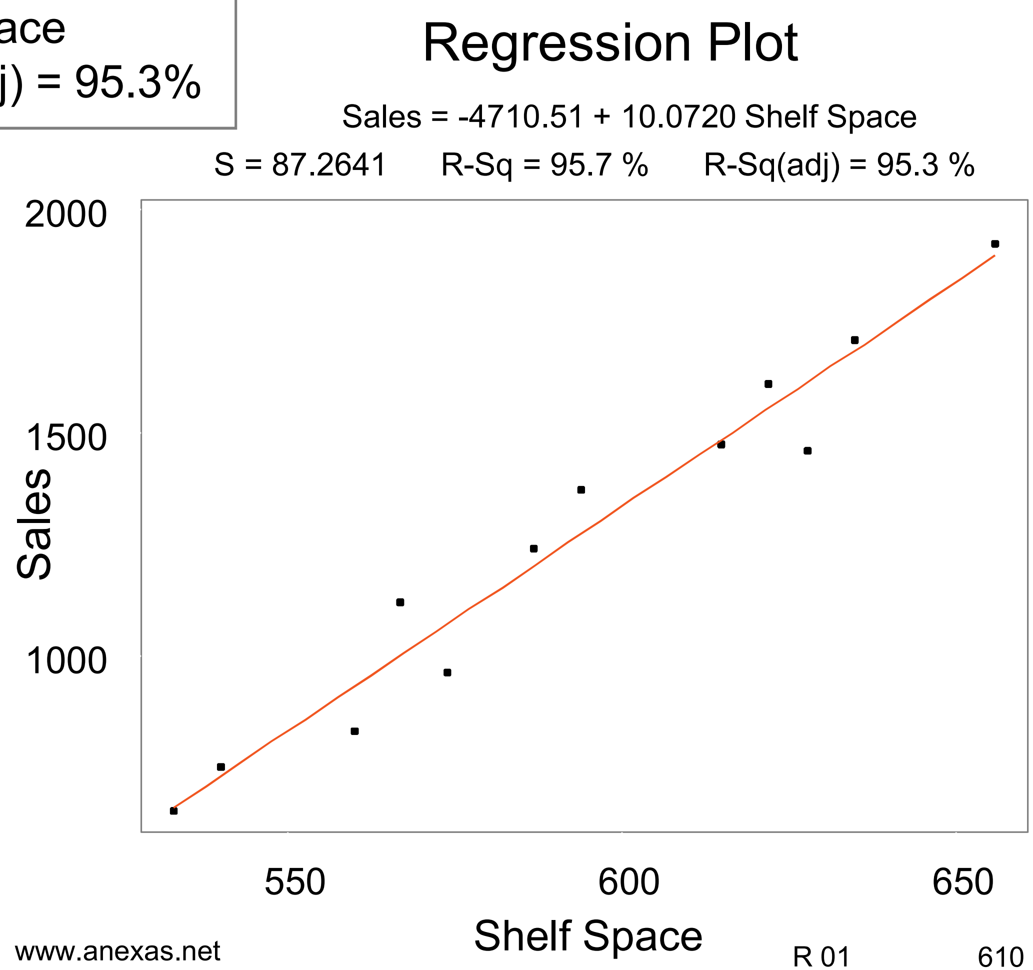
- Tool Bar Menu > Stat > Regression > Fitted Line Plot



Example: Cereal Sales

The regression equation is
Sales = -4710.51 + 10.0720 Shelf Space
S = 87.2641 R-Sq = 95.7 % R-Sq(adj) = 95.3%

- Also from previous, correlation coefficient, r = 0.978
- What do these numbers mean?



Example: Cereal Sales

Session Output from Minitab

Regression Analysis: Sales versus Shelf Space
The regression equation is
Sales = -4710.51 + 10.0720 Shelf Space

S = 87.2641 R-Sq = 95.7 % R-Sq(adj) = 95.3 %
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1709656	1709656	224.511	0.000
Error	10	76150	7615		
Total	11	1785806			

Regression is significant

What About R-squared?

- R-squared is a measure describing the quality of regression
- Measures the proportion of variation that is explained by the regression model
- $R^2 = SS_{regression} / SS_{total} = (SS_{total} - SS_{error}) / SS_{total} = 1 - [SS_{error} / SS_{total}]$

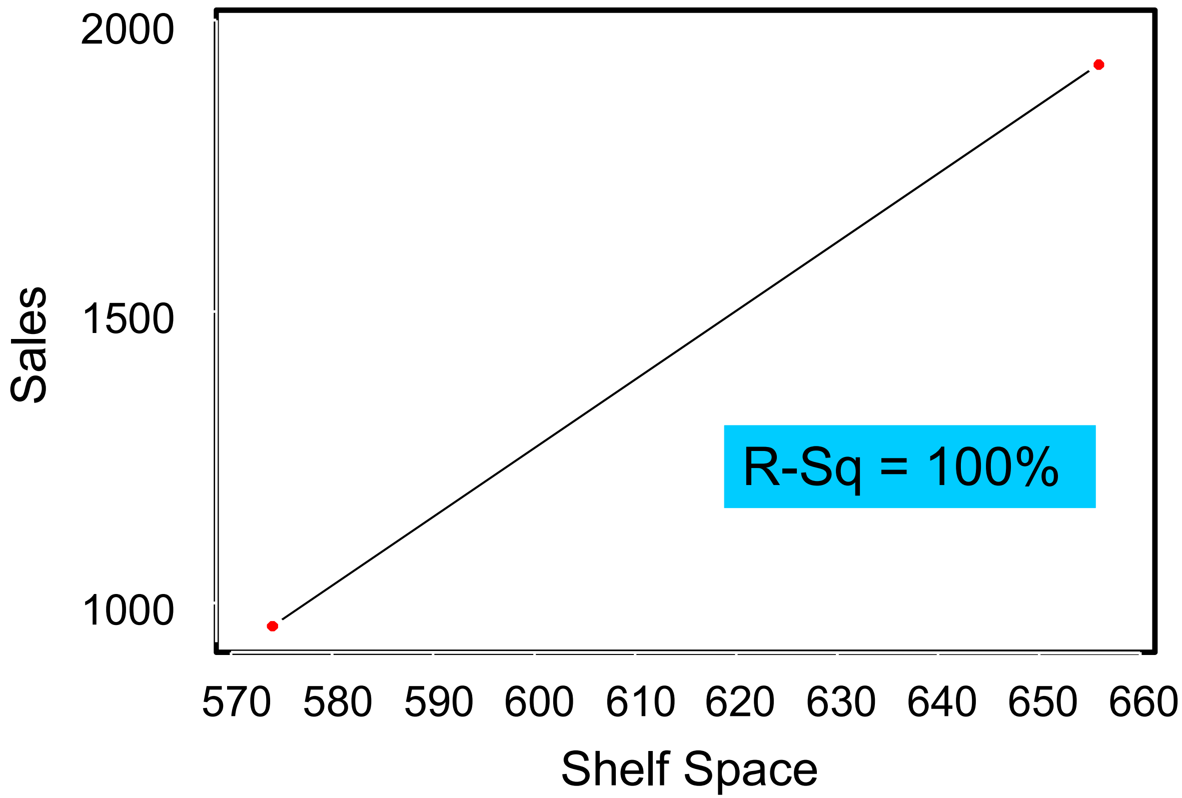
Source	DF	SS	MS	F	P
Regression	1	1709656	1709656	224.511	0.000
Error	10	76150	7615		
Total	11	1785806			

$R^2 = 1709656 / 1785806 = 95.74\%$

95.7% of variation in sales can be explained by variation in shelf space

What About R-Sq?

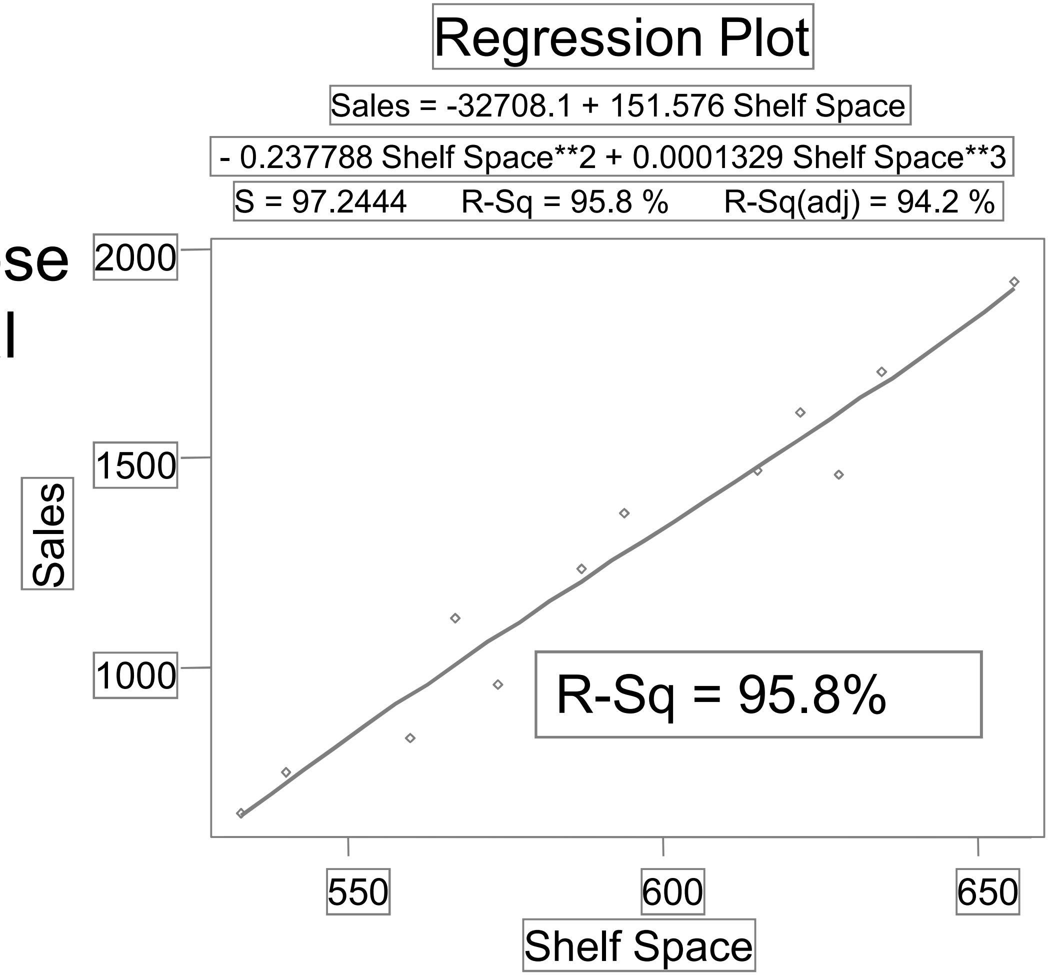
- What is the R-squared on a regression with two data points?
- Does that mean a model with two data points is better?



Example: Cereal Sales

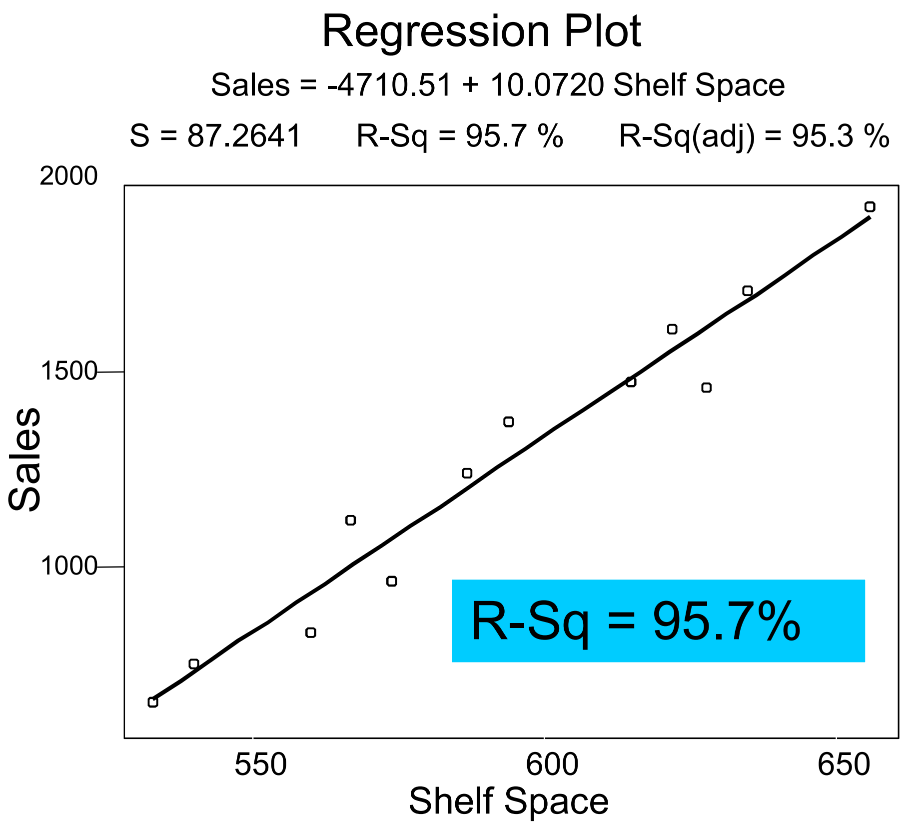
Tool Bar Menu > Stat > Regression > Fitted Line Plot

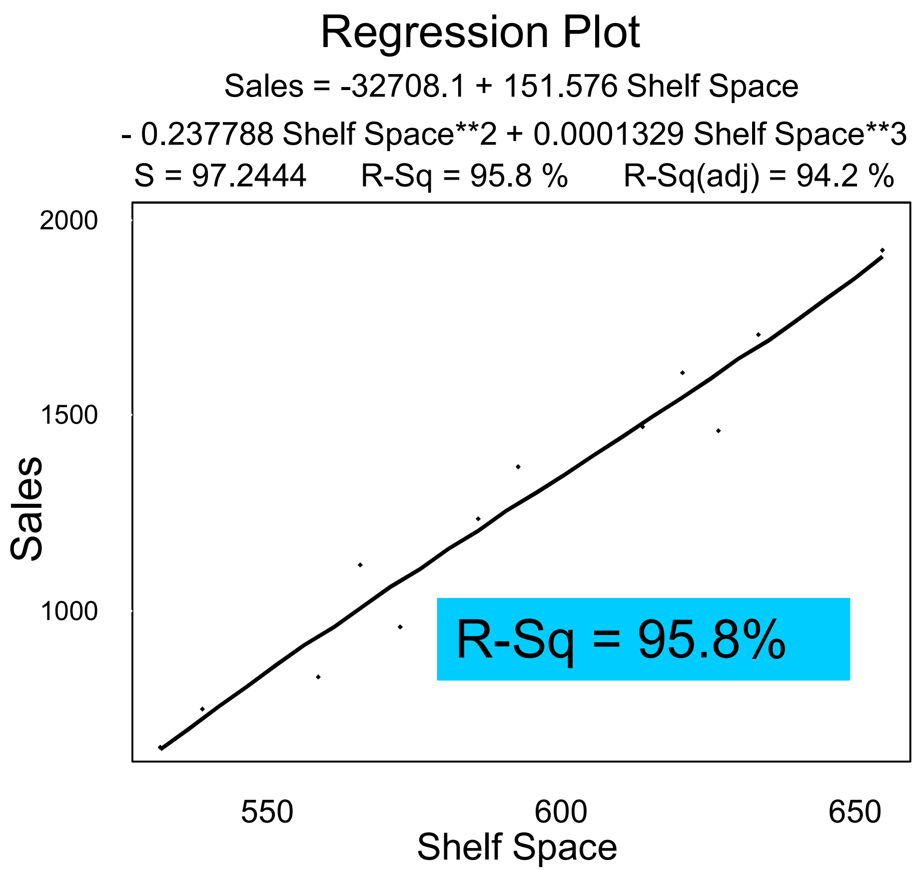
- What is the R-squared if we choose a 'cubic' polynomial regression?



Example: Cereal Sales

- Which model is better? Linear or Cubic model?





- R-Squared gets bigger as we add more and more terms!
- So should we keep adding terms?

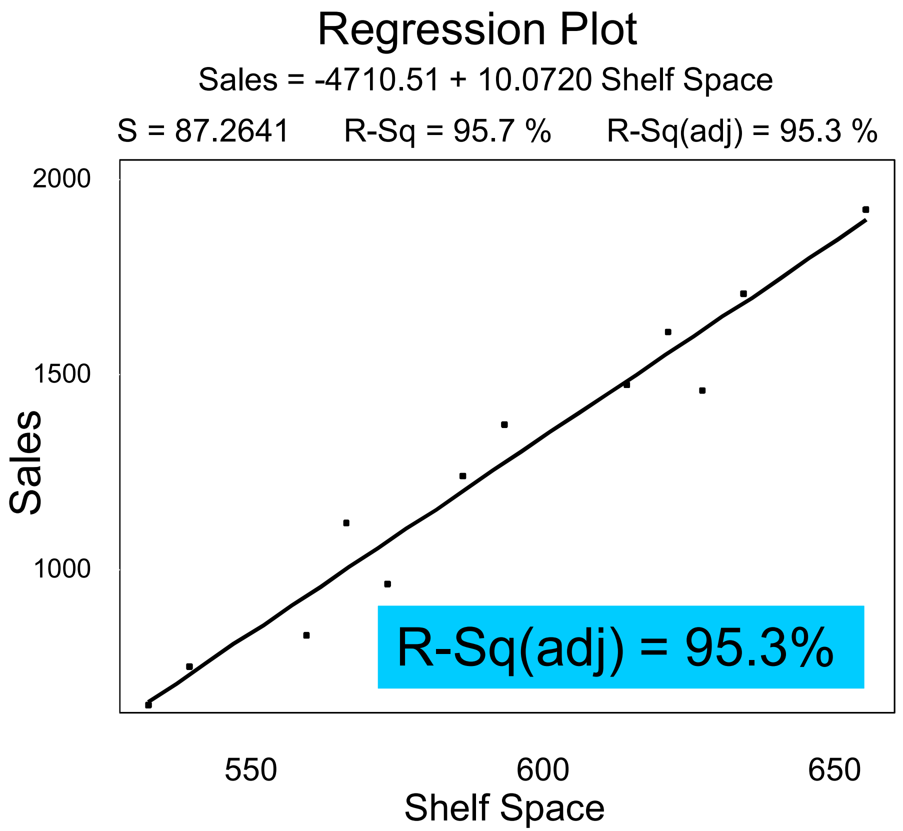
What is R-Sq (adj)?

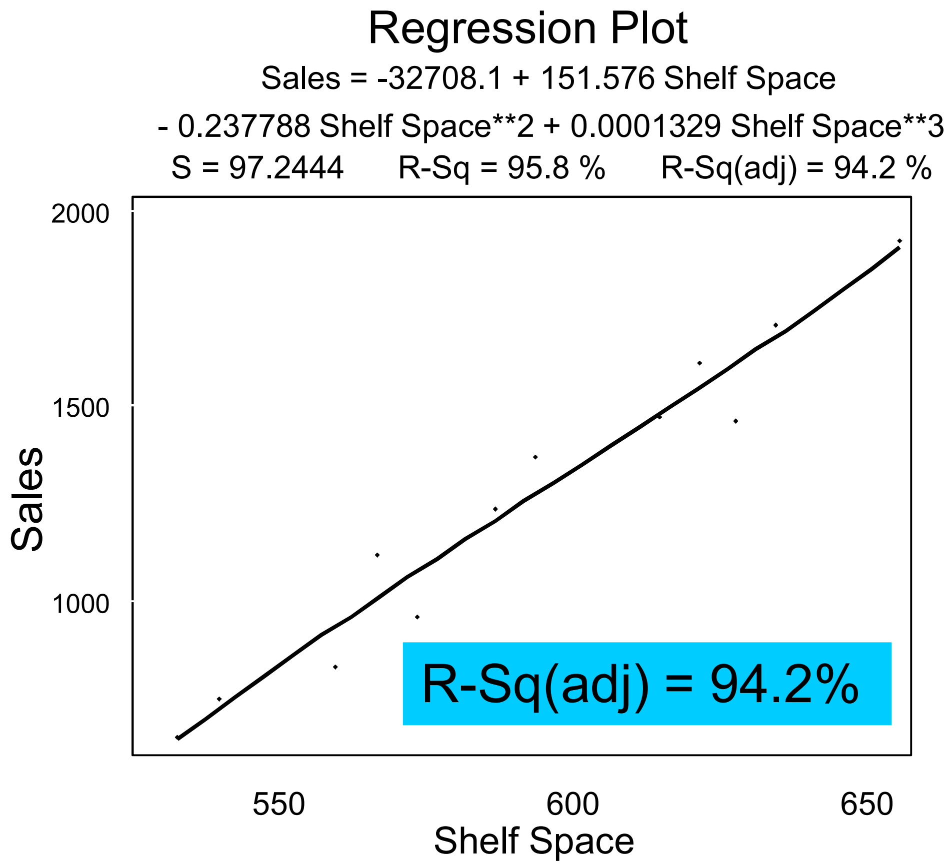
- More realistic measurement and is a modified measure of R-squared
- Takes into account of number of terms in the model and number of data points
- Adj $R^2 = 1 - [SS_{error} / (n-p)] / [SS_{total} / (n-1)] = 1 - \frac{n-1}{n-p}(1 - R^2)$

  where n = number of data points and p = number of terms in the model
- Becomes smaller when added terms provide little new information and as the number of model terms gets closer to the total sample size

Example: Cereal Sales

- Which model is better? Linear or Cubic model?





Linear model is better since the additional terms in cubic model did not add value. How about a quadratic model?

Example: Cereal Sales

The regression equation is

Sales = -4710.51 + 10.0720 Shelf Space

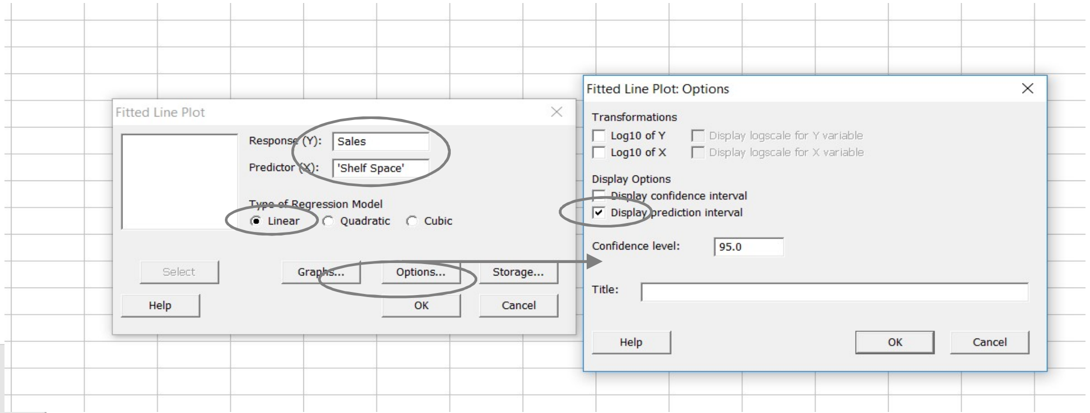
S = 87.2641 R-Sq = 95.7 % R-Sq(adj) = 95.3%

Predict ‘Sales’ for 615 ‘Shelf Space’ in the above equation

- Substitute the value for ‘Shelf Space’ in the above equation
- Sales = -4710.51 + 10.072 (615) = $1483.77
- What about the uncertainty around this prediction? Is sales expected to be exactly $1483.77?

Example: Cereal Sales

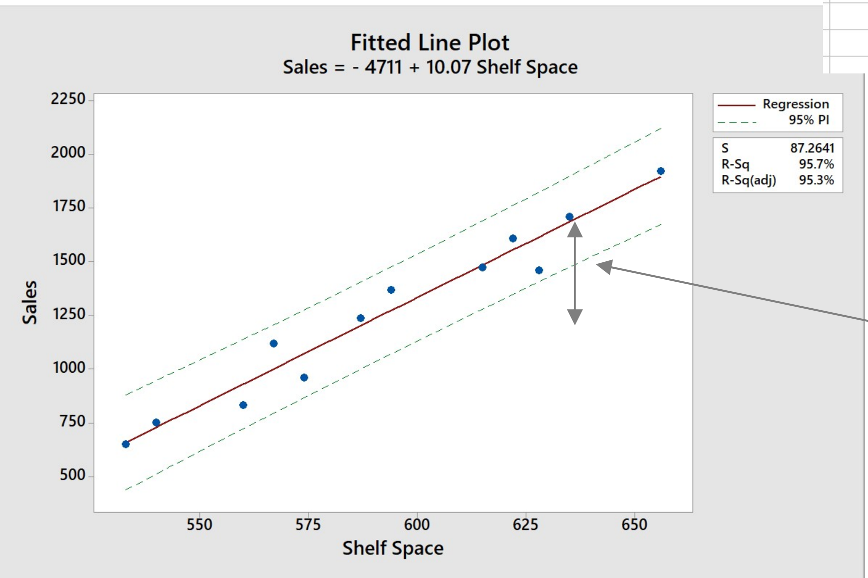
Tool Bar Menu > Stat > Regression > Fitted Line Plot



Fitted Line Plot

Sales = - 4711 + 10.0 Shelf Space

S = 87.2641 R-Sq = 95.7 % R-Sq(adj) = 95.3 %



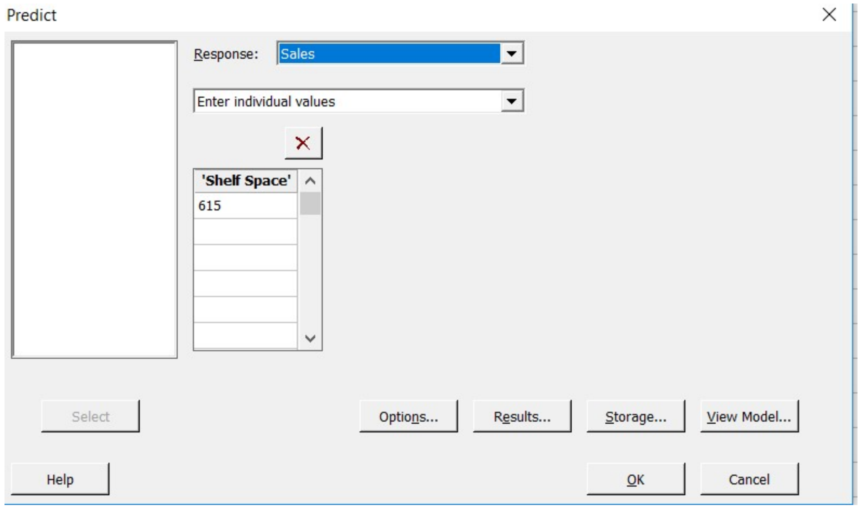
Prediction uncertainty for individual values

Regression

95% PI

Example: Cereal Sales

Tool Bar Menu > Stat > Regression > Regression > Predict



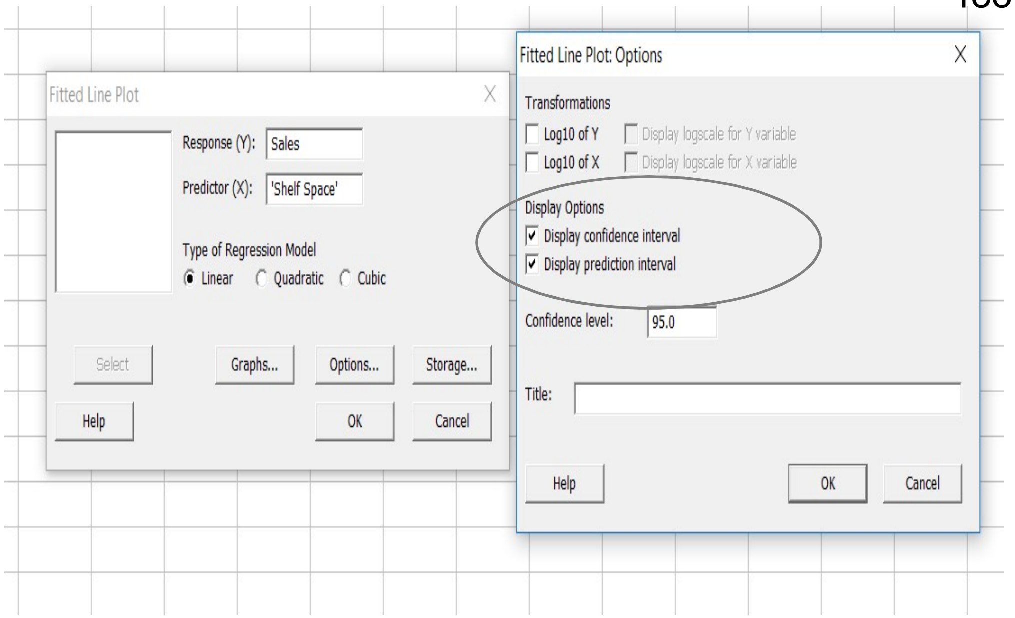
- We are 95% certain that sales will be between $1278.6 and $1688.9 when shelf space is 615 sq. in.
- In the example, the actual value was $1370

Prediction for Sales

```
Regression Equation

Sales = -4711 + 10.072 Shelf Space


Variable      Setting
Shelf Space       615


    Fit   SE Fit        95% CI               95% PI
1483.78  29.3538  (1418.38, 1549.19)  (1278.64, 1688.92)
```

Example: Cereal Sales

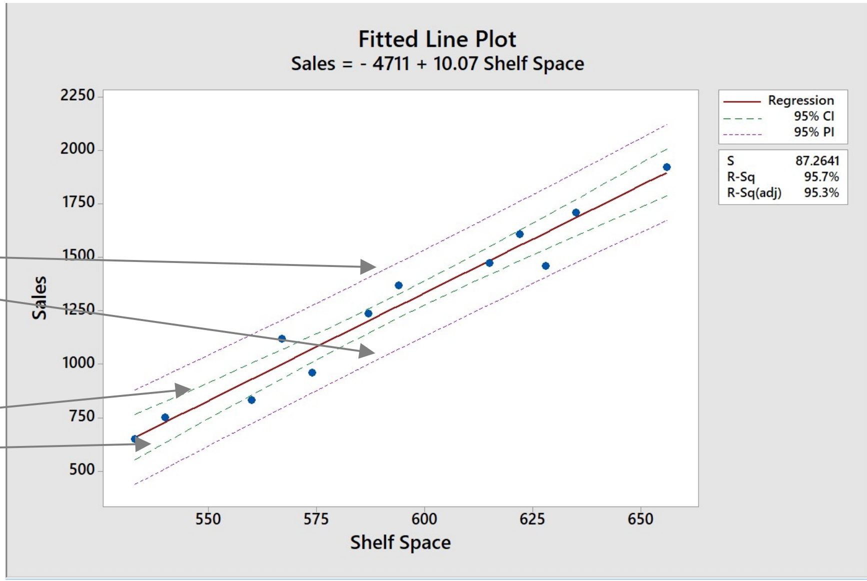
Tool Bar Menu > Stat > Regression > Fitted Line Plot



Fitted Line Plot

Sales = - 4711 + 10.07 Shelf Space

S = 87.2641 R-Sq = 95.7 % R-Sq(adj) = 95.3 %



95% prediction interval a single response

95% confidence interval for the mean response

Assumptions for Regression

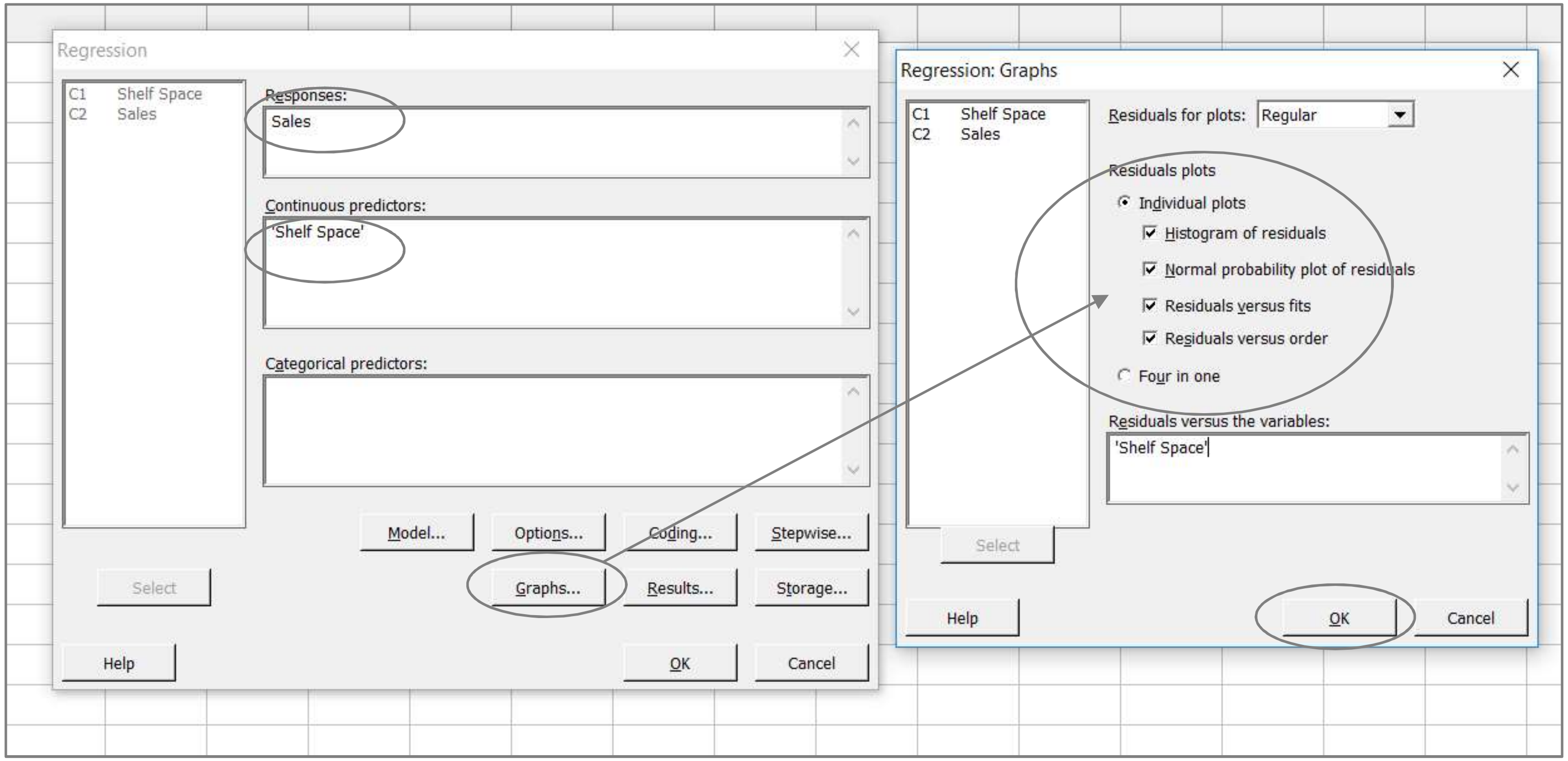
Tool Bar Menu > Stat > Regression > Regression

- To use the results of regression, assumptions about residuals must be satisfied
- What are the assumptions about residuals?
  - Residuals are normally distributed with mean of zero
  - Residuals show no pattern (random)
  - Residuals have constant variance (homogeneous variance or no heteroscedasticity)
  - Residuals are independent of the values of regressor (x) variables
  - Residuals are independent of each other

Assumptions for Regression

Residuals are error in the fit of regression line

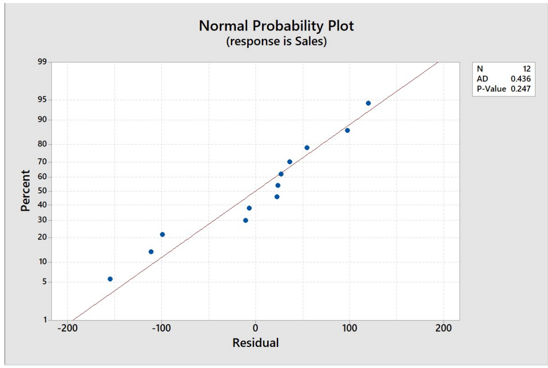
- Difference between the observed value of response variable and fitted value



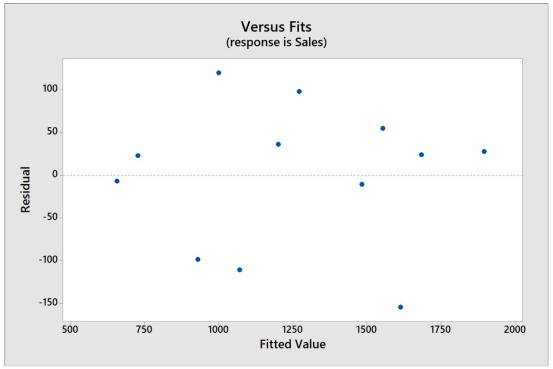
Fit Regression Model
Graphs - Four-in-One Residual Plot

- The four-in-one residual plot displays four different residual plots together in one graph window. This layout can be useful for comparing the plots to determine whether your model meets the assumptions of the analysis. The residual plots in the graph include:
- Histogram - indicates whether the data are skewed or outliers exist in the data
- Normal probability plot - indicates whether the data are normally distributed, other variables are influencing the response, or outliers exist in the data
- Residuals versus fitted values - indicates whether the variance is constant, a nonlinear relationship exists, or outliers exist in the data
- Residuals versus order of the data - indicates whether there are systematic effects in the data due to time or data collection order

Assumptions for Regression

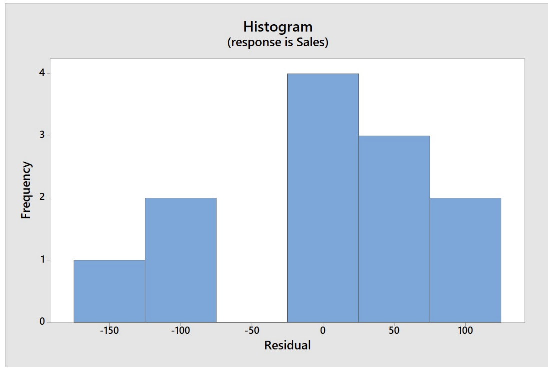


Residuals are normally distributed around mean of zero



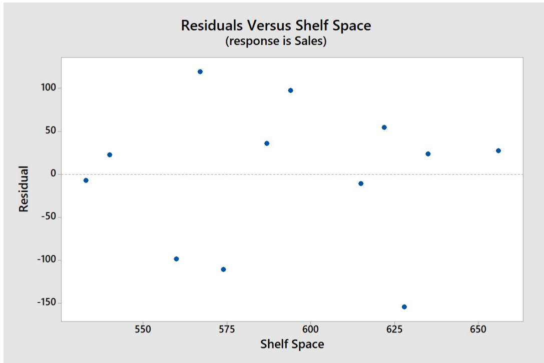
Residuals do not exhibit heteroscedasticity (they have homogenous variance)

Residuals are randomly distributed



Histogram of residuals resemble a normal distribution

with mean of zero

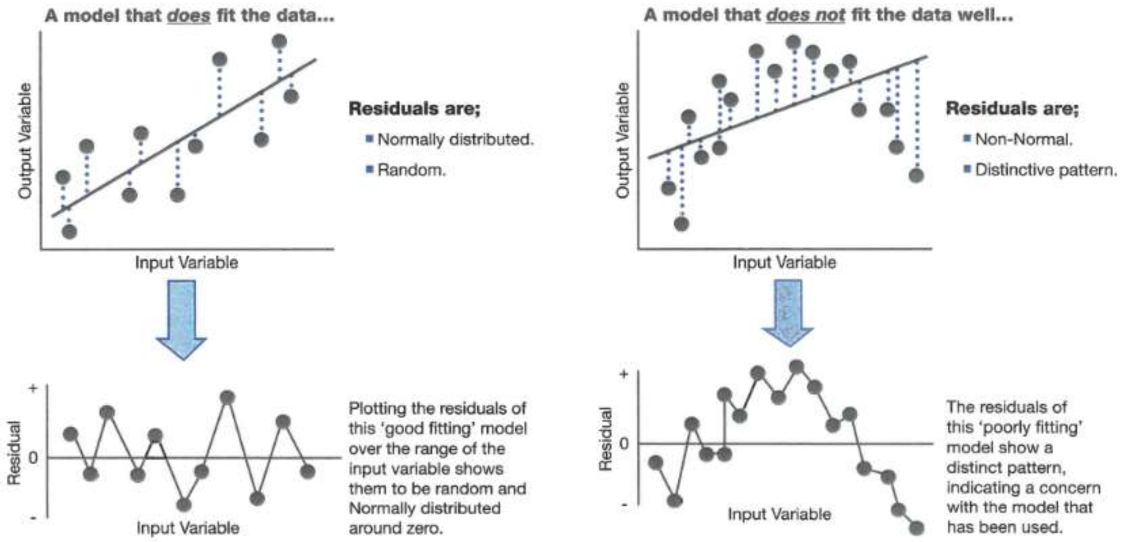


Residuals are independent of 'Shelf Space' variable

No assumptions were violated Regression results are valid

Checking the Model – Analysis of Residuals

- Confirming that your regression model is a reasonable fit can be done visually with simple, regression, because you are able to see the fitted line plot. However this is not possible wit Multiple regression since it is more than two dimensional. Instead, the residual errors between the model and the data points can be analysed in order to decide if the model is a good for the data. This possible because the behavior of residuals for a gods fitting is well established as described below.



Anexas Consultancy Services

Multiple Regression

Module Objectives

By the end of this module participant will be able to:

- Determine, for a given response variable, the key process input variables from a set of multiple input variables
- Perform multiple linear regression for a given set of response variable using several input variables
- Perform model diagnostics and validate assumptions
- Use regression model to predict the value of a response variable for given values of predictor variables

Why Learn Multiple Regression?

- Explore the existence of relationship between a dependent variable and several independent variables
- Screen multiple input variables and determine which variables have the biggest impact on the response variable
- Describe the nature of relationship with an equation and use it for prediction

What is Multiple Regression?

- Procedure of establishing relationship between a continuous type response variable and two or more independent variables
- Multiple regression equation can be used to predict a response based on values of predictor variables
- Multiple regression equation takes the form

$$Y = f(x_1, x_2, x_3, \ldots.)$$

Types of Multiple Regression

Multiple Linear Regression

Multiple regressor (x) variables such as x_1, x_2, x_3 and model linear with respect to coefficients

Example1: $y = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 + \text{error}$

Example2: $y = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_2^2 + \text{error}$

Multiple Non-Linear Regression

Multiple regressor (x) variables such as x_1, x_2, x_3 and model non-linear with respect to coefficients

Example: $y = (a_0 + a_1 x_1) / a_2 x_2 + a_3 x_3 + \text{error}$

This module focuses on multiple linear regression applying general least squares method

Multicollinearity

- A condition in which two or more independent variables (x variables) are correlated (pairwise and more complex linear relationships)
- When used in multiple regression model, they contribute to redundant information
- For example, fuel economy of a truck = f (truck load, engine horse power)
- But truck load may be correlated with engine horse power
- Truck load and horse power provide some overlapping information leading to potential problems

Problems Due to Multicollinearity

- Multicollinearity can cause severe problems
  - calculations of coefficients and standard errors are affected (unstable, inflated variances)
  - difficulty in assessing any particular variable's effect
  - opposite signs (from what is expected) in the estimated parameters
  - if two input variables x_1 and x_2 are highly correlated, then p-value for both might be high

Detecting Multicollinearity

- High values of pairwise correlation (generally > 0.8) provide warnings of potential multicollinearity problems
- If the above two variables are strongly correlated, one of them should be removed from regression model

Variance Inflation Factor

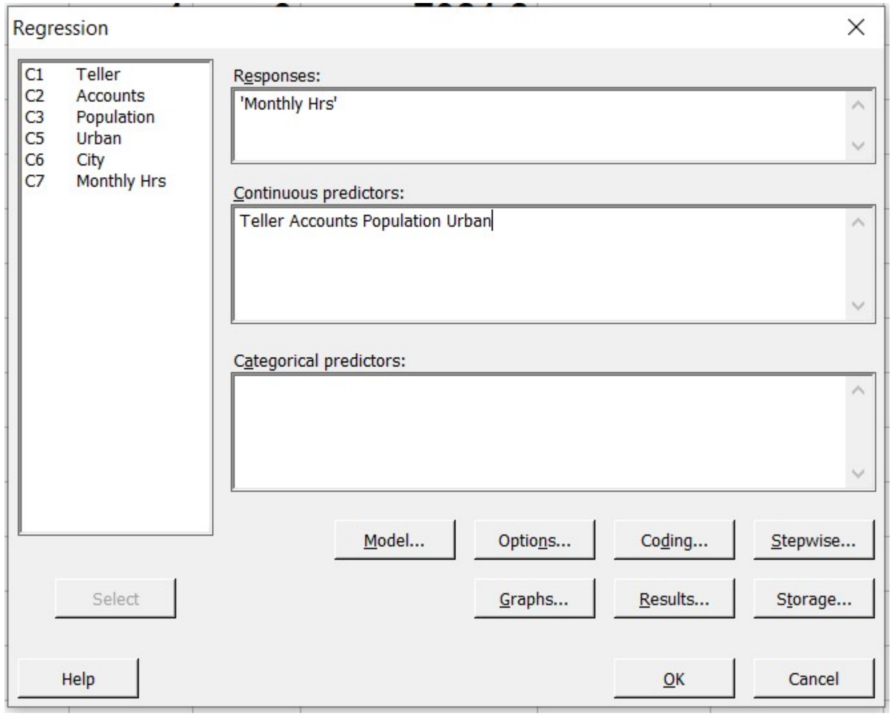
- A metric, called variance inflation factor (VIF) calculates the degree of multicollinearity

$$VIF = \frac{1}{1 - R_i^2}$$

- R_i^2 is the R^2 value obtained when X_i is regressed against other X
- A large VIF implies that at least one variable is redundant
- VIF > 10: high degree of multicollinearity - cause for serious concern ($R_i^2 > .9$)
- VIF > 5: moderate degree of multicollinearity ($0.8 < R_i^2 < 0.9$)
- Guideline: Ensure that VIF < 5 when possible

Calculating VIF

Minitab displays VIF values in the session window through *Stat* > *Regression* > *Regression*> *Fit Regression Model* menu



Regression Analysis: Monthly Hrs versus Teller, Accounts, Population, Urban

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	34308448	8577112	5345.10	0.000
Teller	1	2719647	2719647	1694.83	0.000
Accounts	1	41	41	0.03	0.876
Population	1	8948965	8948965	5576.83	0.000
Urban	1	123813	123813	77.16	0.000
Error	12	19256	1605		
Total	16	34327704			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
40.0583	99.94%	99.93%	99.90%

Coefficients

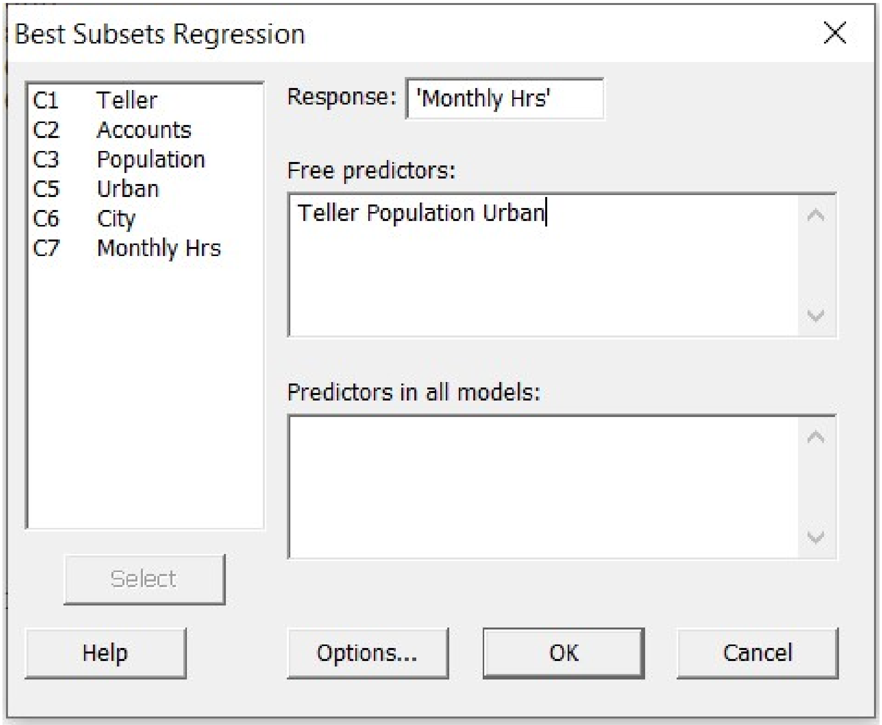
Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	1094	148	7.41	0.000	
Teller	0.9510	0.0231	41.17	0.000	10.59
Accounts	0.0091	0.0571	0.16	0.876	8.31
Population	0.056381	0.000755	74.68	0.000	1.04
Urban	238.5	27.2	8.78	0.000	1.95

Predictor Variable Selection

- What combination of predictor variables is best for the regression model?
- Three options in Minitab:
  - Stepwise: procedure to add and remove variables to the regression model to produce a useful subset of predictors
  - Best Subsets: procedure to give best fitting regression model that can be constructed with one variable, two variable, three variable, etc. models
  - Regression: once the best model is selected, use Regression to get more detailed diagnostics

Best Subsets

Tool Bar Menu > Stat > Regression > Regression> Best Subsets



Use 'Best Subsets' technique to select a group of likely models for further analysis.

Best Subsets Statistics

- Select the smallest subset that fulfills certain statistical criteria
- Minitab displays R^2, R^2 (adjusted), C-p, and s statistics
  - R^2 (large R^2 is desired; use to compare models with the same number of terms)
  - adjusted R^2 (large is desired; use to compare models with different number of terms)
  - s (standard deviation of error terms; small is desired)
  - Mallows' C-p statistic (small is desired; Guideline: want C-p $\leq$ number of terms in model)

Putting It All Together

Multiple regression objective: Establish a model with high prediction ability and minimum multicollinearity

Multiple regression steps:

1. Remove variables contributing to multicollinearity from the predictors
2. Use remaining variables and apply Best Subsets to evaluate best predictor candidates for the model
3. Choose the best candidate and complete regression analysis
4. Perform model diagnostics to identify outliers and unusual observations
5. Analyze residuals for violation of assumptions
6. Assess predictive capability using new observations

Business Process Example: Bank Labor Hours

A banking institution wants to produce an empirical equation that will estimate personnel needs its branches. The following data was collected from its existing branches at various locations. The response variable (Y) for the study was monthly labor hours. The input variables were average number of daily teller transactions (x1), average count of total number of accounts (x2), location of branch (x3), population within 20 Km radius (x4). The data is recorded in the file ***Banking.mtw.***

Business Process Example: Bank Labor Hours

- Establish a multiple regression model to predict monthly labor hours using the predictor variables
- Perform model diagnostics to detect any outliers or unusual observations
- Validate any assumptions used for creating the model

Example: Bank Labor Hours

- ***Banking.mtw***
  - Output variable: Monthly Hrs
  - Input variables: Teller, Accounts, Population, Location
  - Practical questions about the data and process?

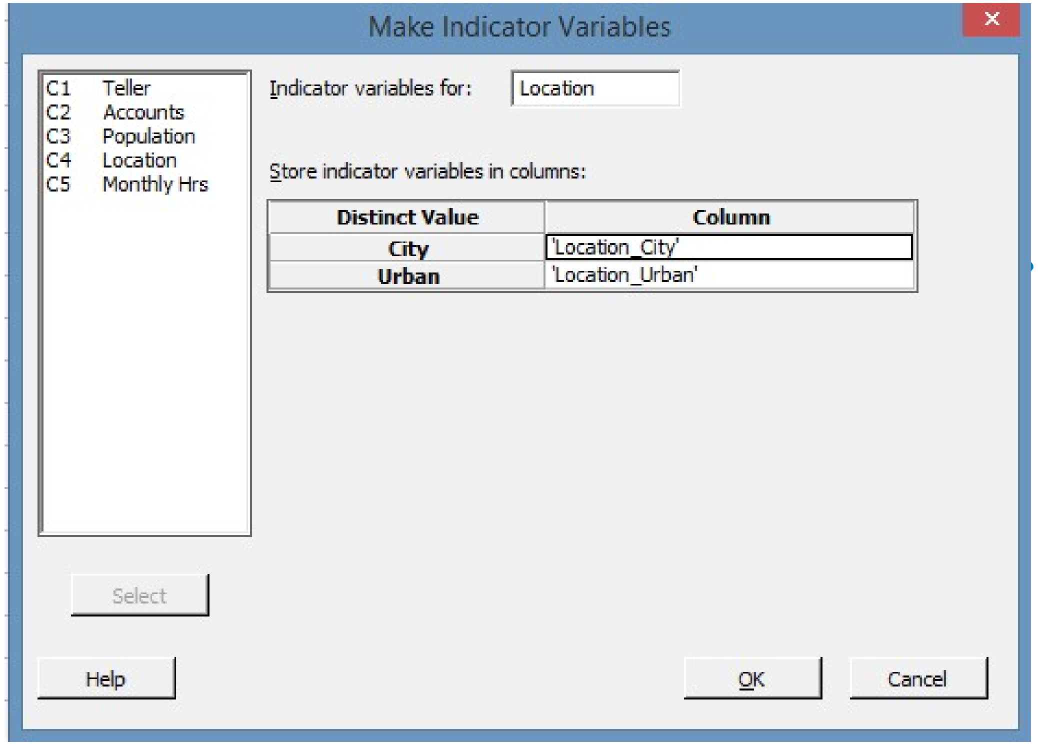
↓	C1	C2	C3	C4-T	C5
	Teller	Accounts	Population	Location	Monthly Hrs
1	2842.8	2967	58800	Urban	7381.8
2	2549.2	3243	65200	Urban	7465.0
3	2718.4	3519	70900	Urban	7925.3
4	3683.2	3818	77400	Urban	9265.2
5	5916.8	4439	79300	City	11282.6
6	5825.6	4347	81000	City	11156.2
7	4785.6	4025	71900	City	9714.0
8	5410.4	4278	63900	Urban	10123.0
9	5062.4	4370	54500	Urban	9269.0
10	5647.6	4301	39500	City	8746.2
11	6676.4	4485	44500	City	9963.6
12	5828.4	4738	43600	Urban	9346.3

Example: Bank Labor Hours

- ***Dealing with indicator variables (dummy variables)***
  - To use independent variables which are categorical (e.g, location, gender) in regression, first create “indicator” variables (dummy variables)
  - Indicators are simply 1’s and 0’s which are used like binary code.
  - Each level of a categorical variable is assigned a column.
  - If a row of data is associated with that level of the variable, the value in that column for that row of data will be 1. If not associated with that level, the value will be 0.

Example: Bank Labor Hours

1. Create an indicator variable for “Location”
   - Toolbar>Calc> Make indicator Variables



Example: Bank Labor Hours

- Result should follow the pattern below
- Order in which the columns are named is important. For alphanumeric data, the columns are created in the order specified as the value order (alphabetic, order of appearance, user defined).

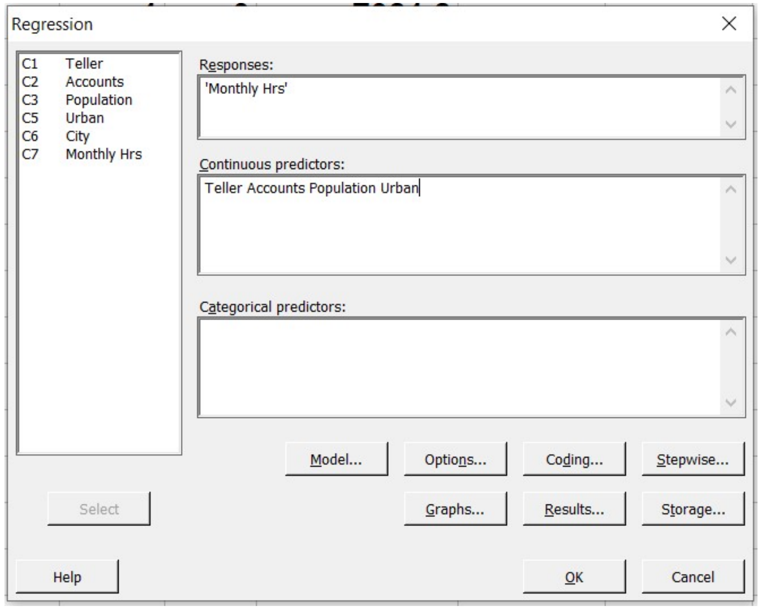
Location	Urban	City	M
Urban	1	0	
Urban	1	0	
Urban	1	0	
Urban	1	0	
City	0	1	
City	0	1	
City	0	1	
Urban	1	0	
Urban	1	0	
City	0	1	
City	0	1	
Urban	1	0	

Example: Bank Labor Hours

- ***Create an indicator variable for "Location"***
- When categorical variables are used in the regression model, one column of indicator values is NEVER included.
- In the example, use either "Urban" or "City" since it would be redundant to use both. (If "Urban"=0, then the observation must be "City")

Example: Bank Labor Hours

- ***Multiple regression steps:***
- Remove variables contributing to multicollinearity from the predictors
- Identify if multicollinearity is a problem by using variance inflation factors (VIF) measurements
- 1. *Stat> Regression> Regression> Fit Regression Model*
- 2. Fill in the dialog as shown below:



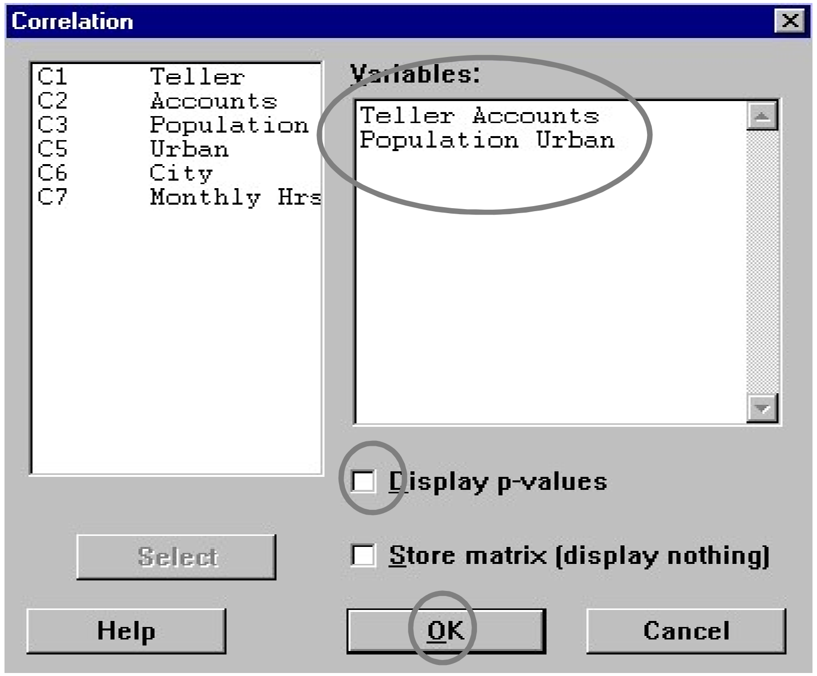
Example: Bank Labor Hours

Serious multicollinearity problem!
Want VIF <5

```
The regression equation is
Monthly Hrs = 1094 + 0.951 Teller + 0.0091 Accounts + 0.0564
Population + 238 Urban

Predictor        Coef      SE Coef        T       P     VIF
Constant       1094.3        147.8     7.41   0.000
Teller        0.95103      0.02310    41.17   0.000    10.6
Accounts      0.00913      0.05706     0.16   0.876     8.3
Populati    0.0563806    0.0007550    74.68   0.000     1.0
Urban          238.49        27.15     8.78   0.000     1.9
```

Example: Bank Labor Hours

b. Identify pairwise correlations between x variables
1. *Stat> Basic Statistics> Correlation..*
2. Fill in the dialog as shown below:
3: Press Ok



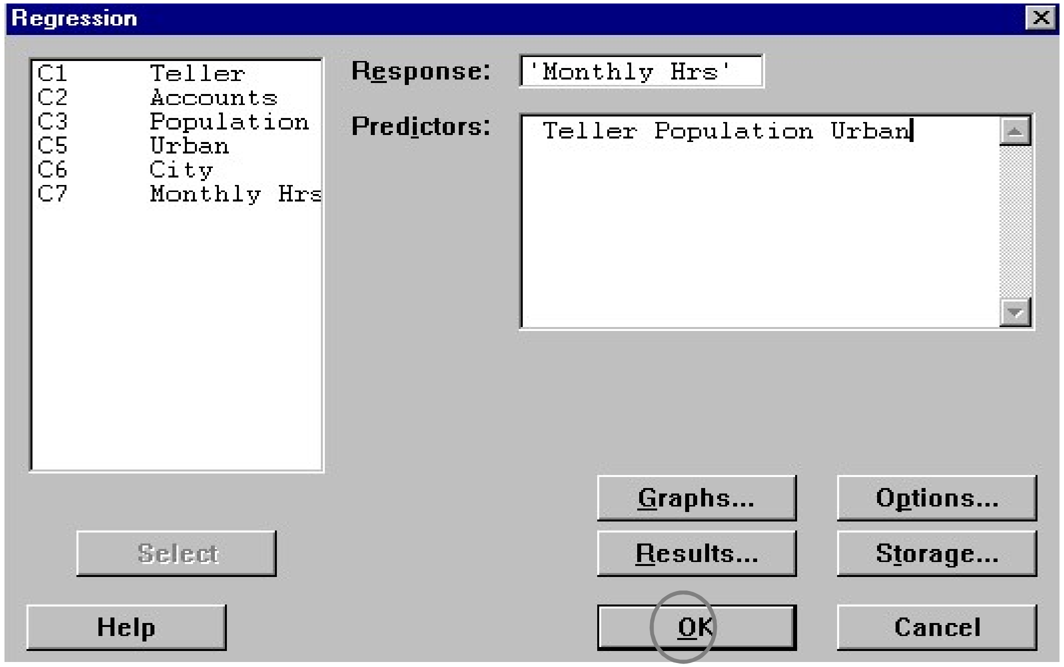
Example: Bank Labor Hours

Next step: remove Accounts and check multicollinearity

	Teller	Accounts	Populati
Accounts	0.918		
Populati	-0.024	-0.082	
Urban	-0.573	-0.372	-0.126

Example: Bank Labor Hours

Remove "Accounts" and repeat regression and check for VIF values



Example: Bank Labor Hours

All VIF <5

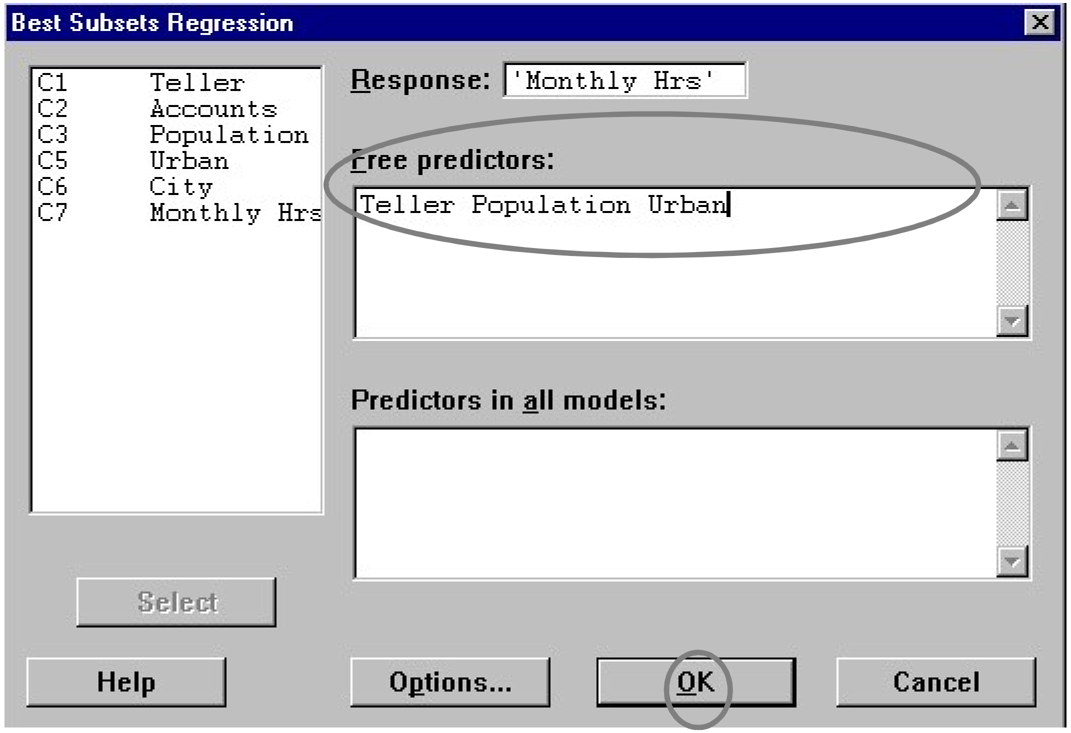
Predictor	Coef	SE Coef	T	P	VIF
Constant	1114.38	74.88	14.88	0.000	
Teller	0.954454	0.008388	113.78	0.000	1.5
Populati	0.0563707	0.0007237	77.89	0.000	1.0
Urban	240.49	23.18	10.38	0.000	1.5

Example: Bank Labor Hours

- ***Multiple regression steps:***

2. Use remaining variables and apply Best Subsets to evaluate best predictor candidates for the model

1. Stat> Regression> Best Subsets..
2. Fill in the dialog as shown below:
3: Press Ok



Example: Bank Labor Hours

Next step: remove LENGTH and check VIF values

Response is Monthly Hrs

Vars	R-Sq	R-Sq(adj)	C-p	S	Teller	Population	Urban
1	73.7	71.9	6075.6	776.22	X		
1	25.7	20.8	2E+04	1303.6			X
2	99.5	99.4	109.7	113.11	X	X	
2	73.7	70.0	6069.0	802.90	X		X
3	99.9	99.9	4.0	38.528	X	X	X

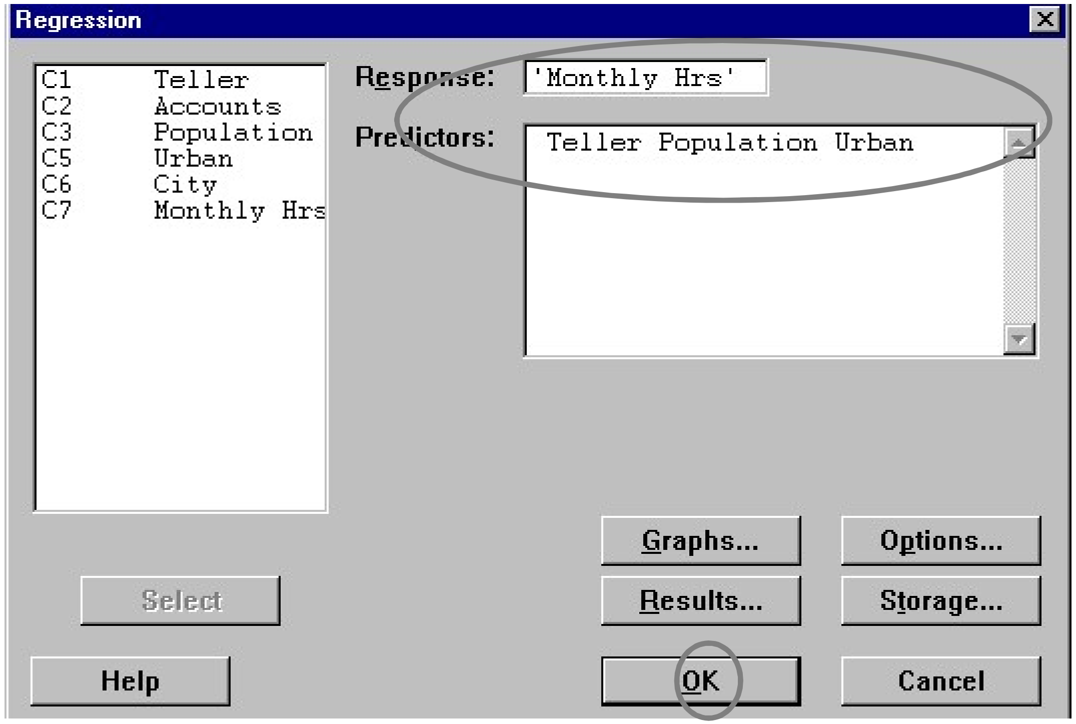
Example: Bank Labor Hours

Multiple regression steps:

3. Choose the best candidate and complete regression analysis

1. Stat> Regression> Regression
2. Fill in the dialog as shown below:

3: Press Ok



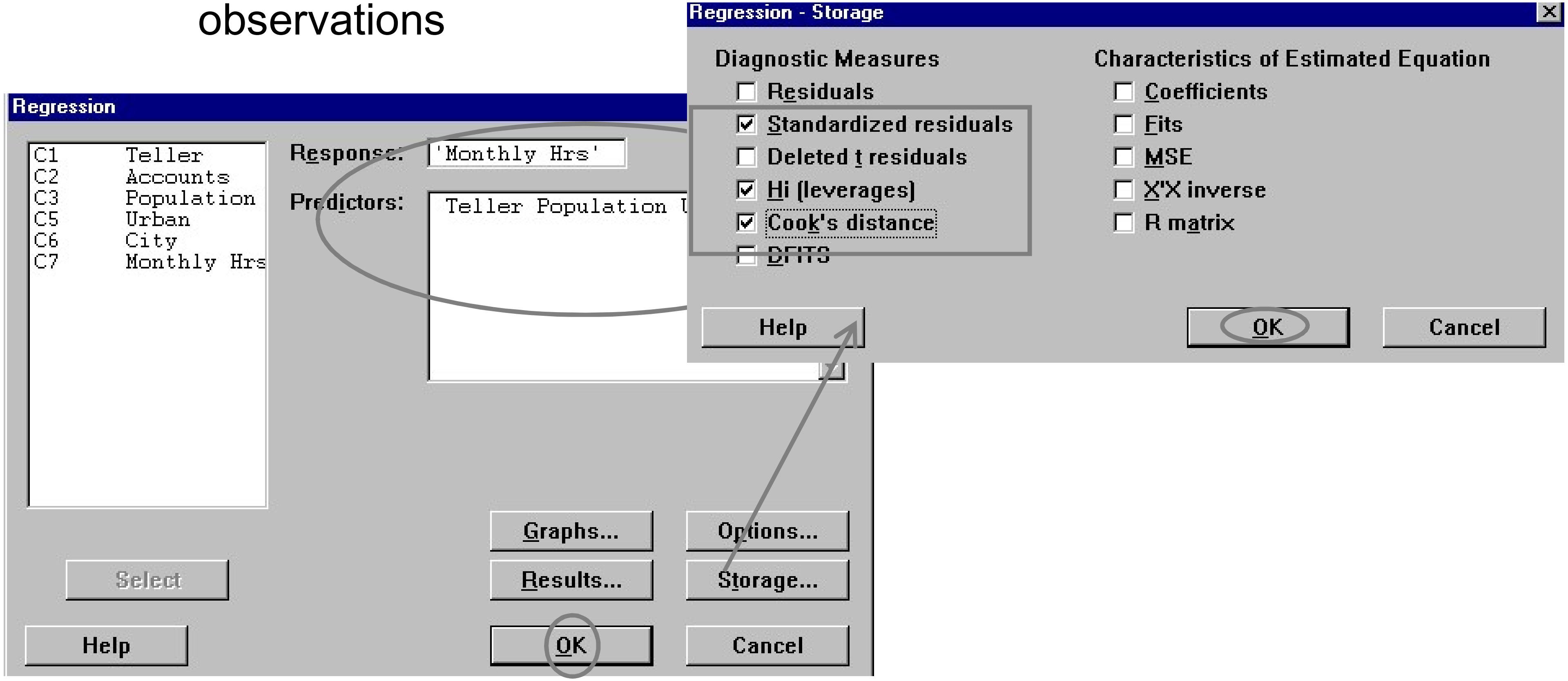
Example: Bank Labor Hours

```
The regression equation is
Monthly Hrs = 1114 + 0.954 Teller + 0.0564 Population
+ 240 Urban

Predictor        Coef     SE Coef        T       P
Constant      1114.38       74.88    14.88   0.000
Teller       0.954454    0.008388   113.78   0.000
Populati    0.0563707   0.0007237    77.89   0.000
Urban          240.49       23.18    10.38   0.000

S = 38.53       R-Sq = 99.9%     R-Sq(adj) = 99.9%
```

Example: Bank Labor Hours

Multiple regression steps:

4. Perform model diagnostics to identify outliers and unusual observations



Example: Bank Labor Hours

Outliers/ Unusual Observations

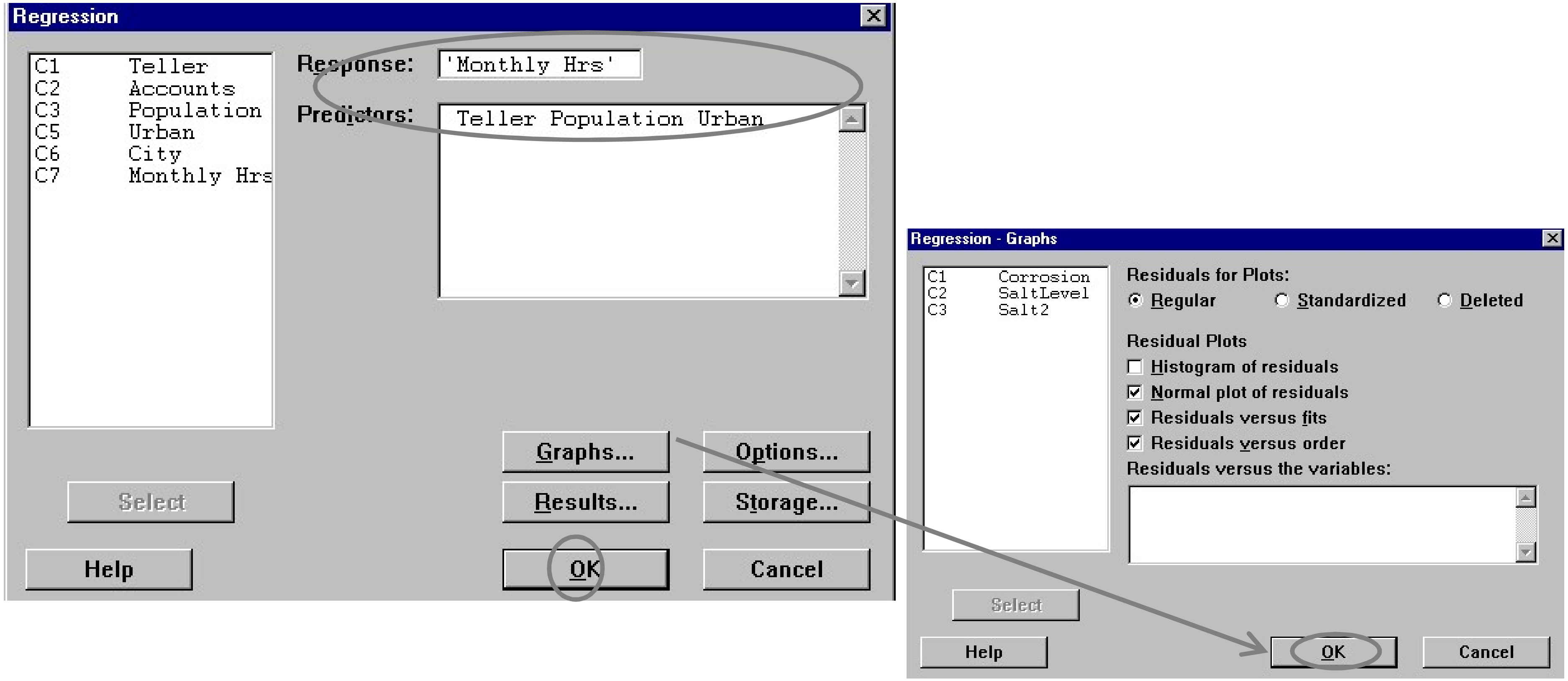
C7	C8	C9	C10
Monthly Hrs	SRES1	HI1	COOK1
7381.8	-0.03088	0.243202	0.000077
7465.0	0.05043	0.275047	0.000241
7925.3	-0.62889	0.256412	0.034096
9265.2	0.92022	0.197013	0.051941
11282.6	1.45481	0.181257	0.117139
11156.2	-2.44597	0.197162	0.367313
9714.0	-0.60984	0.197691	0.022910
10123.0	0.05897	0.158210	0.000163
9269.0	0.28358	0.152478	0.003617
8746.2	0.49623	0.398760	0.040829
9963.6	-0.98303	0.304931	0.105985
9346.3	-0.91801	0.315137	0.096947
9734.0	0.65238	0.172624	0.022199
10390.2	1.78362	0.127810	0.116546
10773.6	-0.36476	0.139764	0.005404
12673.2	0.62914	0.293429	0.041094
11776.1	-0.57219	0.389073	0.052128

Potential trouble spots:
Standardized residual>2
Leverage > 2p/n = 0.4706
Cook's distance > 1

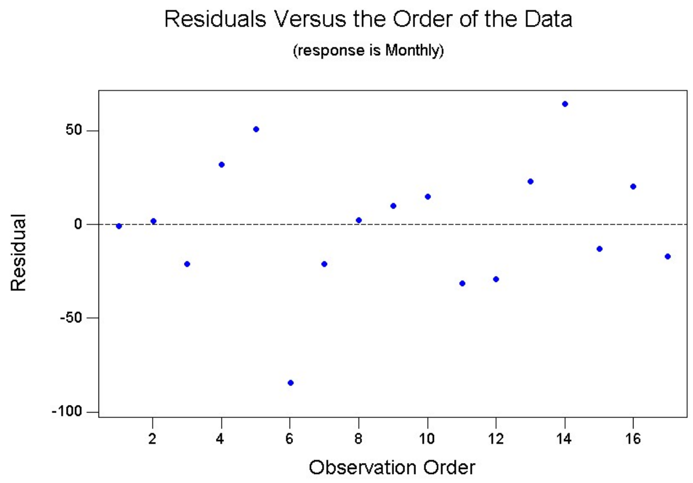
What actions should be taken with the outliers and influential observations, if any ?

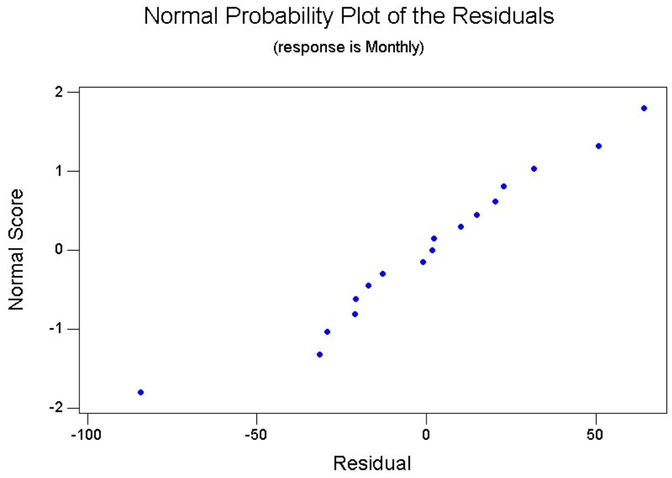
Example: Bank Labor Hours

5. Analyze residuals for violation of assumptions

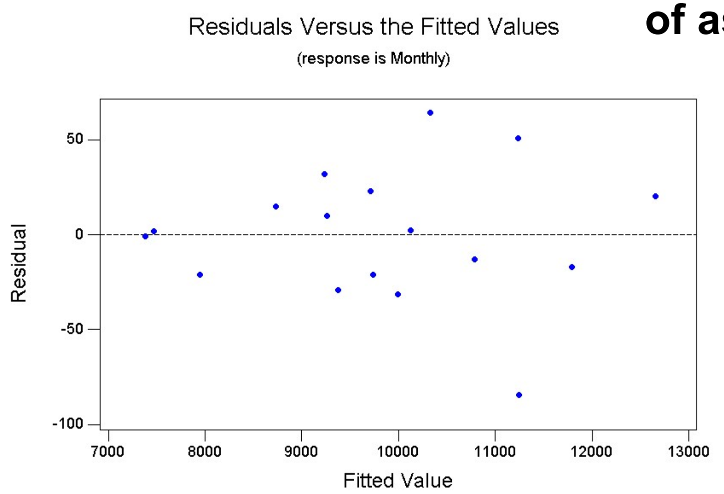


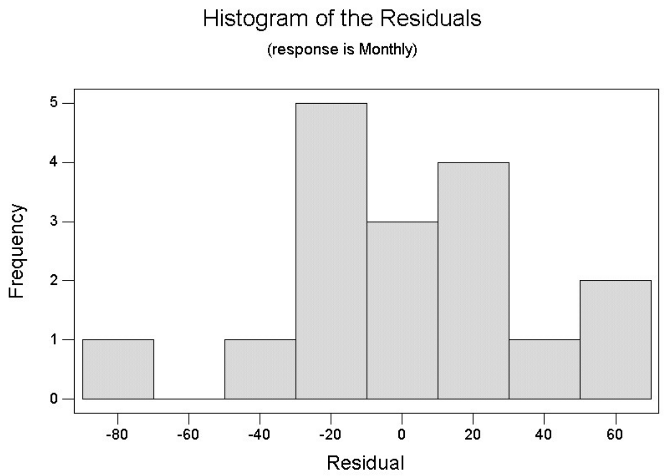
Example: Bank Labor Hours
Residual Plot Analysis





No evidence of violation of assumptions





Industrial Process Example: Alumina Deposition

A chemical engineer wants to model the process of placing Alumina / Ceria on ceramic honeycomb substrate as an acid water slurry. The Key Process Output Variable (KPOV) of interest is the ‘wet weight pickup’ measured in grams per cubic inch of substrate volume of slurry on each ceramic substrate. Thirteen input variables affecting the response variable (wet weight pickup) were also identified.

Before performing design of experiments, engineer wants to narrow down the number of input variables affecting the response variable.

Industrial Process Example: Alumina Deposition

Data collected as part of a passive study conducted to identify the leverage variables affecting the 'wet weight pickup' is given in ***(Multiwet.mtw)***. Perform a multiple regression to model the relationship between input and output variables.

Example: Alumina Deposition

Multiwet.mtw

- Output variable: wet_pu
- Input variables: RATE, b_speed, noz_ht, noz_pre, vair_pre, sl_temp, sl_vi, ol_mv, ol_%sol, ol_ph, LENGTH, AREA, RAW

- Practical questions about the data and process?

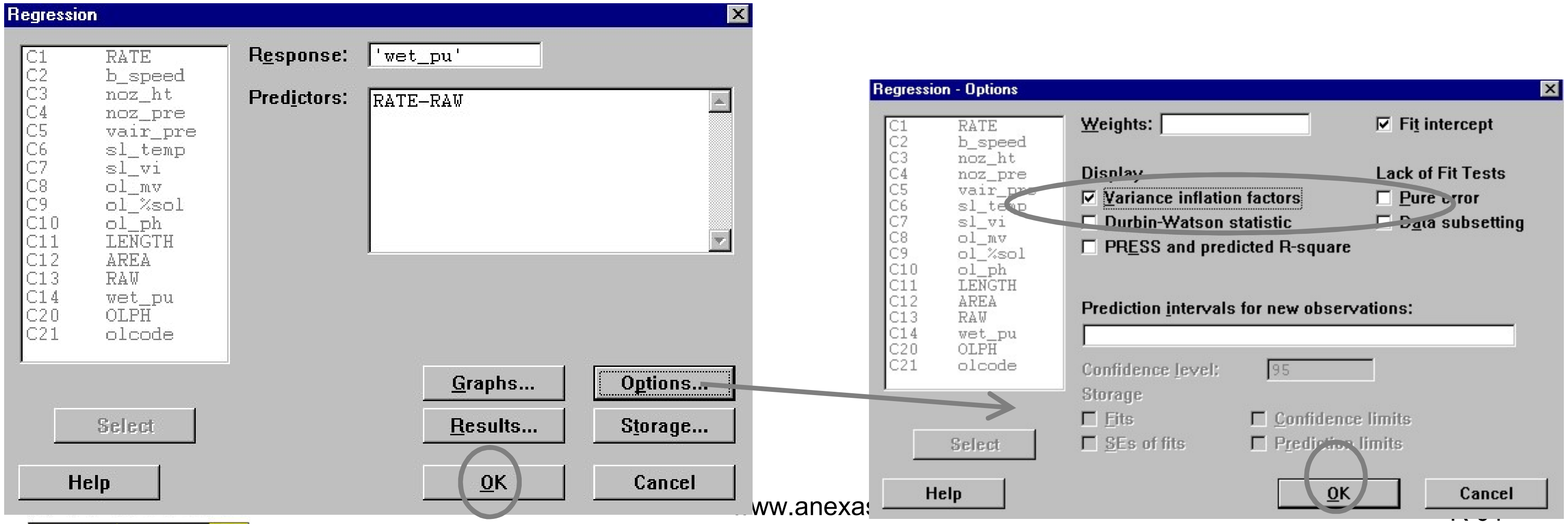
Example: Alumina Deposition

Multiple regression steps:

1. Remove variables contributing to multicollinearity from the predictors

a. Identify if multicollinearity is a problem by using variance inflation factors (VIF) measurements

1. *Stat> Regression> Regression*
2. Fill in the dialog as shown below:



Example: Alumina Deposition

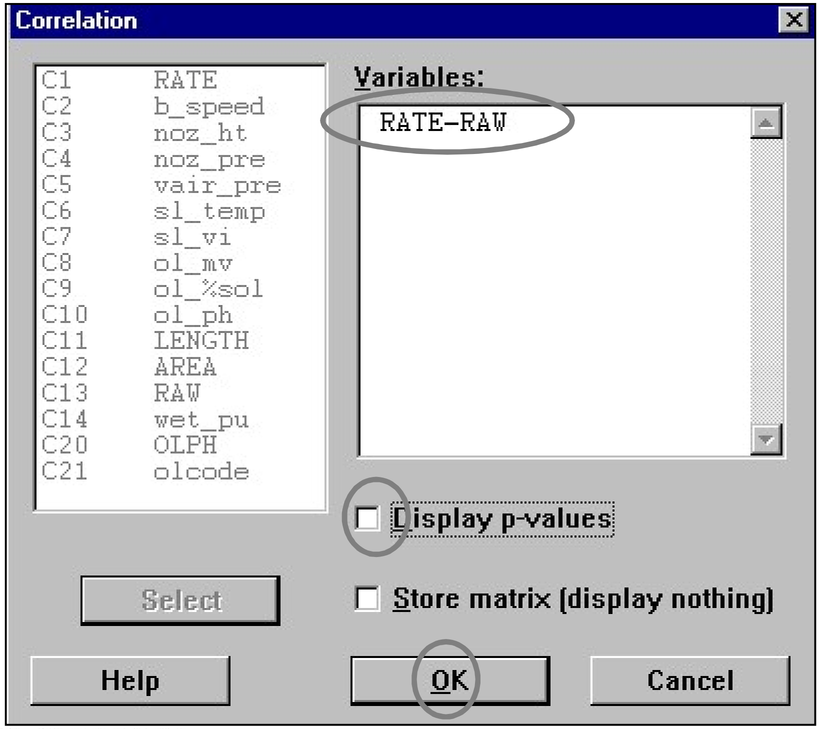
Serious multicollinearity problem! Want VIF <5

Predictor	Coef	SE Coef	T	P	VIF
Constant	-0.503	3.733	-0.13	0.893	
RATE	0.03827	0.02531	1.51	0.139	13.7
b_speed	0.01821	0.01121	1.62	0.113	5.3
noz_ht	-0.6738	0.8084	-0.83	0.410	134.7
noz_pre	0.5272	0.1106	4.77	0.000	11.8
vair_pre	0.006180	0.007003	0.88	0.383	8.3
sl_temp	-0.02794	0.01442	-1.94	0.060	9.0
sl_vi	-0.001636	0.004425	-0.37	0.714	2.3
ol_mv	0.02743	0.02616	1.05	0.301	2.2
ol_%sol	0.03942	0.01781	2.21	0.033	2.1
ol_ph	-0.2010	0.1225	-1.64	0.109	5.2
LENGTH	-0.4734	0.2634	-1.80	0.080	109.7
AREA	-0.11130	0.03847	-2.89	0.006	64.5
RAW	0.4473	0.3337	1.34	0.188	5.0

Example: Alumina Deposition

b. Identify pairwise correlations between x variables

1. *Stat> Basic Statistics> Correlation..*
2. Fill in the dialog as shown below:
3: Press Ok



Example: Alumina Deposition

Next step: remove noz_ht and check multicollinearity

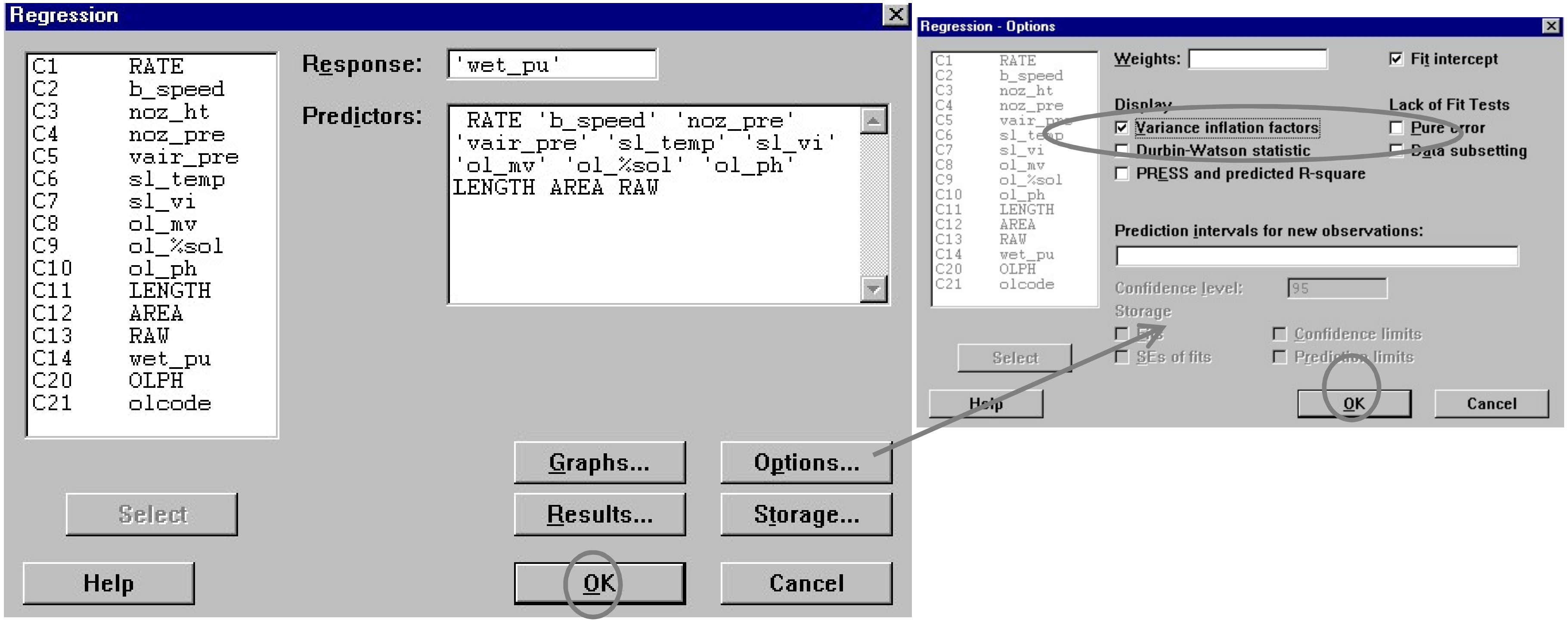
	RATE	b_speed	noz_ht	noz_pre	vair_pre	sl_temp	sl_vi	ol_mv
b_speed	0.164							
noz_ht	0.661	0.462						
noz_pre	-0.451	0.044	0.138					
vair_pre	0.202	0.332	-0.042	-0.469				
sl_temp	-0.445	-0.197	-0.781	-0.118	0.335			
sl_vi	-0.122	-0.185	-0.131	-0.110	-0.031	0.250		
ol_mv	-0.007	0.512	0.328	0.262	0.289	-0.193	-0.206	
ol_%sol	-0.275	-0.529	-0.372	0.081	-0.251	0.261	0.147	-0.369
ol_ph	0.534	0.391	0.723	0.064	0.335	-0.540	-0.290	0.436
LENGTH	-0.516	-0.490	-0.959	-0.161	-0.030	0.755	0.019	-0.397
AREA	0.240	0.573	0.857	0.503	-0.073	-0.704	-0.204	0.542
RAW	-0.485	-0.526	-0.508	-0.086	-0.226	0.263	0.386	-0.213

	ol_%sol	ol_ph	LENGTH	AREA
ol_ph	-0.462			
LENGTH	0.421	-0.703		
AREA	-0.382	0.686	-0.891	
RAW	0.277	-0.579	0.360	-0.448

Example: Alumina Deposition

c. Remove ‘noz_ht’ and assess VIF values

1. *Stat> Regression> Regression*
2. Fill in the dialog as shown below:



Example: Alumina Deposition

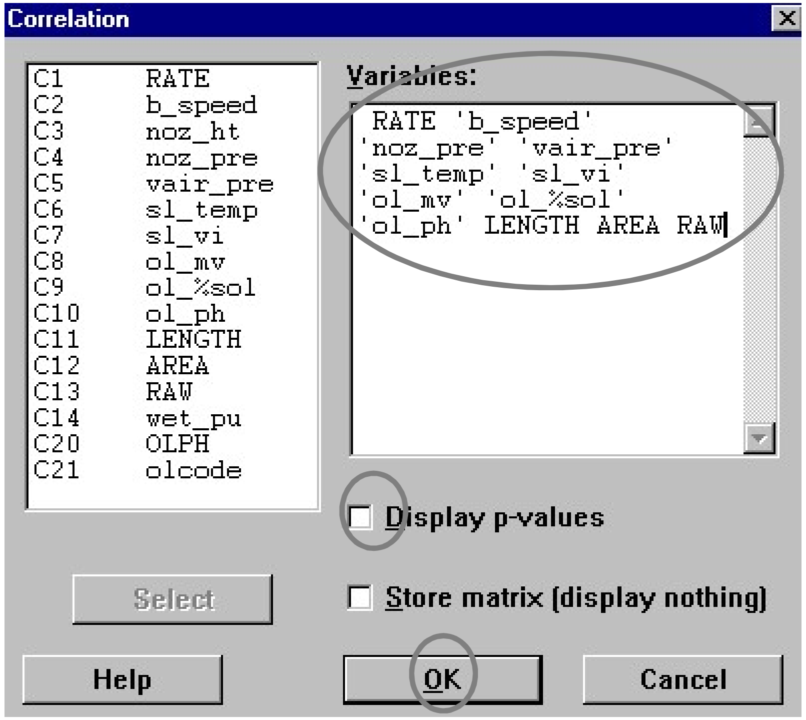
Several factors still have high VIF! Want VIF <5

Predictor	Coef	SE Coef	T	P	VIF
Constant	-1.920	3.310	-0.58	0.565	
RATE	0.02193	0.01595	1.37	0.177	5.5
b_speed	0.01763	0.01114	1.58	0.122	5.3
noz_pre	0.5305	0.1100	4.82	0.000	11.8
vair_pre	0.009866	0.005409	1.82	0.076	5.0
sl_temp	-0.03070	0.01398	-2.20	0.034	8.5
sl_vi	-0.000349	0.004130	-0.08	0.933	2.0
ol_mv	0.02591	0.02599	1.00	0.325	2.2
ol_%sol	0.03325	0.01613	2.06	0.046	1.7
ol_ph	-0.2139	0.1210	-1.77	0.085	5.1
LENGTH	-0.2901	0.1445	-2.01	0.052	33.3
AREA	-0.11591	0.03792	-3.06	0.004	63.1
RAW	0.5904	0.2850	2.07	0.045	3.7

Example: Alumina Deposition

d. Remove ‘noz_ht’ and assess VIF values

1. *Stat> Basic Statistics> Correlation..*
2. Fill in the dialog as shown below:
3: Press Ok



Example: Alumina Deposition

Next step: remove AREA and check multicollinearity

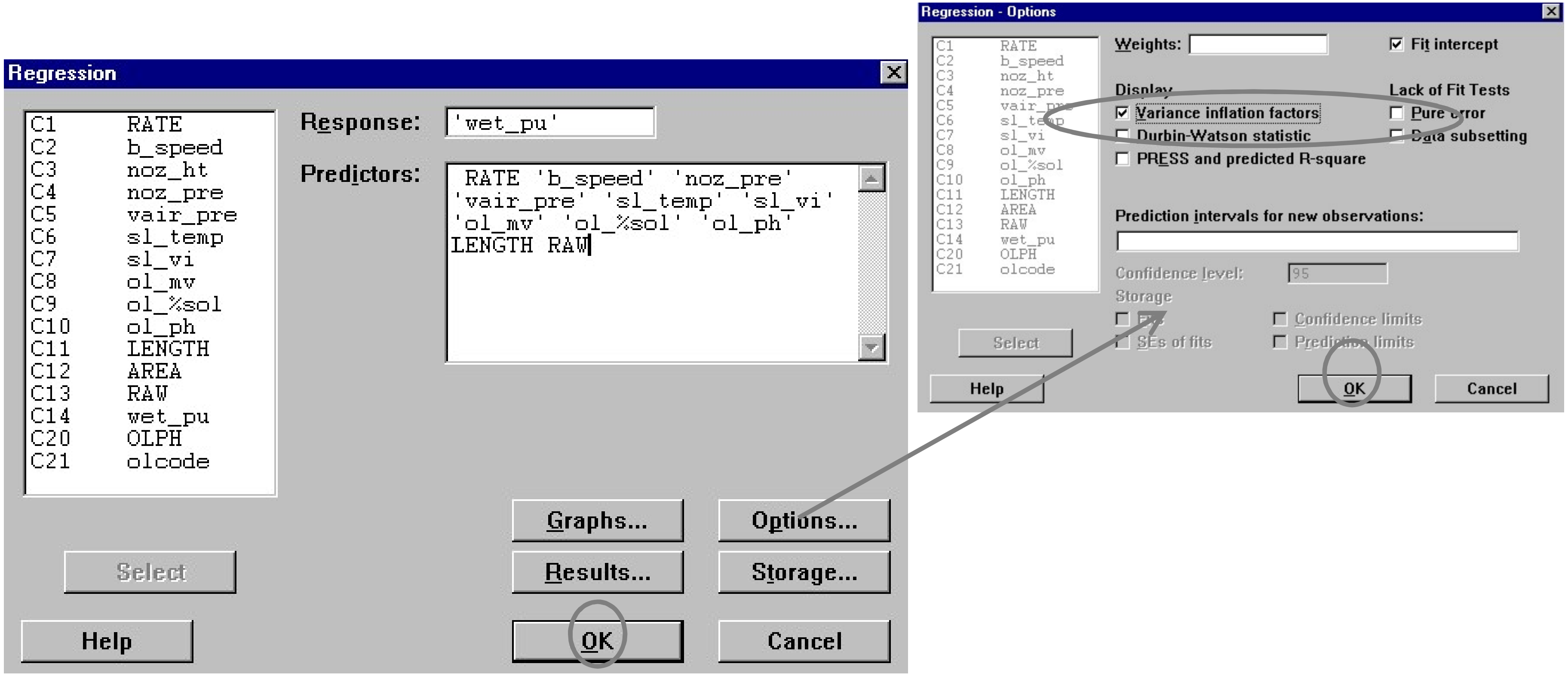
	RATE	b_speed	noz_pre	vair_pre	sl_temp	sl_vi	ol_mv	ol_%sol
b_speed	0.164							
noz_pre	-0.451	0.044						
vair_pre	0.202	0.332	-0.469					
sl_temp	-0.445	-0.197	-0.118	0.335				
sl_vi	-0.122	-0.185	-0.110	-0.031	0.250			
ol_mv	-0.007	0.512	0.262	0.289	-0.193	-0.206		
ol_%sol	-0.275	-0.529	0.081	-0.251	0.261	0.147	-0.369	
ol_ph	0.534	0.391	0.064	0.335	-0.540	-0.290	0.436	-0.462
LENGTH	-0.516	-0.490	-0.161	-0.030	0.755	0.019	-0.397	0.421
AREA	0.240	0.573	0.503	-0.073	-0.704	-0.204	0.542	-0.382
RAW	-0.485	-0.526	-0.086	-0.226	0.263	0.386	-0.213	0.277

	ol_ph	LENGTH	AREA
LENGTH	-0.703		
AREA	0.686	-0.891	
RAW	-0.579	0.360	-0.448

Example: Alumina Deposition

e. Remove ‘AREA’ and assess VIF values

1. *Stat> Regression> Regression*
2. Fill in the dialog as shown below:



Example: Alumina Deposition

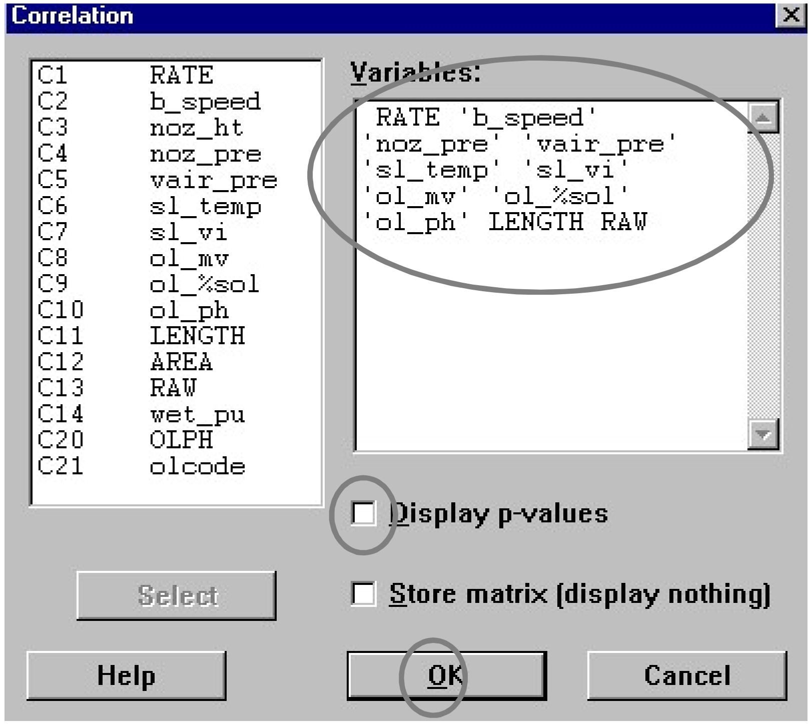
Several factors still have high VIF! Want VIF <5

Predictor	Coef	SE Coef	T	P	VIF
Constant	-4.649	3.512	-1.32	0.193	
RATE	0.03761	0.01664	2.26	0.029	4.9
b_speed	-0.00136	0.01019	-0.13	0.894	3.7
noz_pre	0.27940	0.08070	3.46	0.001	5.2
vair_pre	0.007805	0.005913	1.32	0.195	4.9
sl_temp	-0.01220	0.01389	-0.88	0.385	6.9
sl_vi	0.003396	0.004345	0.78	0.439	1.8
ol_mv	0.00540	0.02767	0.20	0.846	2.0
ol_%sol	0.02337	0.01741	1.34	0.187	1.7
ol_ph	-0.3187	0.1279	-2.49	0.017	4.7
LENGTH	0.08079	0.08651	0.93	0.356	9.8
RAW	0.7490	0.3087	2.43	0.020	3.5

Example: Alumina Deposition

f. Remove 'AREA' and assess VIF values

1. *Stat> Basic Statistics> Correlation..*
2. Fill in the dialog as shown below:
3: Press Ok



Example: Alumina Deposition

Next step: remove LENGTH and check VIF values

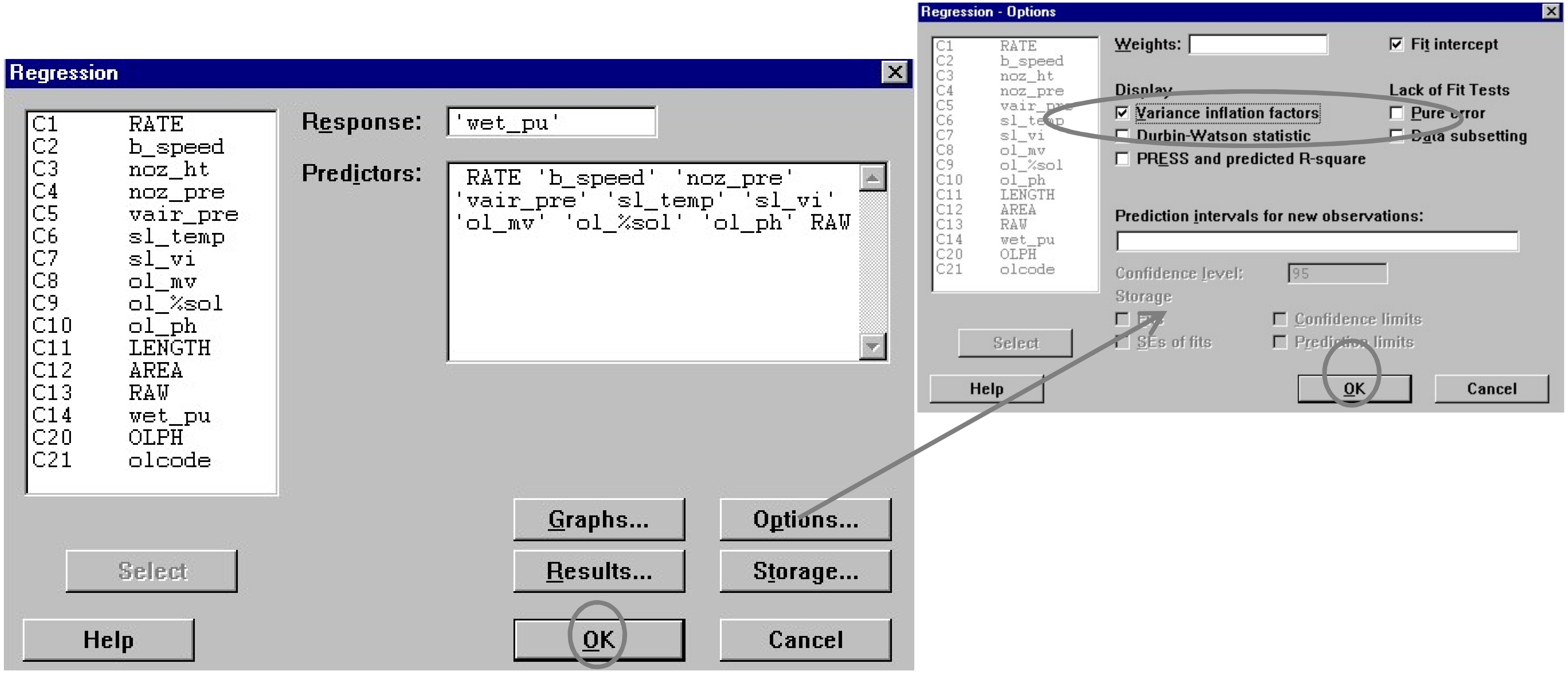
	RATE	b_speed	noz_pre	vair_pre	sl_temp	sl_vi	ol_mv	ol_%sol
b_speed	0.164							
noz_pre	-0.451	0.044						
vair_pre	0.202	0.332	-0.469					
sl_temp	-0.445	-0.197	-0.118	0.335				
sl_vi	-0.122	-0.185	-0.110	-0.031	0.250			
ol_mv	-0.007	0.512	0.262	0.289	-0.193	-0.206		
ol_%sol	-0.275	-0.529	0.081	-0.251	0.261	0.147	-0.369	
ol_ph	0.534	0.391	0.064	0.335	-0.540	-0.290	0.436	-0.462
LENGTH	-0.516	-0.490	-0.161	-0.030	0.755	0.019	-0.397	0.421
RAW	-0.485	-0.526	-0.086	-0.226	0.263	0.386	-0.213	0.277

	ol_ph	LENGTH
LENGTH	-0.703	
RAW	-0.579	0.360

Example: Alumina Deposition

g. Remove 'LENGTH' and assess VIF values

1. *Stat> Regression> Regression*
2. Fill in the dialog as shown below:



Example: Alumina Deposition

All VIF <5

Predictor	Coef	SE Coef	T	P	VIF
Constant	-3.111	3.097	-1.00	0.321	
RATE	0.02845	0.01343	2.12	0.040	3.2
b_speed	-0.006774	0.008372	-0.81	0.423	2.5
noz_pre	0.23409	0.06439	3.64	0.001	3.3
vair_pre	0.005700	0.005457	1.04	0.303	4.2
sl_temp	-0.002936	0.009704	-0.30	0.764	3.4
sl_vi	0.001197	0.003646	0.33	0.744	1.3
ol_mv	0.00778	0.02751	0.28	0.779	2.0
ol_%sol	0.02297	0.01738	1.32	0.194	1.7
ol_ph	-0.3436	0.1248	-2.75	0.009	4.5
RAW	0.6230	0.2772	2.25	0.030	2.9

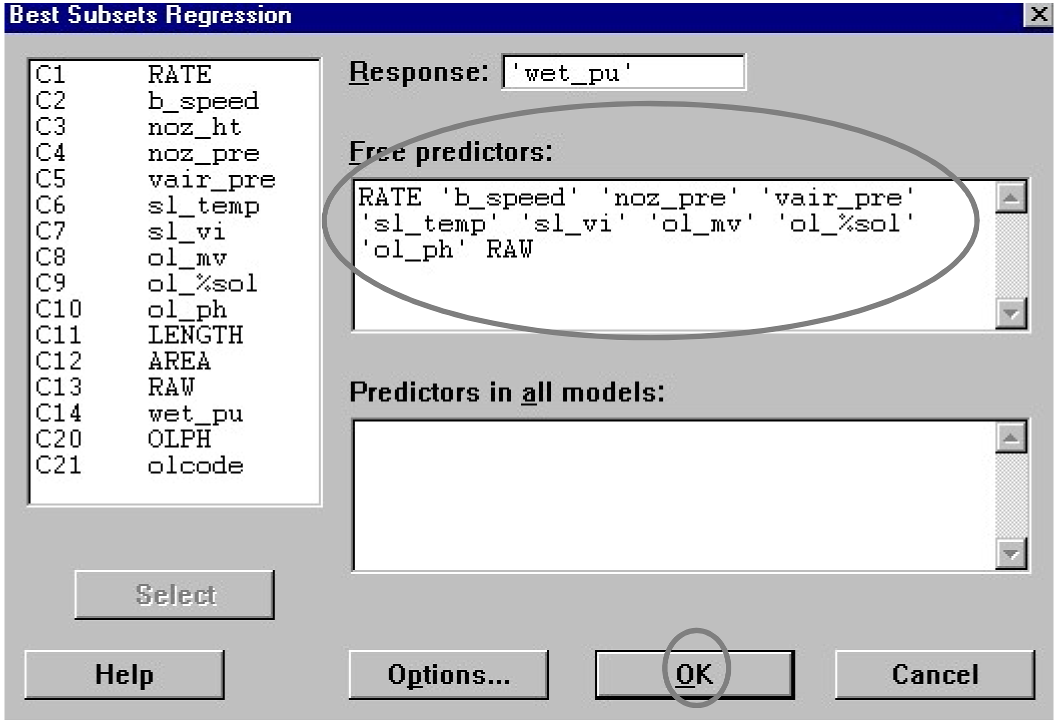
Example: Alumina Deposition

Multiple regression steps:

2. Use remaining variables and apply Best Subsets to evaluate best predictor candidates for the model

1. *Stat> Regression> Best Subsets..*
2. Fill in the dialog as shown below:

3: Press Ok



Example: Alumina Deposition

Response is wet_pu

Next step: remove LENGTH and check VIF values

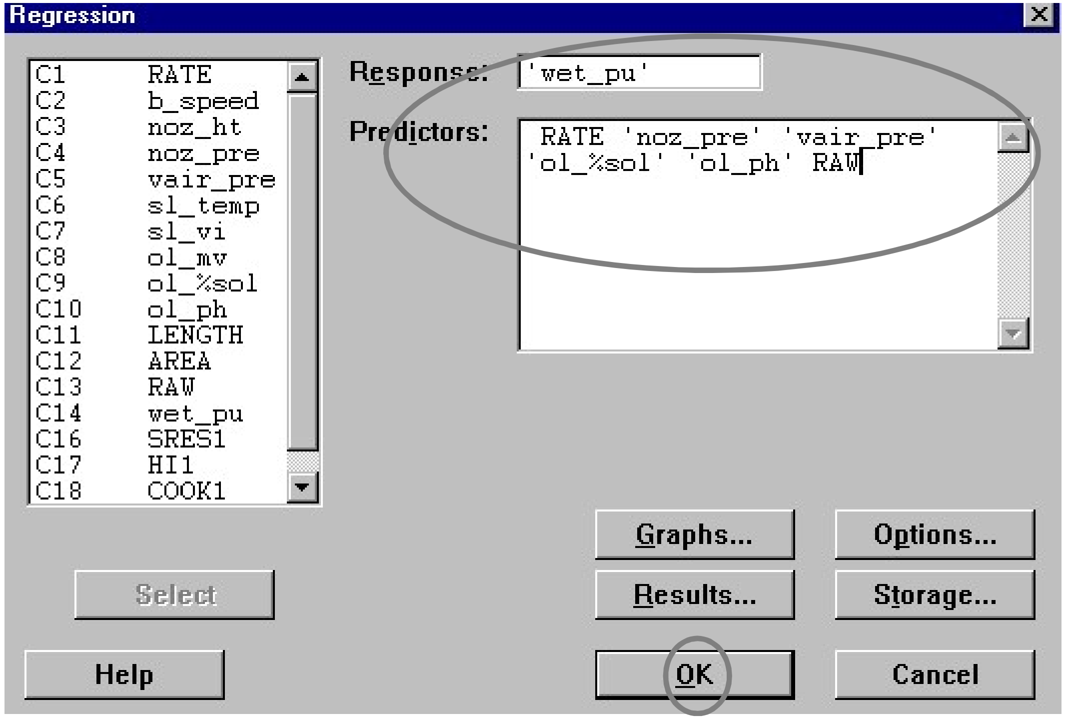
Vars	R-Sq	R-Sq(adj)	C-p	S	RATE	b_speed	noz_pre	vair_pre	sl_temp	sl_vi	ol_mv	ol_%sol	ol_ph	RAW
1	31.8	30.4	25.0	0.16911									X	
1	27.1	25.6	29.9	0.17484										X
2	45.6	43.3	12.4	0.15255			X						X	
2	41.6	39.2	16.6	0.15808			X							X
3	52.4	49.4	7.2	0.14423			X						X	X
3	52.1	49.0	7.6	0.14475		X	X						X	
4	56.8	53.1	4.5	0.13885	X		X						X	X
4	56.0	52.1	5.4	0.14022			X					X	X	X
5	60.0	55.5	3.2	0.13512	X		X					X	X	X
5	58.2	53.6	5.1	0.13808	X	X	X						X	X
6	61.4	56.1	3.7	0.13422	X		X	X				X	X	X
6	60.5	55.1	4.7	0.13579	X		X		X			X	X	X
7	61.8	55.6	5.3	0.13502	X	X	X	X				X	X	X
7	61.4	55.2	5.7	0.13570	X		X	X		X		X	X	X
8	61.9	54.7	7.2	0.13647	X	X	X	X	X			X	X	X
8	61.9	54.7	7.2	0.13647	X	X	X	X			X	X	X	X
9	62.0	53.7	9.1	0.13797	X	X	X	X	X	X		X	X	X
9	62.0	53.6	9.1	0.13799	X	X	X	X		X	X	X	X	X

Example: Alumina Deposition

Multiple regression steps:

3. Choose the best candidate and complete regression analysis

1. *Stat> Regression> Best Subsets..*
2. Fill in the dialog as shown below:
3: Press Ok



Example: Alumina Deposition

The regression equation is
wet_pu = - 4.75 + 0.0309 RATE + 0.235 noz_pre + 0.00452 vair_pre + 0.0286 ol_%sol - 0.313 ol_ph + 0.758 RAW

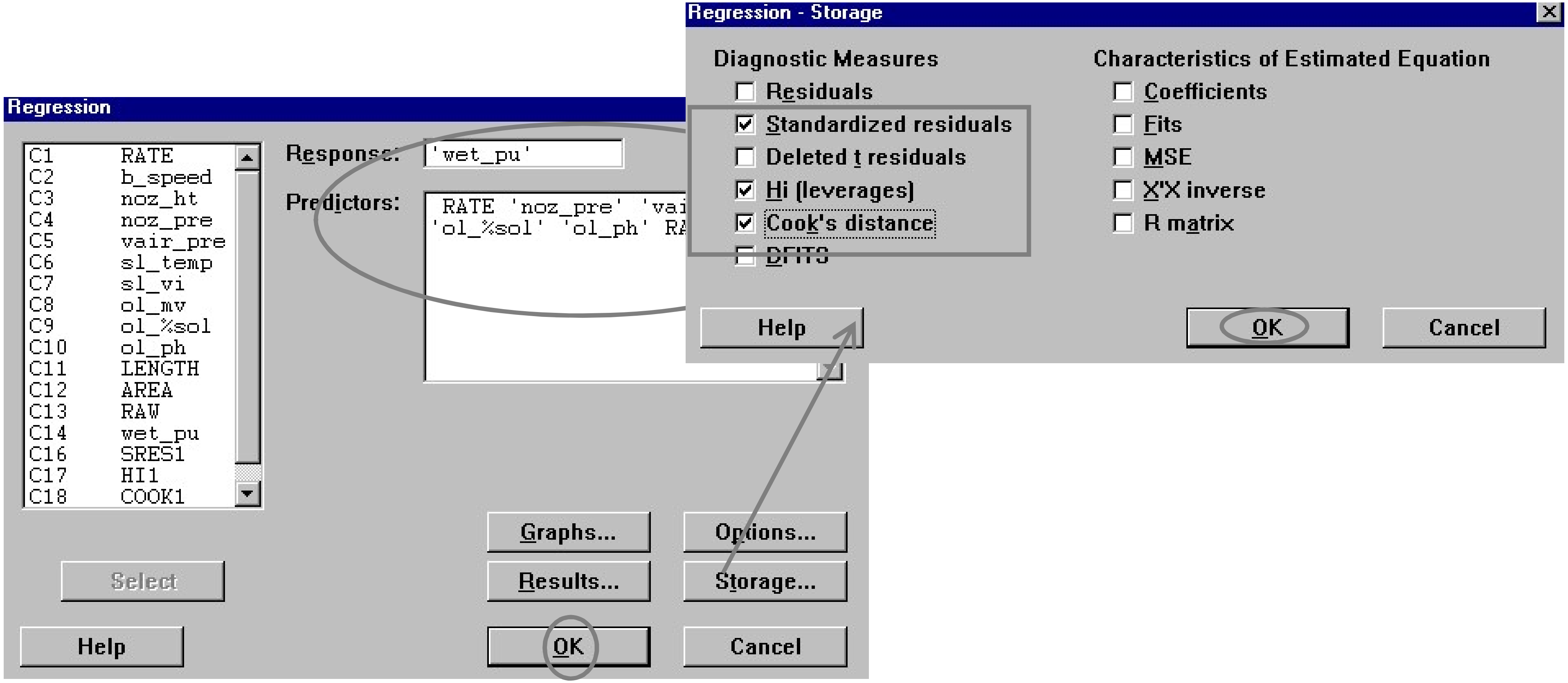
Predictor	Coef	SE Coef	T	P
Constant	-4.754	2.184	-2.18	0.035
RATE	0.03093	0.01245	2.48	0.017
noz_pre	0.23479	0.05661	4.15	0.000
vair_pre	0.004525	0.003571	1.27	0.212
ol_%sol	0.02865	0.01470	1.95	0.058
ol_ph	-0.31336	0.09312	-3.37	0.002
RAW	0.7576	0.2142	3.54	0.001

S = 0.1342 R-Sq = 61.4% R-Sq(adj) = 56.1%

Example: Alumina Deposition

<u>Multiple regression steps</u>:

4. Perform model diagnostics to identify outliers and unusual observations



Example: Alumina Deposition

Outliers/ Unusual Observations

	SRES1	HI1	COOK1
6	2.73754	0.100785	0.119993
7	0.64728	0.117710	0.007985
8	-0.75073	0.140894	0.013204
9	2.60919	0.082681	0.087660
10	0.08823	0.121181	0.000153
11	-1.95640	0.184598	0.123786
12	0.06623	0.050418	0.000033
13	-0.54417	0.049358	0.002196
14	-2.60239	0.048948	0.049794
15	-1.43050	0.044407	0.013585
16	-0.19782	0.084059	0.000513
17	0.52585	0.163286	0.007709
18	-0.30950	0.072739	0.001073
19	-0.70209	0.090436	0.007001
20	0.58939	0.108930	0.006067
21	-0.47165	0.054785	0.001842
22	0.36363	0.058157	0.001166
23	-0.13536	0.139829	0.000426
24	-0.26053	0.093215	0.000997
25	1.83274	0.418808	0.345778
26	-0.76024	0.423783	0.060724
27	[illegible]	[illegible]	[illegible]

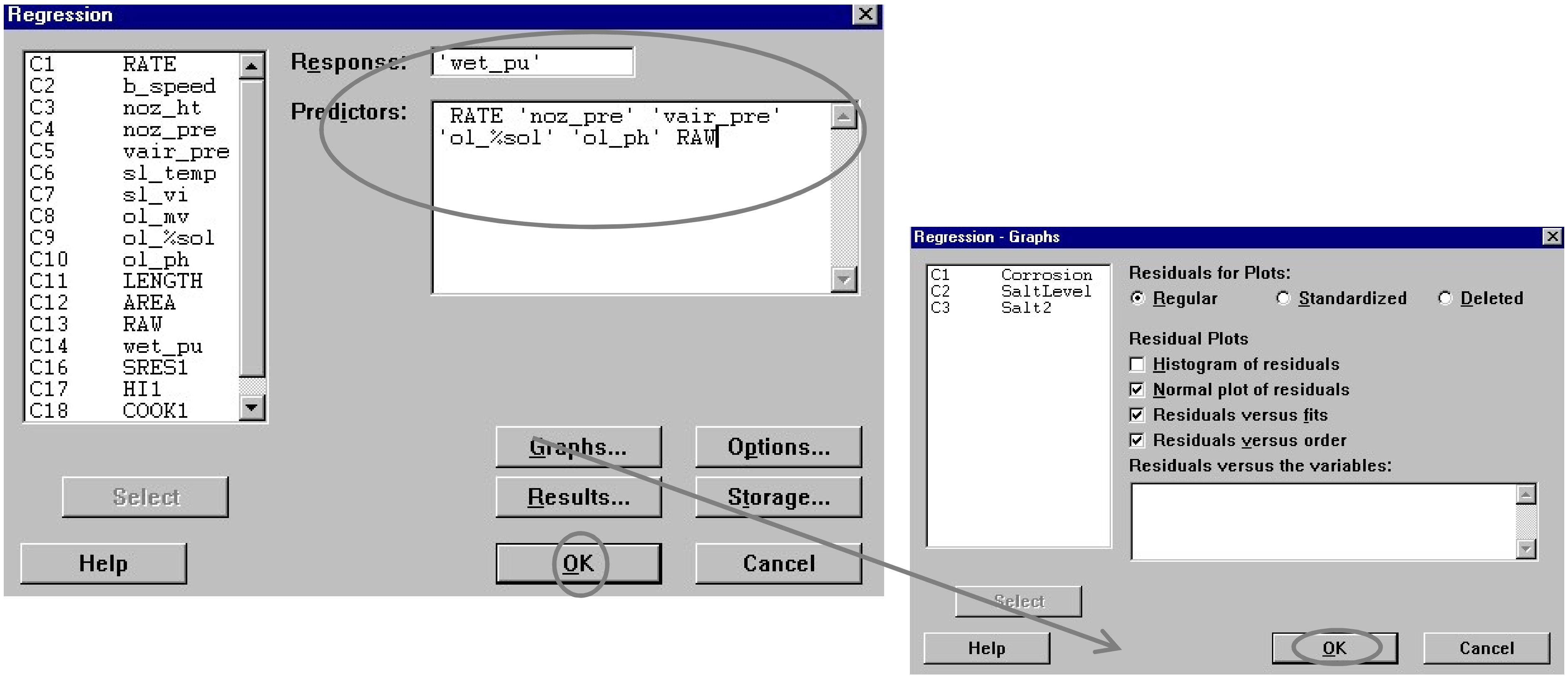
<u>Potential trouble spots</u>:
Standardized residual>2
Leverage > 2p/n = 0.3529
Cook's distance > 1

What actions should be taken with the outliers and influential observations?

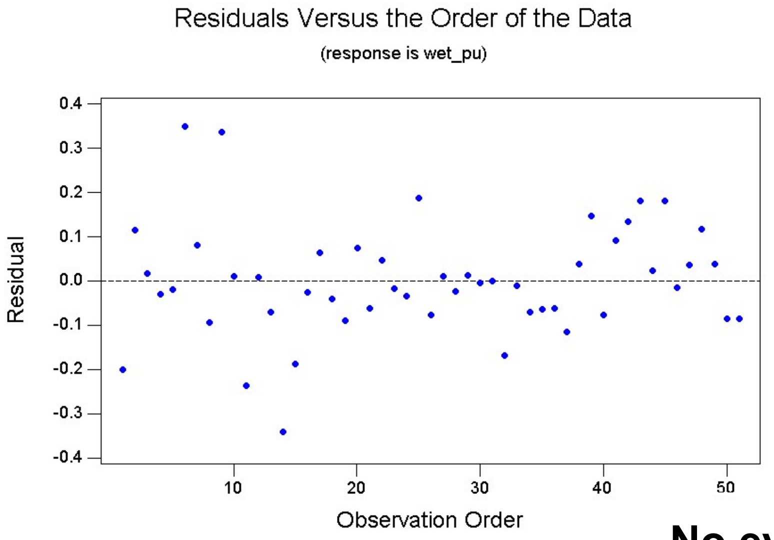
Example: Alumina Deposition

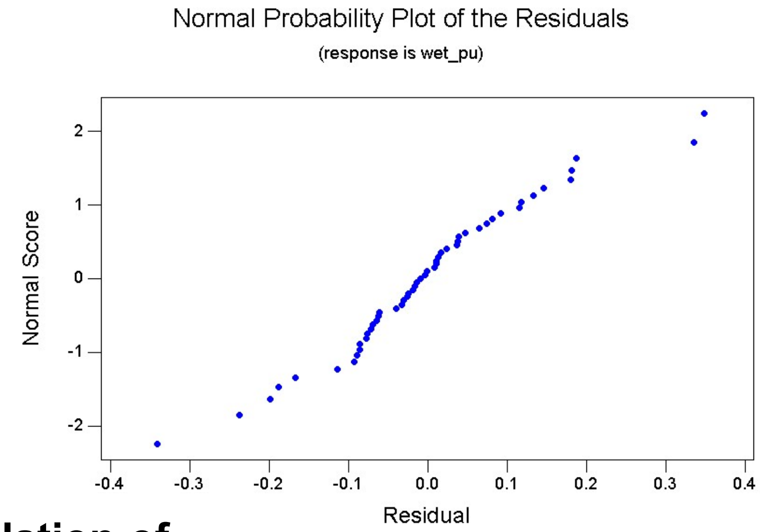
Multiple regression steps:

5. Analyze residuals for violation of assumptions

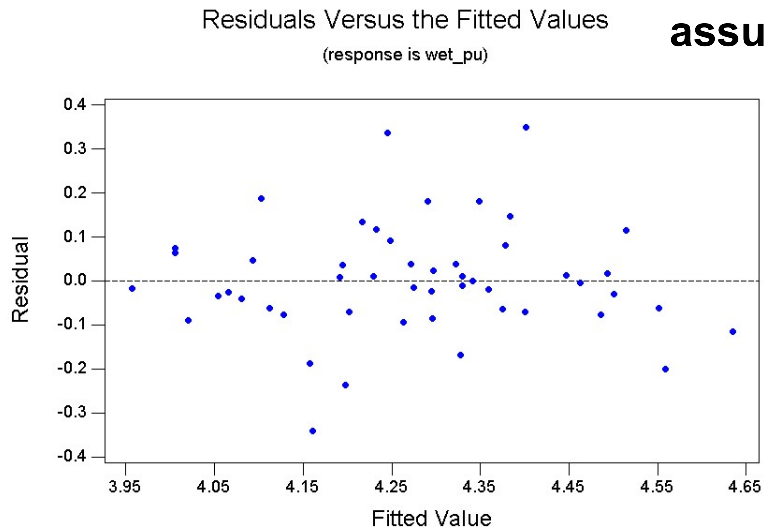


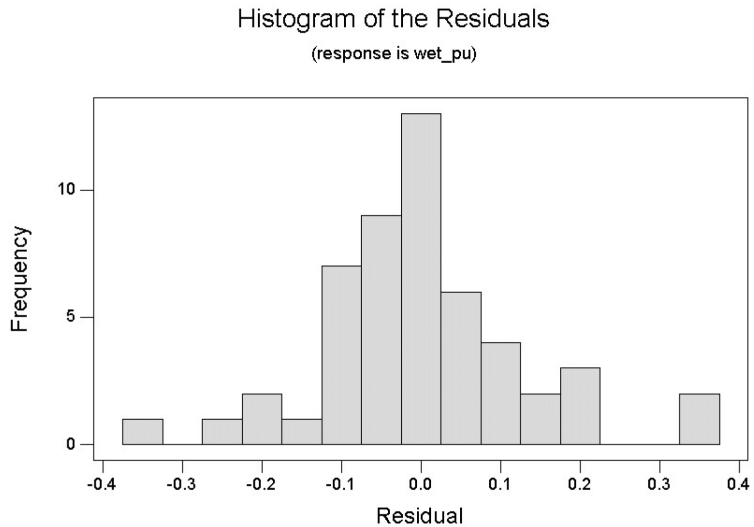
Example: Alumina Deposition - Residual Plot Analysis





No evidence of violation of assumptions





Business Process Case Study: Compensation Debate

You are a Six Sigma Black Belt team working for Sigma Soft, a successful software company with locations in New York, Seattle and Phoenix.

Recently, complaints were filed by three software specialists at Sigma Soft's Seattle office alleging they are victims of discriminatory salary practices. Specifically, the three employees charge that salaries at Sigma Soft are based on social networking abilities and gender bias.

Sigma Soft prides itself on having a fair and equitable corporate citizenship. Understandably, the company is taking the accusations very seriously.

The Executive VP of human resources has asked your Six Sigma Black Belt team to investigate the issues surrounding the employees' complaints and determine their validity.

During a preliminary investigation you discovered the controversy was triggered in part by a recent magazine article on software specialists. Among other things, the article alleged that women software specialists with similar education and experience as male counterparts received 20% less financial compensation.

Business Process Case Study: Compensation Debate

Following statistics were also published in the magazine article regarding disparity in compensation for software specialists at different geographical locations:

COMPENSATION STATISTICS FOR SOFTWARE SPECIALIST			
LOCATION	**New York**	**Seattle**	
Average Compensation, $	$140,000	$105,000	
Average IS experience	9.2 years	9.2 years	

Business Process Case Study: Compensation Debate

The personnel profiles on the three employees lodging complaints against Sigma Soft are as follows.

COMPENSATION DATA FOR SOFTWARE SPECIALISTS			
	Employee1	**Employee2**	**Employee3**
Compensation, $	72,000	90,000	94,100
IS experience	7 years	10 years	11 years
Education	MS	BS	BS
Other experience	3 years	3 years	1 year
Sex	Female	Female	Female
Age	35	33	30

Business Process Case Study: Compensation Debate

In addition your team has obtained compensation information ***(salary.mtw)*** for comparable positions in three software companies, including Sigma Soft and two competitors.

Team breakout exercise:

- How is your team going to approach the problem? Create a list of practical questions that will aid in your investigation.
- Create a flipchart for your thought processes.

Data in ***salary.mtw***

Business Process Case Study: Compensation Debate

- Utilize the compensation data to analyze the issues and determine the validity of the employees' complaints as well as the magazine's claims.
  - Is the magazine information regarding average compensation and gender bias accurate?
  - Is there a difference in salaries between men and women at Sigma Soft?
  - Is there a difference in salaries between women at Sigma Soft and women in the other software companies?
- Establish a multiple regression model to predict a software specialist's salary using input variables.
  - Perform model diagnostics to detect any outliers or unusual observations.
  - Validate any assumptions used in creating the multiple regression model
- Utilize the regression model to predict the salaries of the three employees making accusations against Sigma Soft.
- Are the employees' complaints valid?
- Are salaries at Sigma Soft gender biased?

Anexas Consultancy Services

Logistic Regression Analysis

Discrete Ys

Days Between Maintenance and Chances of Good Start-Ups

- Suppose you work on a chemical blending process for a small-volume, highly regulated product
- It is a one-shift operation and you must shut down and clean the blender at the end of each day
- There is no preventive maintenance schedule in place: maintenance is called after certain mechanical problems are observed and procedures are done at the end of the shift
- You are interested in establishing a preventive maintenance schedule and would like to learn how many days you can go between maintenance procedures and still have a chance of a good start-up each day (machine starts on first attempt)

Days Between Maintenance and Chances of Good Start-Ups, cont.

- You check the log for the last 89 maintenance procedures
  - What data would you collect to answer this question?
  - How would you display them?
  - Can you predict an attribute outcome (yes/no) with a continuous variable?

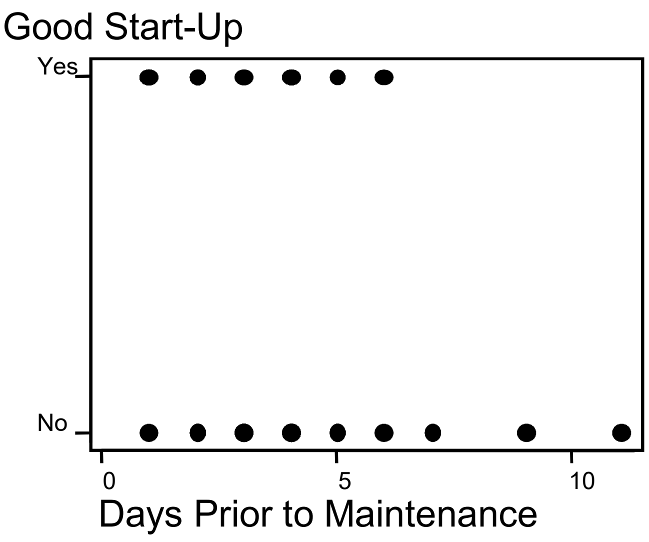
Days Between Maintenance and Chances of Good Start-Ups, cont.

Maintenance Procedure	Days Prior to Maintenance	Good Start-Up First Run Next Day?
1	2	Yes
2	1	Yes
3	7	No
4	2	Yes
5	5	No
.	.	.
86	2	Yes
87	4	No
88	2	Yes
89	3	Yes

Possible Ways to Display Discrete Y-Data

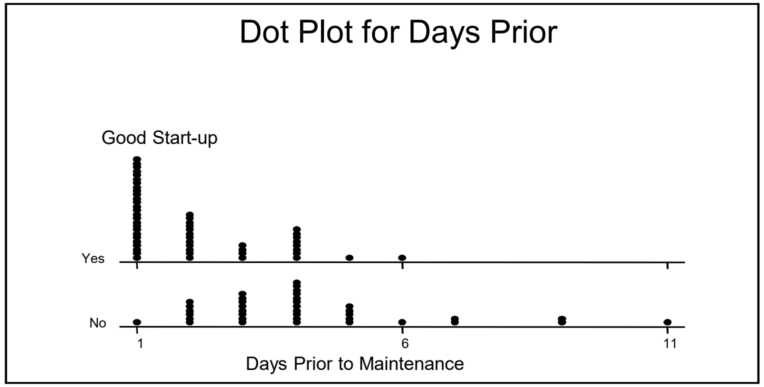
1. Scatter plot of raw data

- Inappropriate data for scatter plot—Y is discrete-attribute, not continuous
- Thus, the plot is not useful; cannot understand relationship or make predictions based on this pattern



2. Stratified dot plot

- Useful
- Can start to see patterns that reveal information about the relationship



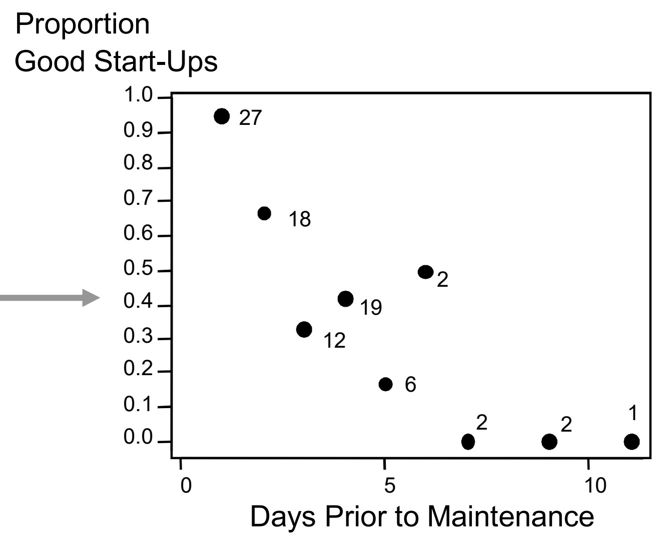
Possible Ways to Display Discrete Y-Data, cont.

3. Scatter plot of summarized data

– Very useful

– Can pick out patterns to help us answer our question

Each point is labeled with the number of maintenance procedures at those conditions



Use Proportions for Discrete Data

- Logistic regression predicts the **proportion** or **probability** of a particular Y attribute
- In other words, you would like to know the percent of times the chemical blender works right the first run of the day after a maintenance procedure

Raw Data

Maintenance Procedure	(X) Days Prior to Maint	(Y) Good Start-Up
1	2	Yes
2	1	Yes
3	7	No
.	.	.
87	4	No
88	2	Yes
89	3	Yes

A particular Y-attribute

X = continuous data

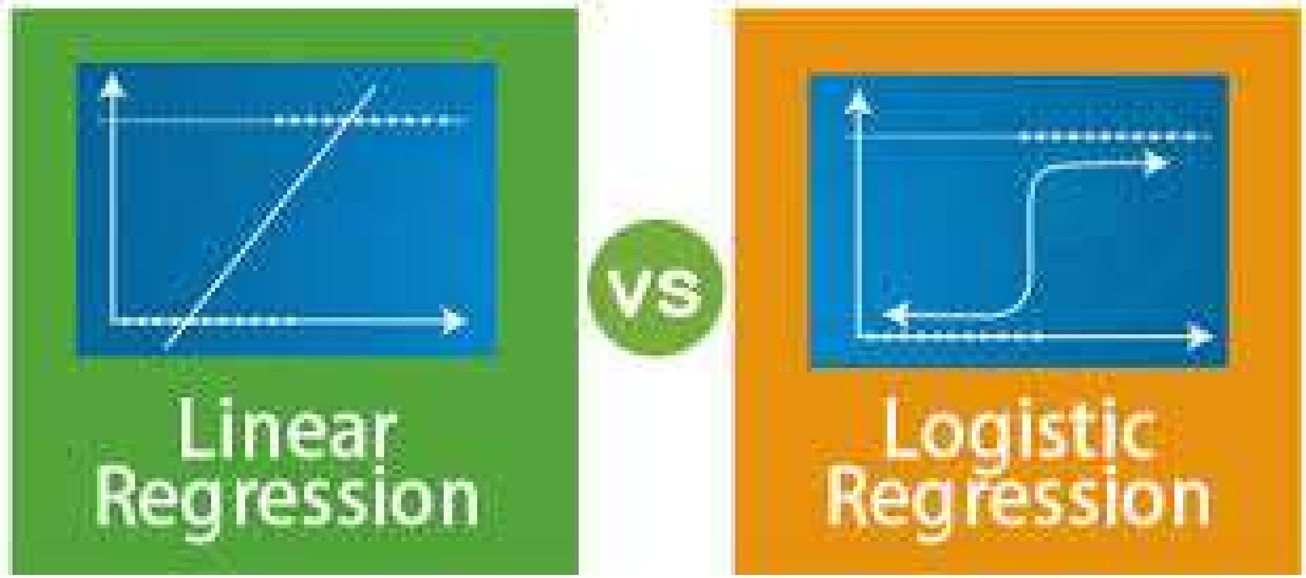
Y = discrete attribute data

Appropriate Data for Y in Logistic Regression

Type of data for Y

- Discrete, attribute
- Two levels only
  - "Success"
  - "Failure"
- Choose one and call it an **event**
  - People are usually more interested in successes, but you can just as easily predict failures
  - Minitab will want to know which level interests you and will call it the "event" (of interest)

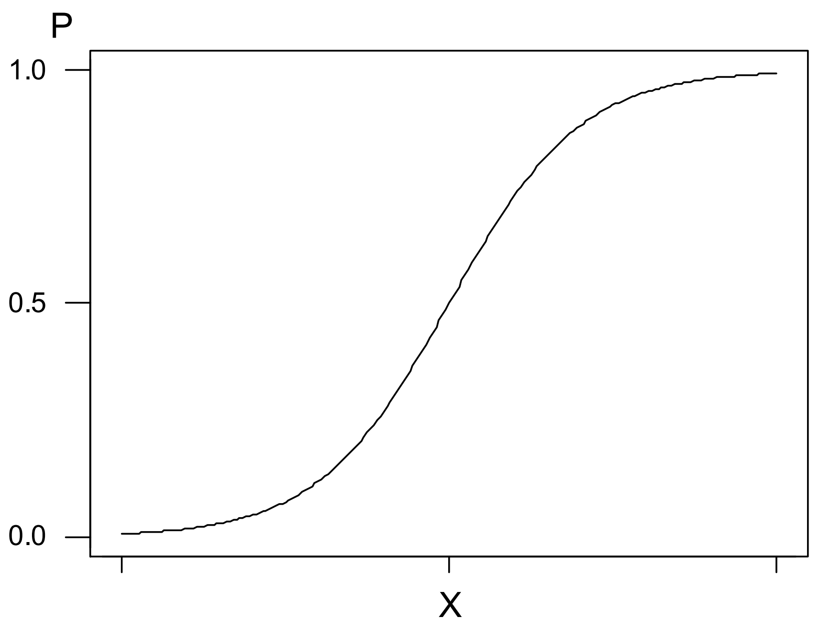
Linear Regression Vs Logistic Regression

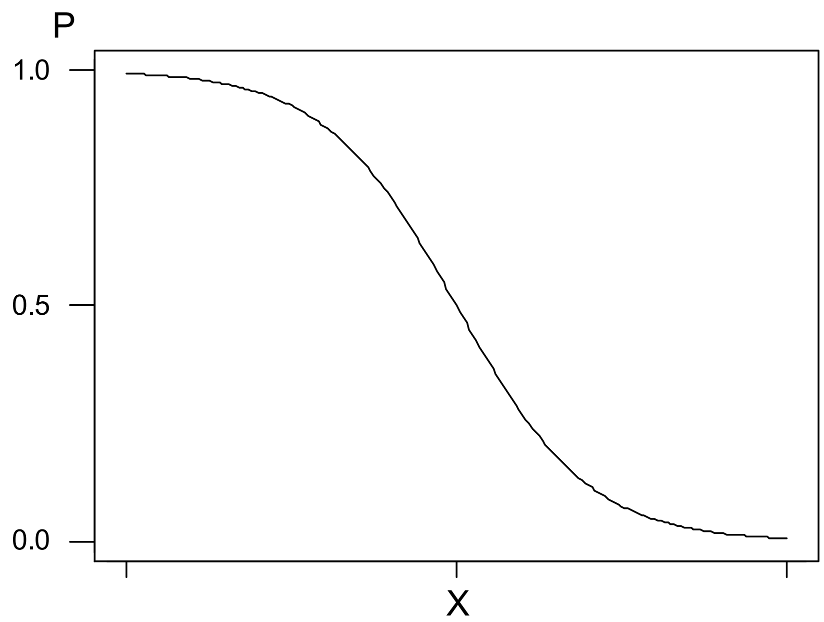


Logistic Regression Fits a Curve to the Data

The relationship between an event probability (p) and a predictor (X) is usually curved, not straight

- It looks like a tilted “S,” backward “S,” or some portion of an “S”
- It has asymptotes at 0 and 1

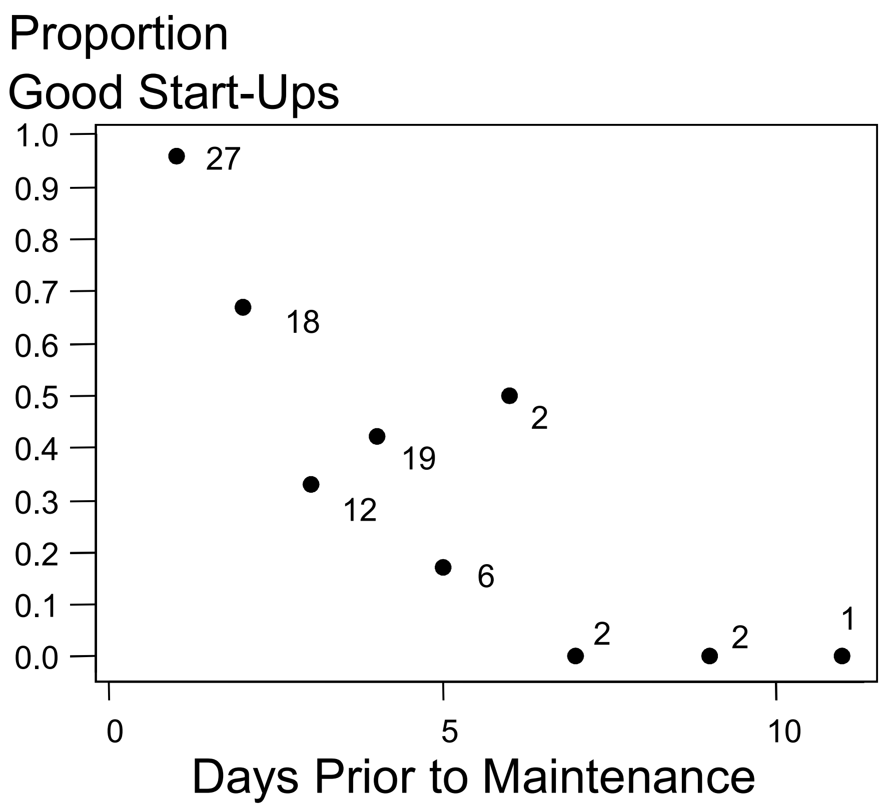




Logistic Regression Fits a Curve to the Data, cont.

Maintenance example

- The proportion of good start-ups decreases as the days prior to maintenance increase, but not at a constant rate
- Draw a curve that might fit the points on this plot

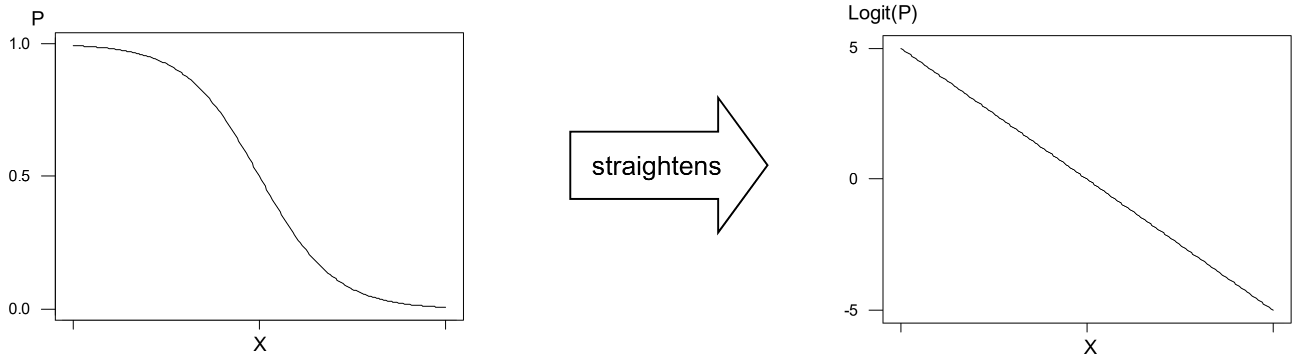


How Does Logistic Regression Work?

- The Y-variable is actually P, the proportion of Y-attributes at each X-value
- The logit transformation straightens the S-shaped relationship between P and X

P (proportion) vs. X

Logit P (transformation) vs. X



- Logistic regression gets its name from this transformation

Doing Logistic Regression

- We will use Minitab to:
  - Obtain b_0 and b_1
  - Back-transform the fits to obtain predicted P's (event probabilities or EPROs) for each value of X
- Logistic regression is an advanced topic
  - Much of Minitab's output is beyond the scope of this course
  - The interpretation of b_1 is not simple
  - We will use plots of the back-transformed fits vs. X to interpret the relationship

Anexas Consultancy Services

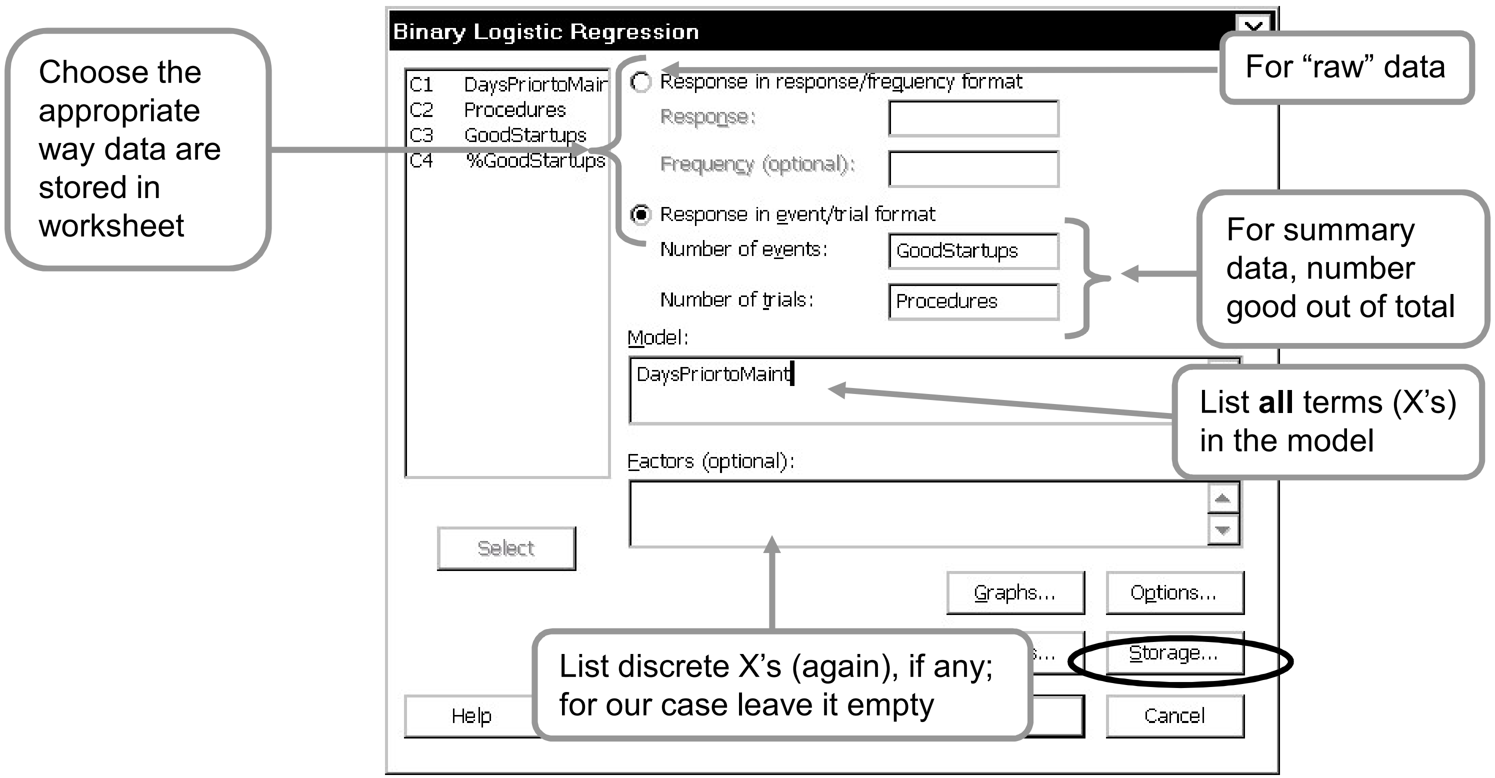
Regression Analysis

Logistic Regression with Discrete Y's

Minitab Follow-Along: Logistic Regression

- **Data: *PrevMain.mtw***
  1. Do a logistic regression analysis on the "Good Start-ups" predicted from "Days Prior to Maint.":

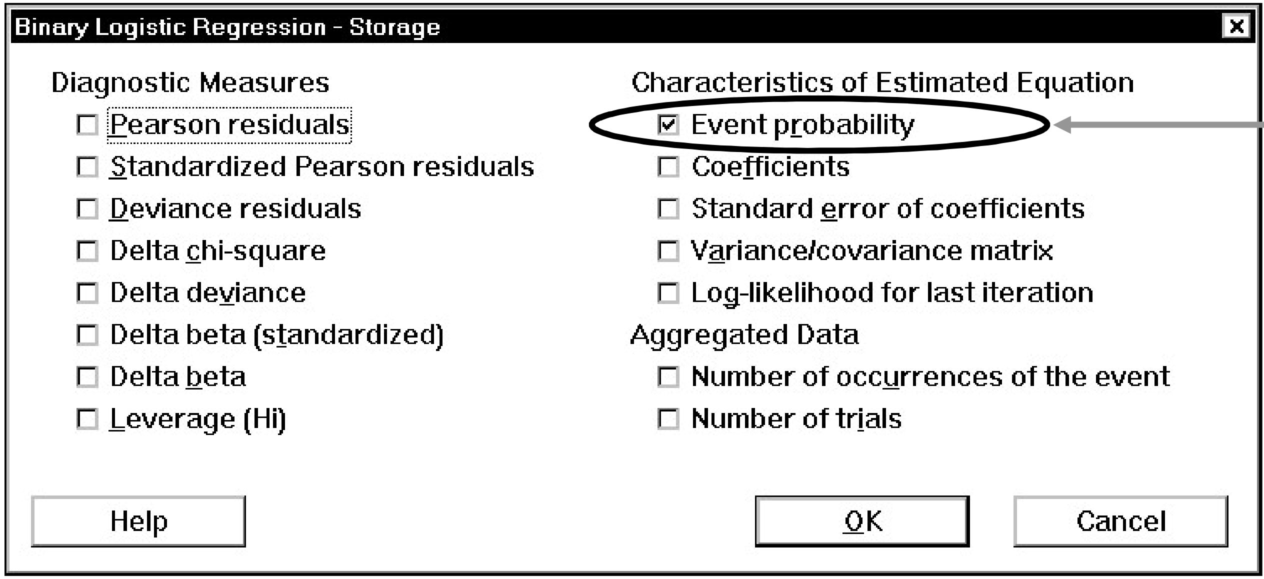
     Stat > Regression > Binary Logistic Regression



Minitab Follow-Along: Logistic Regression, cont.

2. Store the fitted Y's (known as event probabilities) to make a fitted line plot later:

Stat > Regression > Binary Logistic Regression > Storage



Fitted probability values (stored as EPRO1)

Minitab Output: Logistic Regression

Binary Logistic Regression: GoodStartups, Procedures versus DaysPriortoM

```
Link Function:  Logit

Response  Information

GoodStartups  Event         52
              Non-event     37
Procedures    Total         89

Logistic Regression Table
                                                     Odds     95% CI
Predictor             Coef     SE Coef       Z      P  Ratio  Lower  Upper
Constant           2.82120   0.617574    4.57  0.000
DaysPriortoMaint  -0.858419  0.196212   -4.37  0.000   0.42   0.29   0.62

LogLikelihood = 44.643
Test that all slopes are zero: G = 31.555, DF = 1, PValue = 0.000

GoodnessofFit Tests

Method                 ChiSquare    DF       P
Pearson                    9.772     7   0.202
Deviance                   8.497     7   0.291
HosmerLemeshow             5.769     3   0.123

Table of Observed and Expected Frequencies:
(See HosmerLemeshow Test for the Pearson ChiSquare Statistic)

                     Group
Value      1     2     3     4     5   Total
Success
  Obs      2     8     4    12    26      52
  Exp    1.4   6.7   6.7  13.5  23.7
Failure
  Obs     11    11     8     6     1      37
  Exp   11.6  12.3   5.3   4.5   3.3

  Total   13    19    12    18    27      89

Measures of Association:
(Between the Response Variable and Predicted Probabilities)

Pairs          Number  Percent     Summary Measures
Concordant       1483    77.1%     Somers' D              0.66
Discordant        217    11.3%     GoodmanKruskal Gamma   0.74
Ties              224    11.6%     Kendall's Taua         0.32
Total            1924   100.0%
```

Logistic regression equation:

$$\ln \frac{p}{(1-p)} = 2.82 - 0.858(\text{Days Prior})$$

Both slope and intercept are significant

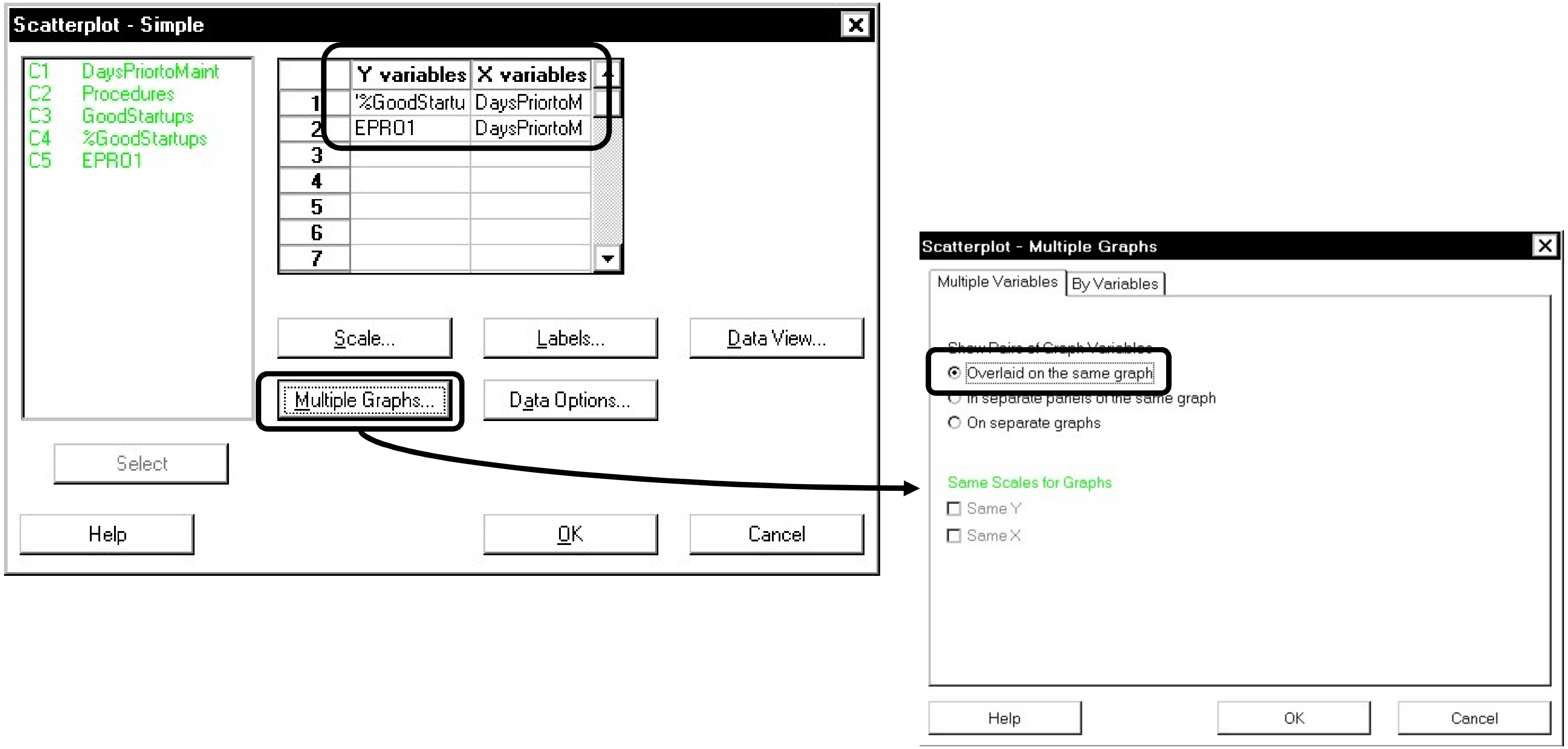
Testing for a lack of fit (curve through points). Since P > 0.05, conclude no lack of fit in any of three tests.

Beyond scope of course

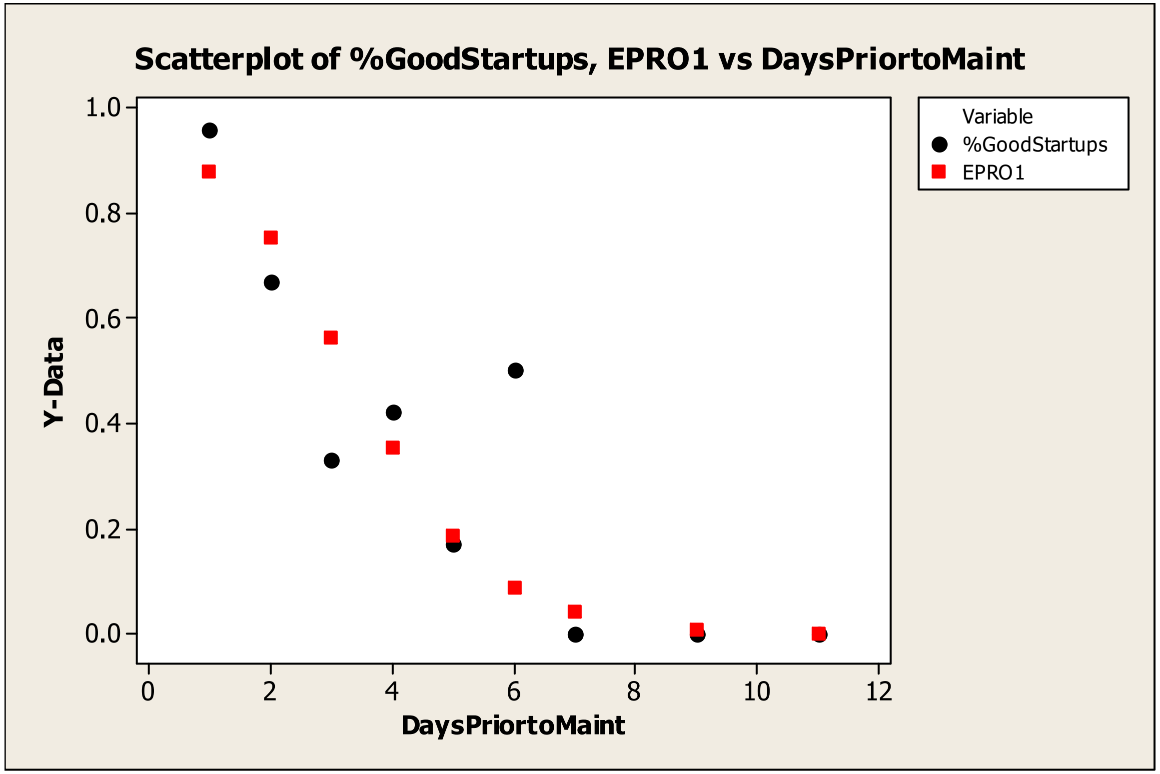
Minitab Follow-Along: Logistic Regression, cont.

3. Make a fitted curve plot for the data:

   Graph > Scatter plot > Simple



Minitab Follow-Along: Logistic Regression, cont.



Conclusion: If you schedule maintenance every two days, you'll have a 75% chance of a good start-up the next day.

Anexas Consultancy Services

Regression Analysis

Logistic Regression with Discrete Y's

Multiple Logistic Regression

- You can try to improve the prediction of event probabilities by using several predictors (X's), not just one
  - The predictors (X's) can be either continuous or discrete
  - The multiple logistic regression equation is

$$\log_e\left(\frac{p}{1-p}\right) = b_0 + b_1X_1 + b_2X_2 + \ldots b_kX_k$$

  - If any of the X's are discrete (in groups), you must designate one group to be the reference group
  - The coefficient for a discrete X group compares its intercept with the reference group (see discussion in previous section)
- Multiple logistic regression is useful for identifying key drivers (X's), particularly those that affect Y (event probabilities) in combination with each other

Practice: Applications of Logistic Regression

- **Objective:** Practice identifying predictor variables for logistic regression situations
- **Instructions:**
  - Circle the outcome you would define as a "success" for each discrete Y
  - List some possible predictors
- **Time:** 5 minutes

Discrete Y's	Predictors (X's)
Shipment is on time or late	
Customer buys product or not	
Deal was won or lost	
Customer retained this year or not	
Product works or not	
Machine breaks down or not	

Answers: Applications of Logistic Regression

Discrete Y's	Predictors (X's)
Shipment is **on time** or late	• Size of order • Number of other orders in queue
Customer **buys** product or not	• Product price • Presence of CTQ
Deal was **won** or lost	• Cost • Experience level of company representative
Customer **retained** this year or not	• Length of time with company • Amount price increased or decreased
Product **works** or not	• Number of defects • Quality of materials
Machine breaks down or **not**	• Type of maintenance procedure used • Experience level of maintenance operator

Exercise: Do a Multiple Logistic Regression (Part 1)

- **Objective:** Practice doing a multiple logistic regression in Minitab and interpreting the results
- **Data:** ***Retain.mtw***
- **Background:**
  - Suppose you work for a company that manufactures custom and standard surgical devices for doctors; competition in this market is fierce
  - You are interested in finding the key factors that help predict whether your company will retain a customer next year or not
  - Last year's data on 63 customers are given below
  - The event of interest is "customers kept"
  - Q-Score range is 1 – 10, 1 being the best score and 10 is worst
- **Time:** 25 minutes

Exercise: Do a Multiple Logistic Regression (Part 1), cont.

- **Instructions:**
  - Work in pairs
  - Open the appropriate Minitab window and enter the answers to questions 1 through 4 before proceeding

  Stat > Regression > Binary Logistic Regression

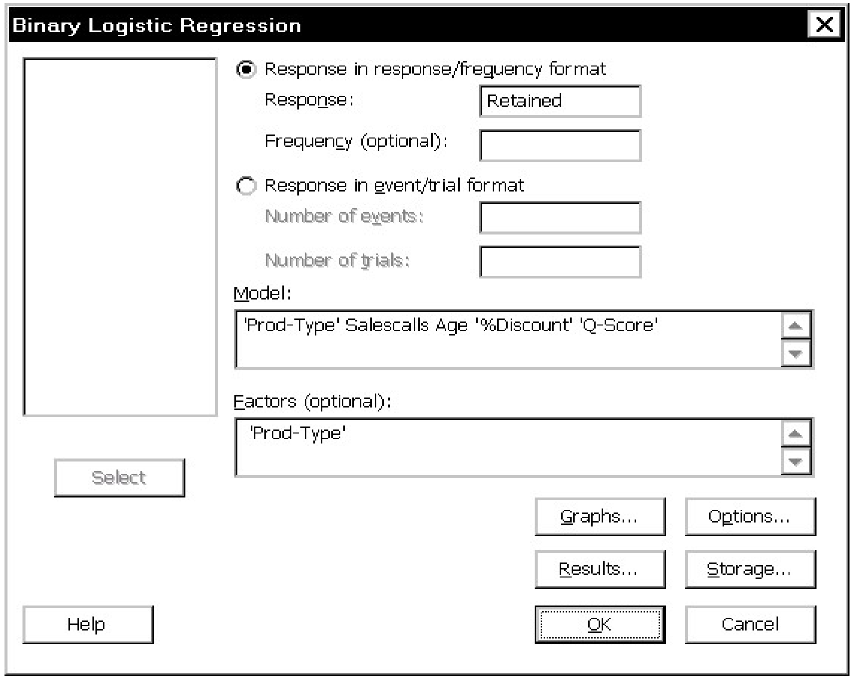
  1. Which variable is Y?
  2. Are these raw data or a summary table of counts?
     - Choose the appropriate data format in Minitab
  3. How many predictors (X's) are there?
     - List each in Minitab's "Model" box
  4. How many of the predictors (X's) are discrete?
     - List only the discrete X's in Minitab's optional "Factors" box

Answers: Do a Multiple Logistic Regression (Part 1)

Results for Questions 1 through 4

1. Y variable = **Retained**
2. Raw data or summary? **Raw data**
3. How many predictors are there? **Five**
4. How many predictors are discrete?
   One (Product type)

This is what your Minitab window should look like so far

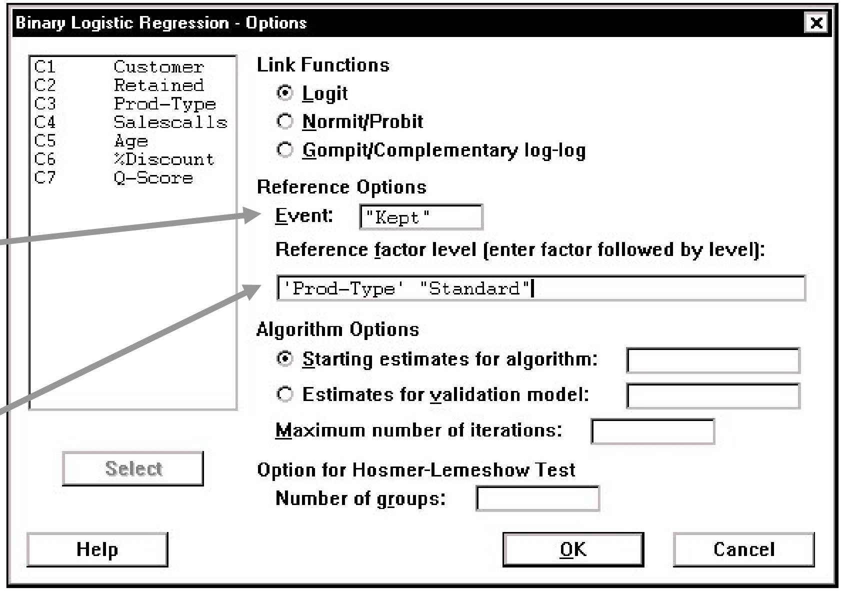


Exercise: Do a Multiple Logistic Regression (Part 2)

- Select the Options button in Minitab and designate:
  - a. The event of interest
    - Select the Options button; type in the event of interest in double quotes in the box labeled “A” below
  - b. The reference group (or the discrete X)
    - Type the factor name followed by the level of X that you want to be the reference group in the box labeled “B” below
    - Type the factor name in single quotes and the level in double quotes

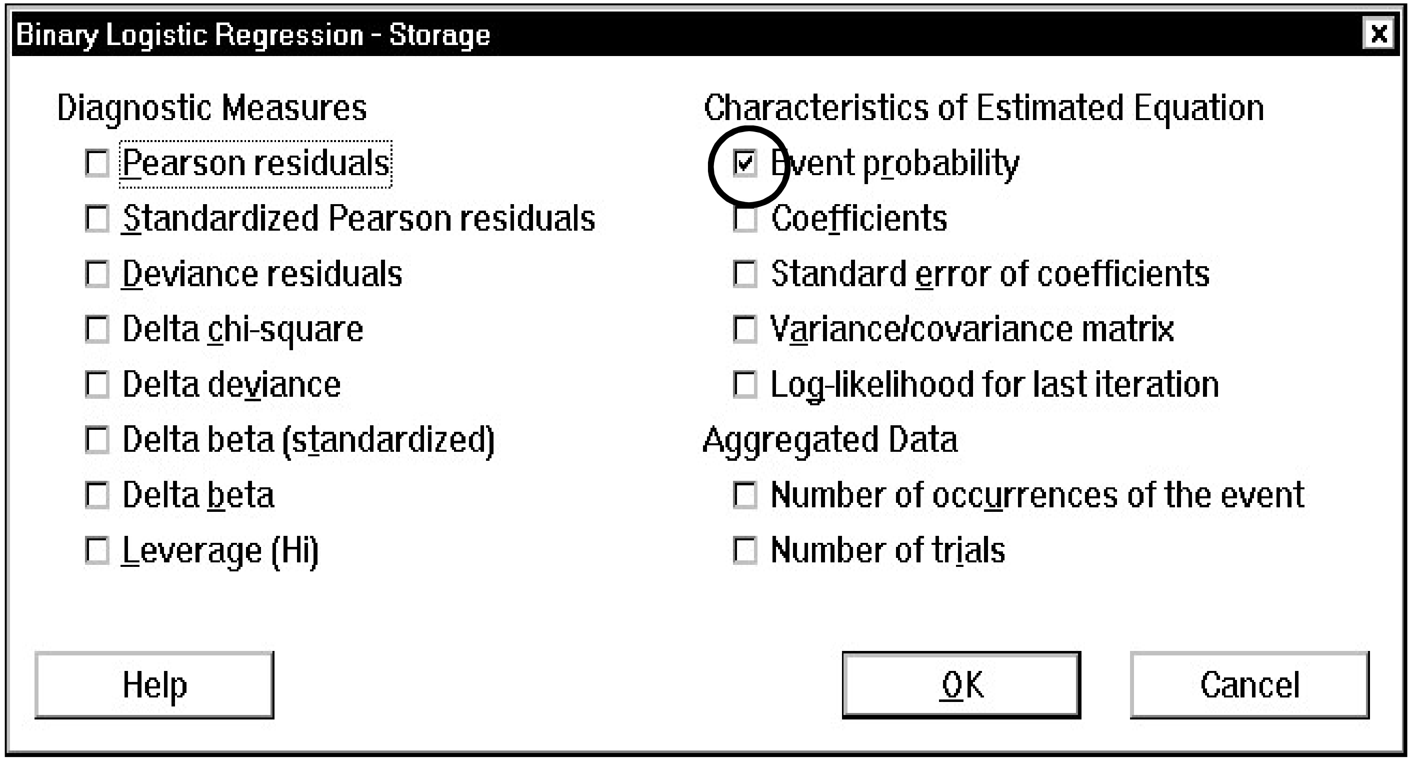
a. If this box is left empty, the default event becomes the one in **last** alphabetical order; in this case the default would be “lost.”

b. Use double quotes for discrete X reference group if it is text. If this box is left empty, the default reference group becomes the **first** one in alphabetical order; in this case the default is “custom.”



Exercise: Do a Multiple Logistic Regression (Part 2), cont.

- Select the Storage button in Minitab and check "Event probability" to store it so you can make plots with it
  – This is the same as the fits in regular regression



Exercise: Do a Multiple Logistic Regression (Part 2), cont.

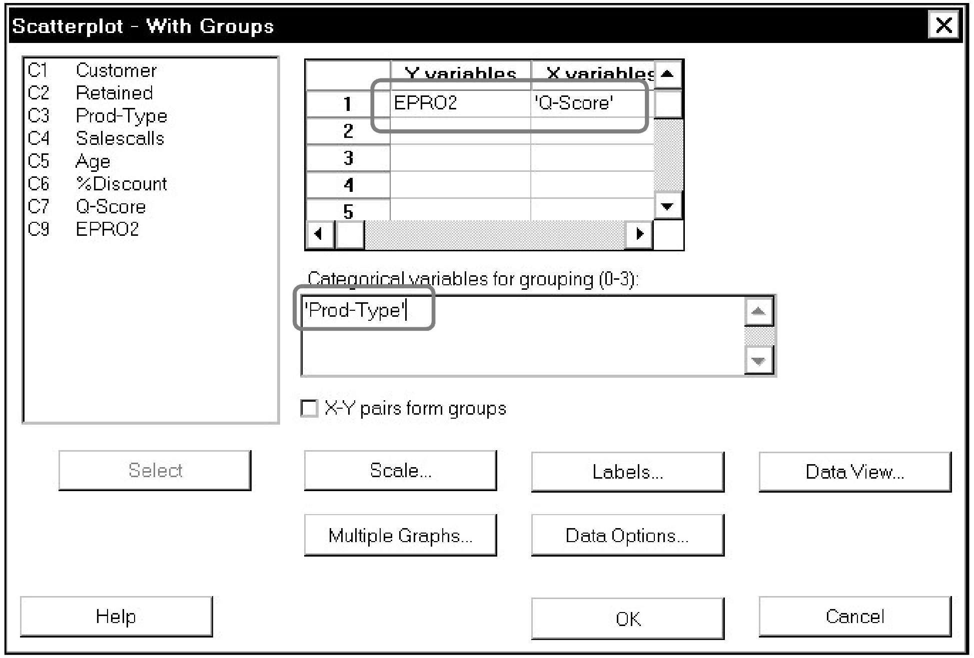
5. Which predictors (X's) help explain whether a customer will be kept or lost?
6. Remove the non-significant predictors (X's) and redo the multiple logistic regression
   a. Be prepared to report an interpretation of the output to the whole group
   b. Which type of product has the greatest probability of retaining customers?

Exercise: Do a Multiple Logistic Regression (Part 2), cont.

7. a. Create a scatter plot of predicted event probabilities vs. the significant X-values; stratify by the discrete X groups

   Graph > Scatter plot

   b. Interpret the plot



Answers: Do a Multiple Logistic Regression (Part 2)

Minitab output for full model

```
Binary Logistic Regression: Retained versus ProdType, Salescalls,...
Link Function: Logit

Response Information

Variable  Value  Count
Retained  Kept      47  (Event)
          Lost      14
          Total     61

* NOTE * 61 cases were used
* NOTE * 2 cases contained missing values

Logistic Regression Table
                                                   Odds      95% CI
Predictor       Coef    SE Coef      Z      P     Ratio   Lower   Upper
Constant       1.959      3.056   0.64  0.522
ProdTyp
 Custom        2.218      1.152   1.92  0.054      9.18    0.96   87.89
Salescal      0.1157     0.1133   1.02  0.307      1.12    0.90    1.40
Age           0.3737     0.2873   1.30  0.193      1.45    0.83    2.55
%Discoun      0.1416     0.1927   0.73  0.463      1.15    0.79    1.68
QScore       0.7476     0.2508    2.98  0.003      0.47    0.29    0.77

LogLikelihood = 19.518
Test that all slopes are zero: G = 26.683, DF = 5, PValue = 0.000

GoodnessofFit Tests
Method              ChiSquare   DF      P
Pearson                46.617   50  0.610
Deviance               39.036   50  0.869
HosmerLemeshow          2.978    8  0.936
```

[Some output deleted to save space (and it is all beyond the scope of this course).]

Product type is discrete. Recall that "Standard" is the reference product. In this regression, this is the slope adjustment for "Custom," relative to "Standard."

Event of interest is "customer kept."

Beyond scope of class

Two significant predictors (X's)

No significant lack of fit since P > 0.05

Answers: Do a Multiple Logistic Regression (Part 2), cont.

Question 5: Answer (cont.)

- Product type and Q-Score are significant predictors of whether or not we will retain customers next year
- We will remove the non-significant predictors (X's) and redo the regression

Answers: Do a Multiple Logistic Regression (Part 2), cont.

Question 6: Output for reduced model

The positive coefficient means that we have a higher chance of retaining customers who purchase custom products than we have of retaining customers who purchase standard products.

The negative coefficient correlates to the probability of keeping the customer. As the Q-Score increases, the chance of keeping the customer decreases. (Low Q-Scores are good.)

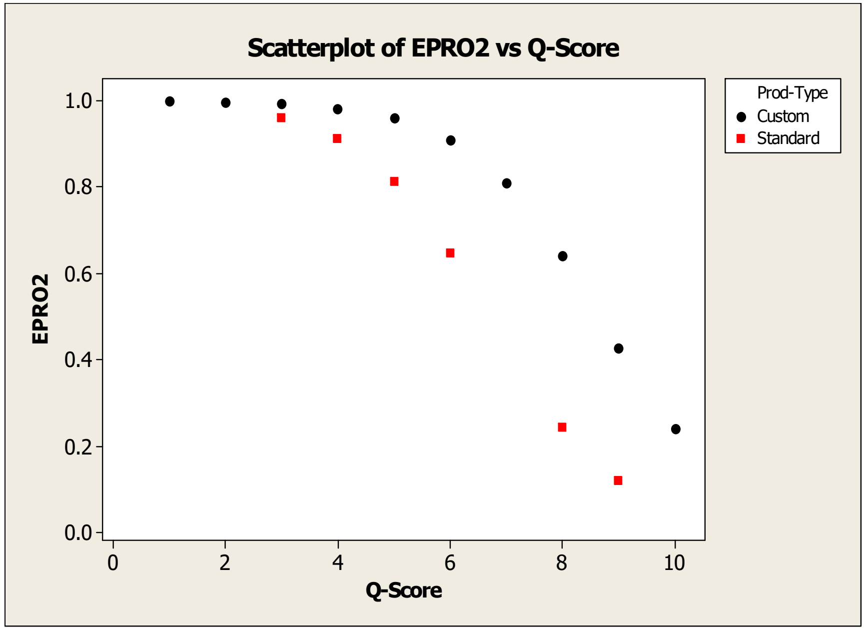
Beyond scope of class

```
Binary Logistic Regression: Retained versus ProdType, QScore


Link Function:  Logit

Response Information

Variable  Value       Count
Retained  Kept           48  (Event)
          Lost           15
          Total          63

Logistic Regression Table
                                                        Odds      95% CI
Predictor       Coef    SE Coef        Z      P        Ratio   Lower    Upper
Constant       5.810      1.767     3.29  0.001
ProdTyp
 Custom       1.7091     0.8840     1.93  0.053        5.52     0.98    31.24
QScore       0.8672    0.2398    3.62  0.000        0.42     0.26     0.67

LogLikelihood = 22.403
Test that all slopes are zero: G = 24.352, DF = 2, PValue = 0.000

GoodnessofFit Tests

Method              ChiSquare    DF       P
Pearson                21.240    13   0.068
Deviance               16.272    13   0.235
HosmerLemeshow          2.206     4   0.698

[Some output removed.]
```

Answers: Do a Multiple Logistic Regression (Part 2), cont.

Question 7: Scatter plot

Conclusions from scatter plot



- Your chance of keeping customers who purchase standard products decreases sharply with a quality score (QScore) of six or higher
- Overall, you have a better chance of keeping customers who purchase custom products

Applications to Your Business

- **Objective:** Practice identifying applications of logistic regression in your business
- **Instructions:**
  - Work alone or, if there are other participants whose work is related to yours, in pairs or small groups
  - Think of a discrete Y-variable—an output or result that has a particular attribute that interests you
  - List some possible predictors of the attribute
  - Would logistic regression be useful to you? Why or why not?
  - Volunteers will be asked to share with the whole group
- **Time:** 5 minutes

Anexas Consultancy Services

Process Analysis (Lean)

Identifying Causes with Process Maps

You Are Here

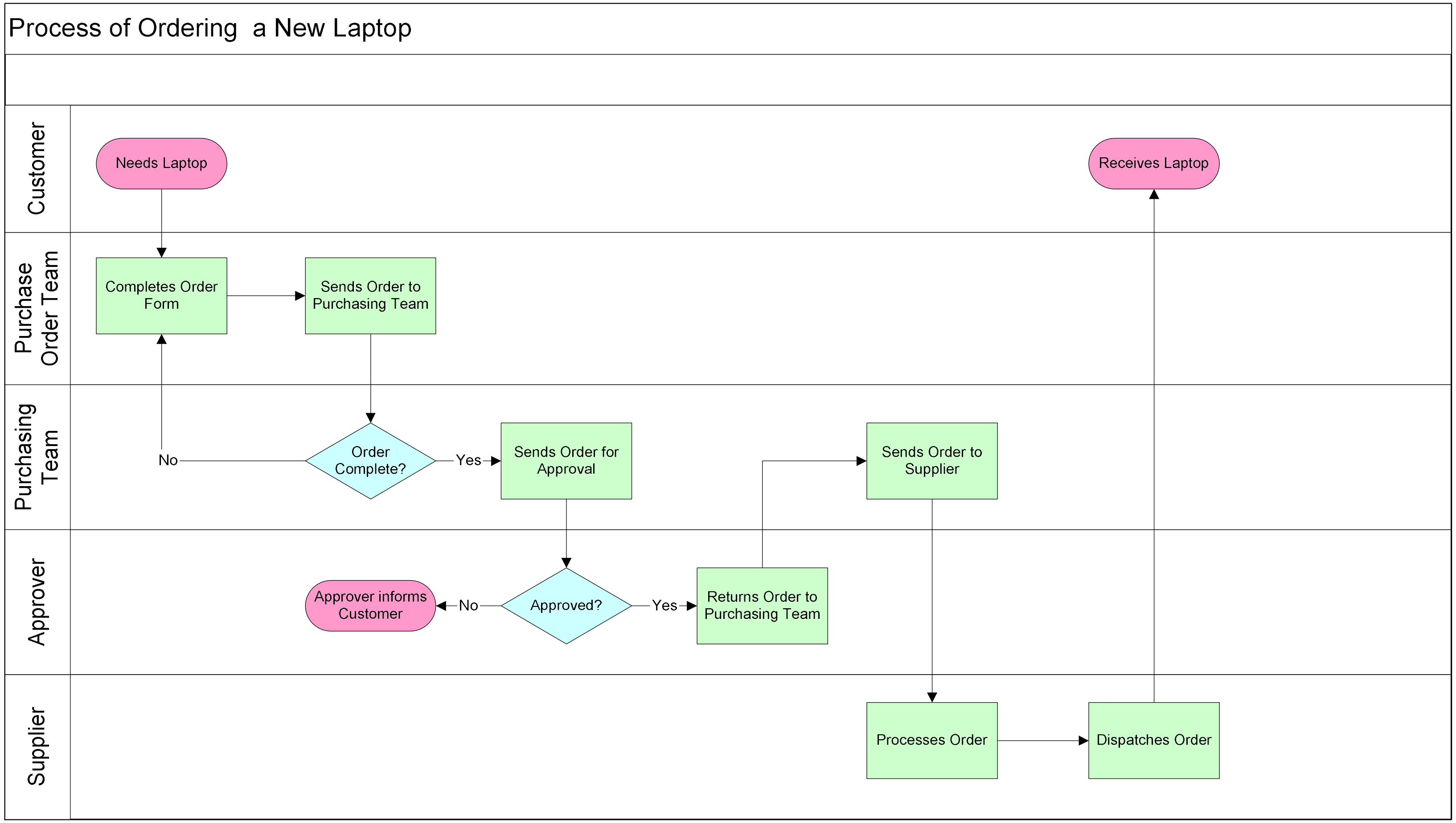
Identify potential causes → Organize potential causes → Collect data → Statistical methods to quantify cause-effect relationship

Identify the Value-Added Path

"The Happy Path"

Process Mapping

WHO



PROCESS FLOW

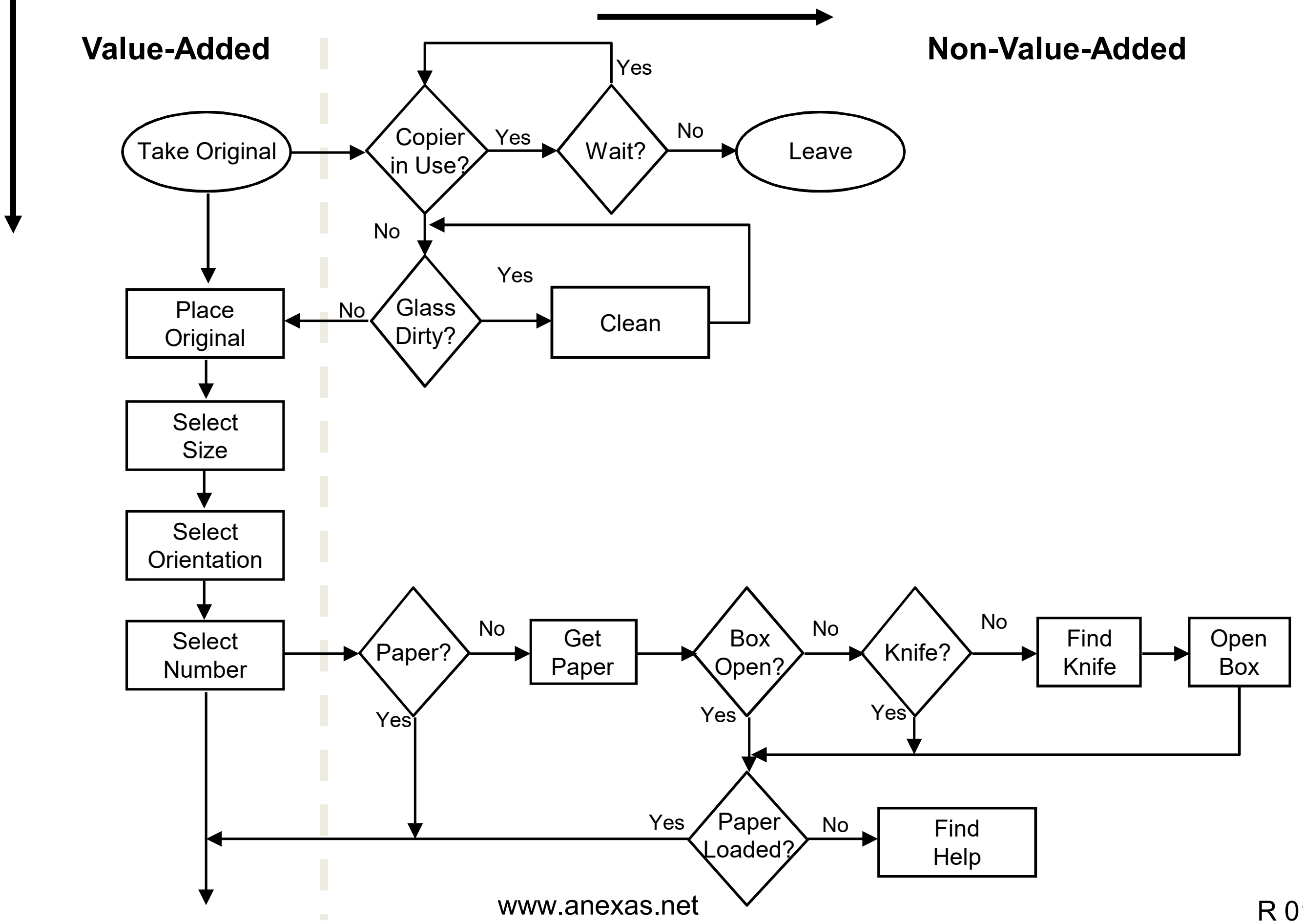
Value-Added and Non-Value-Added Steps

- Value-added steps:
  - Customers are willing to pay for it
  - Physically change the product
  - Are done right the first time
- Non-value-added steps:
  - Not essential to produce output
  - Include:
    - Defects, errors, omissions
    - Preparation/setup, control/inspection
    - Overproduction, processing, inventory
    - Transporting, motion, waiting, delays

Opportunity Process Map Features

Steps that are essential—even when everything works correctly—move down the left side

Steps that would not be needed if everything worked right the first time move horizontally across the right side

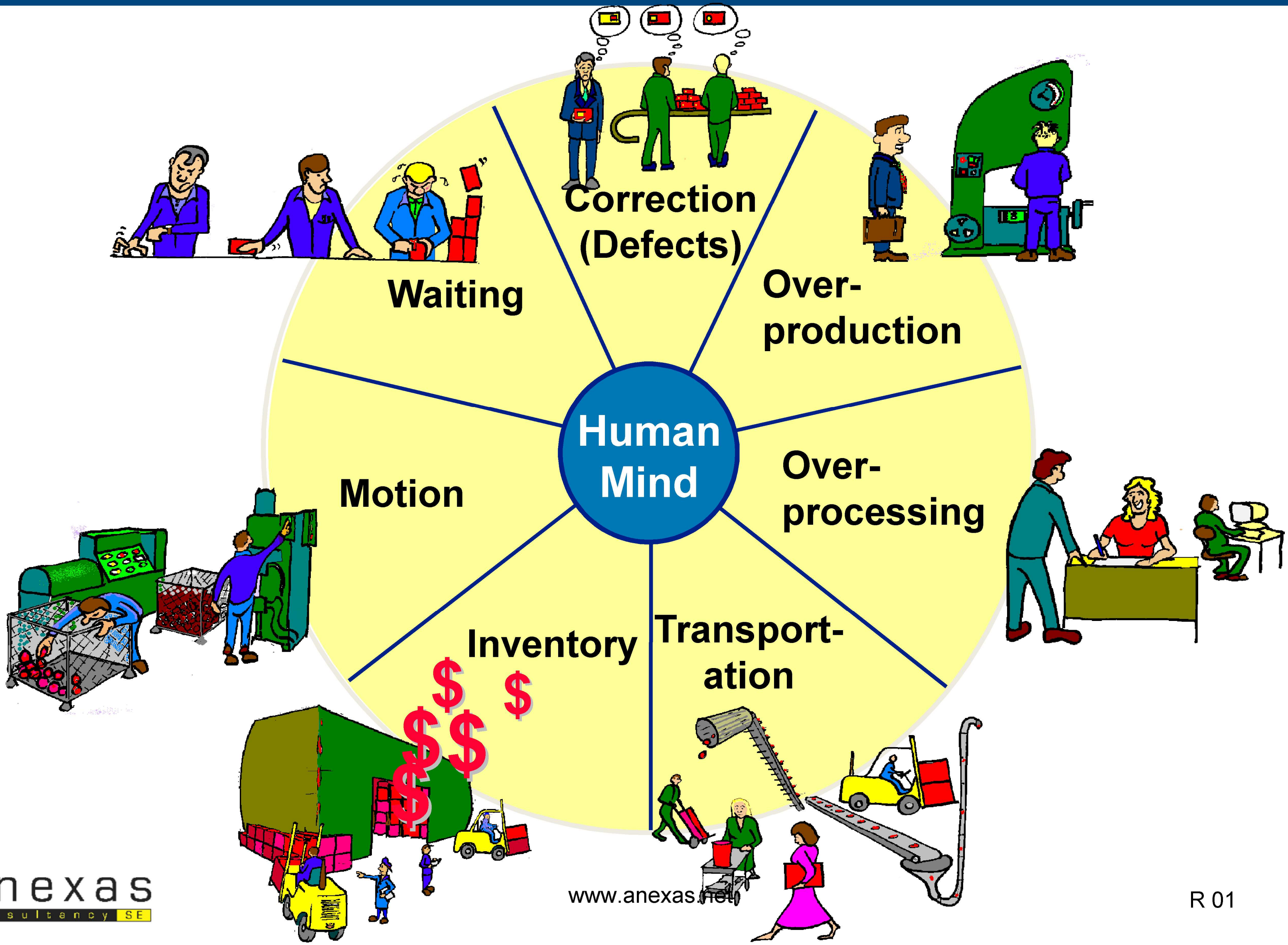


Anexas Consultancy Services

Identifying Flow Issues

Waste

Major Categories of Waste: TIMWOOD



Anexas Consultancy Services

Identifying Flow Issues

Cycle Time

Value Analysis Matrix

- You can track specific types of non-value-added time with a value analysis matrix
- This helps clarify not only the types of waste present in the process, but also the percentage of the overall process that each non-value-added step adds

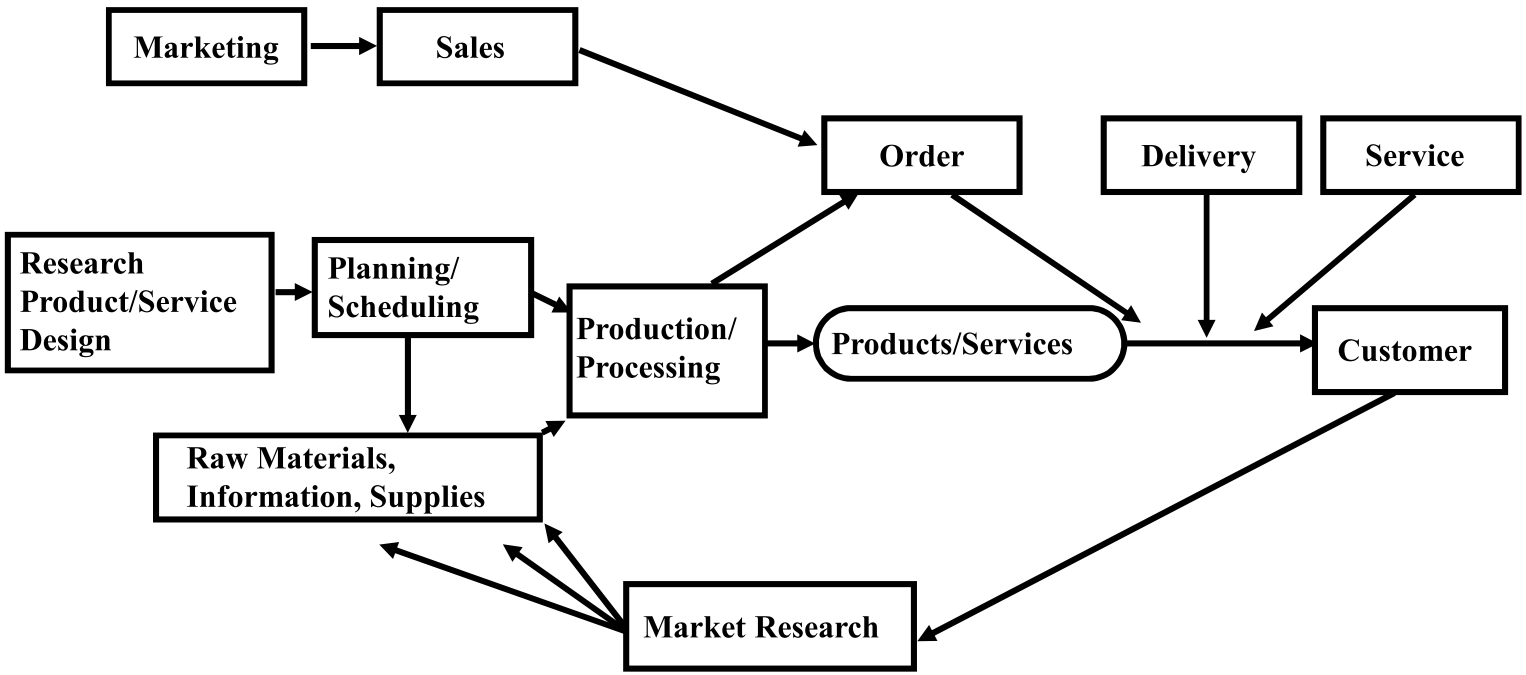
Process step	1	2	3	4	5	6	7	8	9	10	Total	%Total
Time (hours)	12	10	1	10	20	6	10	1	10	20	100	100%
Value-added			✓					✓			2	2%
Non-value-added												
Fixing errors									✓		10	10%
Prep/set-up												
Control/inspection						✓					6	6%
Delay	✓				✓					✓	52	52%
Transporting/motion		✓		✓			✓				30	30%
Total											100	100%

Anexas Consultancy Services

The Value Stream

Work as a System

Making improvements that last requires us to see work as a system—the result of a series of interactive functions, operations, methods, and processes

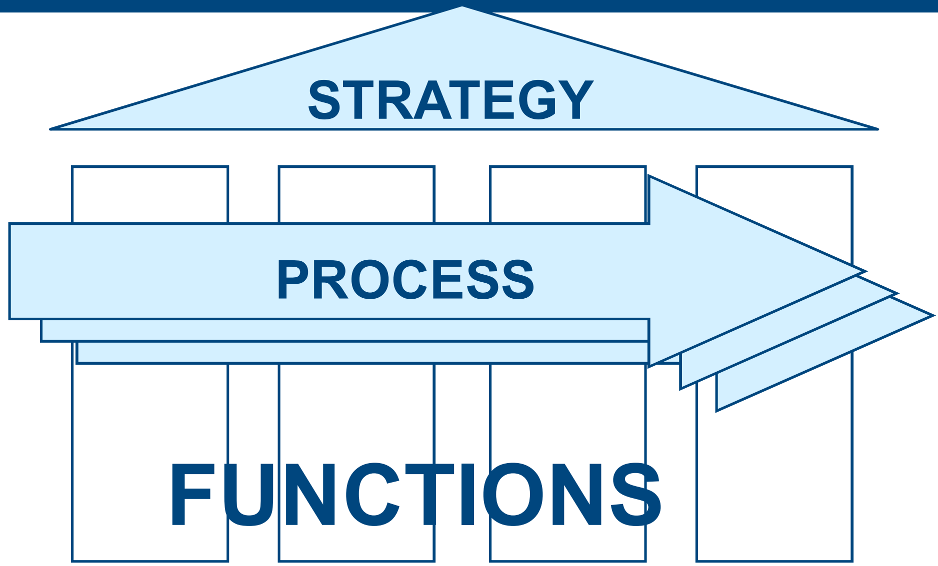


Visualize the workflow from end to end!

Quality, Systems, and Processes

- Quality is judged by customers based on the output of a process or the system
- Focusing only on the individual worker will not lead to greatly improved quality that lasts
- To improve quality, the processes and system must be improved
- Simply focusing on or defining a process or the system is **not** improvement—we have to make changes and use data to show the change is improvement

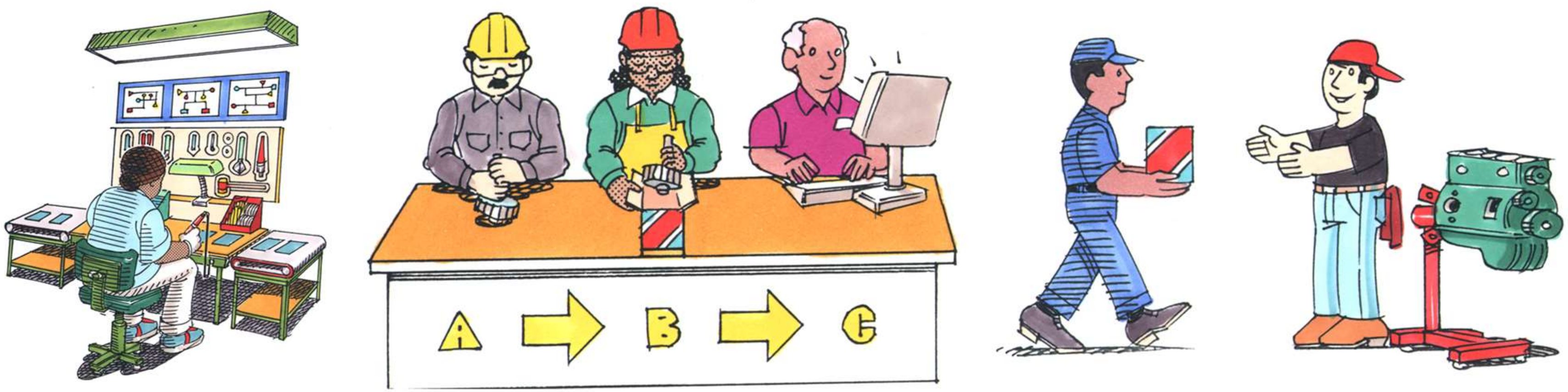
The Real Organization



- Products and services for customers are not produced by functions, but by processes that tend to cross functional lines
- Some of these processes tend to be the way customers identify with the company
- Functions are (or should be) the residence and building place for competencies
- Process capabilities and competencies are the key leverage points to achieve strategy (desired state of the organization)

What Is the Value Stream?

The value stream is the entire set of activities required to bring a product or service into the hands of the customer[1]

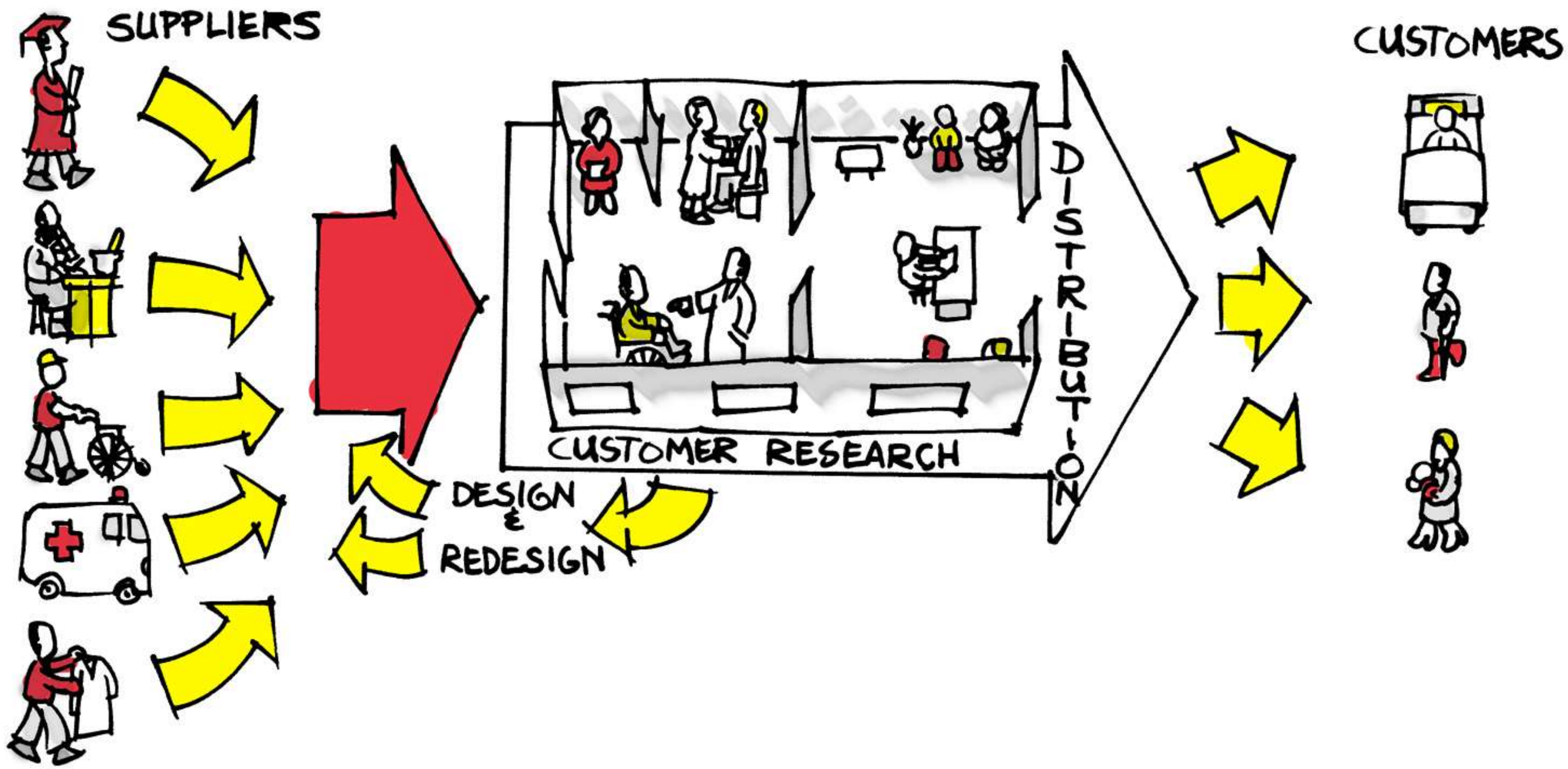


Suppliers ⇨ **Processes** ⇨ **Customers**

[1] From *Lean Thinking*, Womack and Jones, 1996.

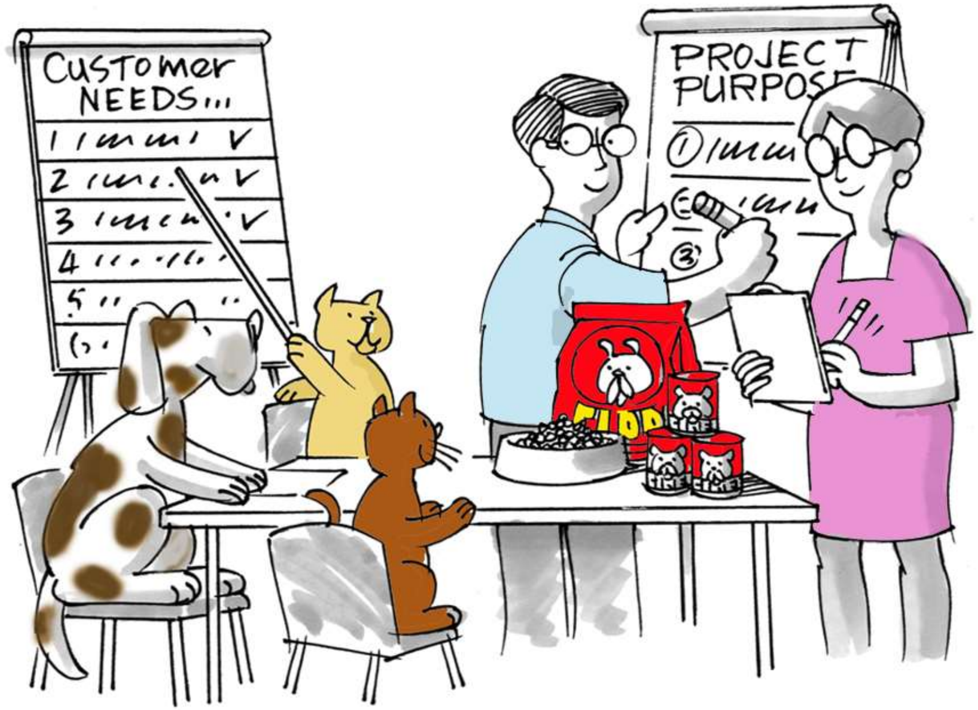
What Is the Value Stream?, cont.

Value streams can be defined for any industry



Value Stream and Customer Requirements

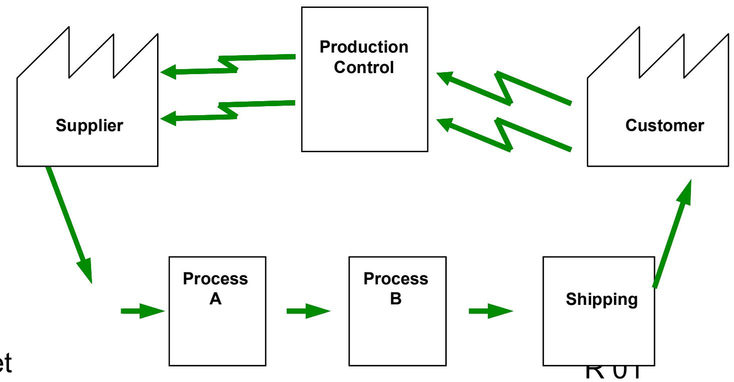
- The value stream exists to provide products and services that meet the customer requirements
- Understanding customer requirements is critical to the value stream mapping process



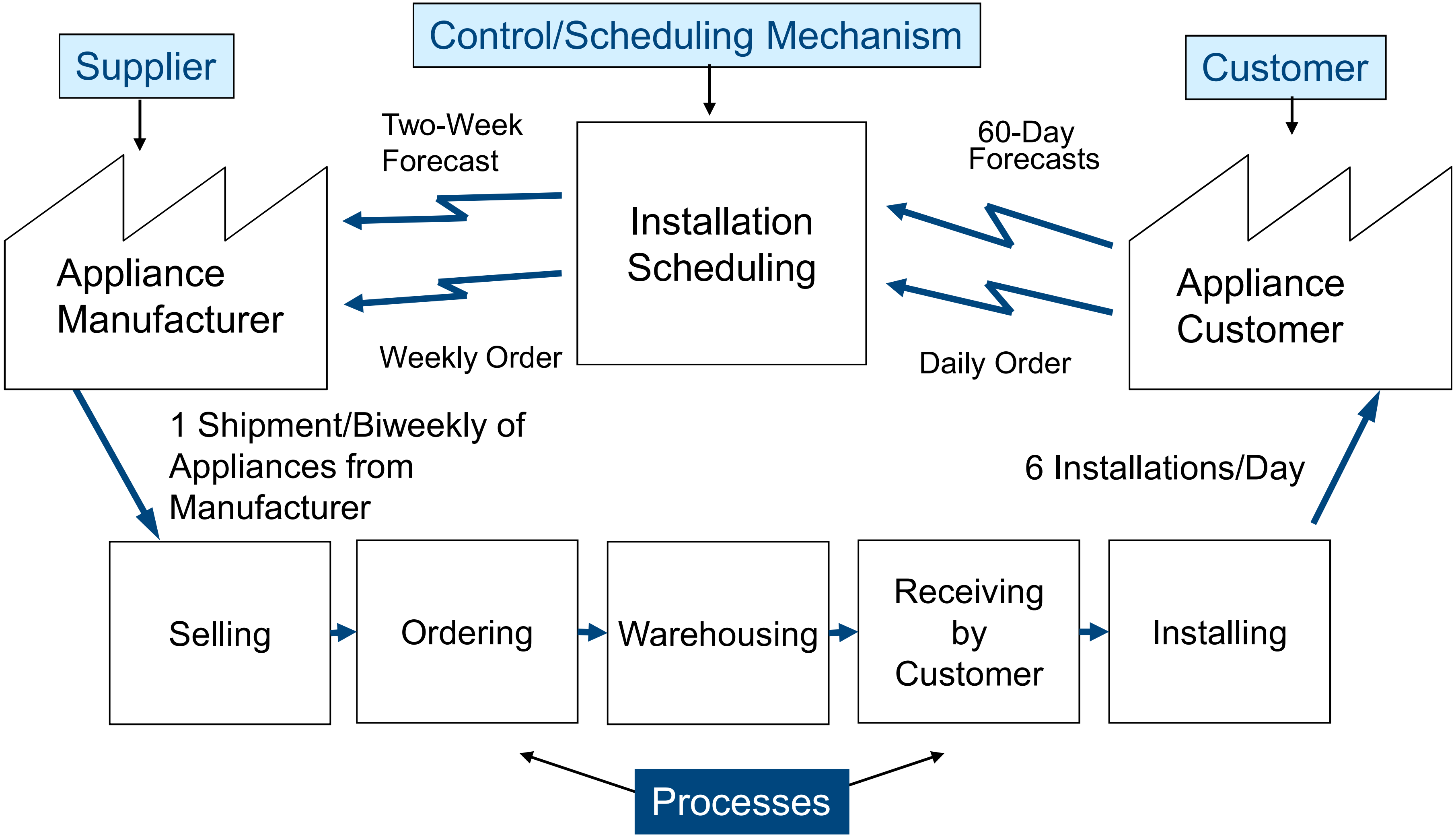
What Is a Value Stream Map (VSM)?

A workflow visualization tool for representing how customer needs are met

- By showing the flow of materials and information, waste is easier to see and opportunities to improve are easier to identify
- A picture of the entire value stream:
  - Includes material and information flows
  - Can be applied to any industry, product, or service
  - Is a paper-and-pencil technique



Example: High-Level Value Stream—Appliance Sales and Installation



Selecting a Value Stream

- Maintain a customer focus
- Select a product/service family
- Stay narrowly focused; create the flow for one product family or one service at a time

Financial Services Company
Service Families
Credit cards
Auto loans
Direct banking
Commercial loans

Truck and Railcar Loading Manufacturer
Product Families
Loading racks and platforms
Loading arms
Fall prevention systems

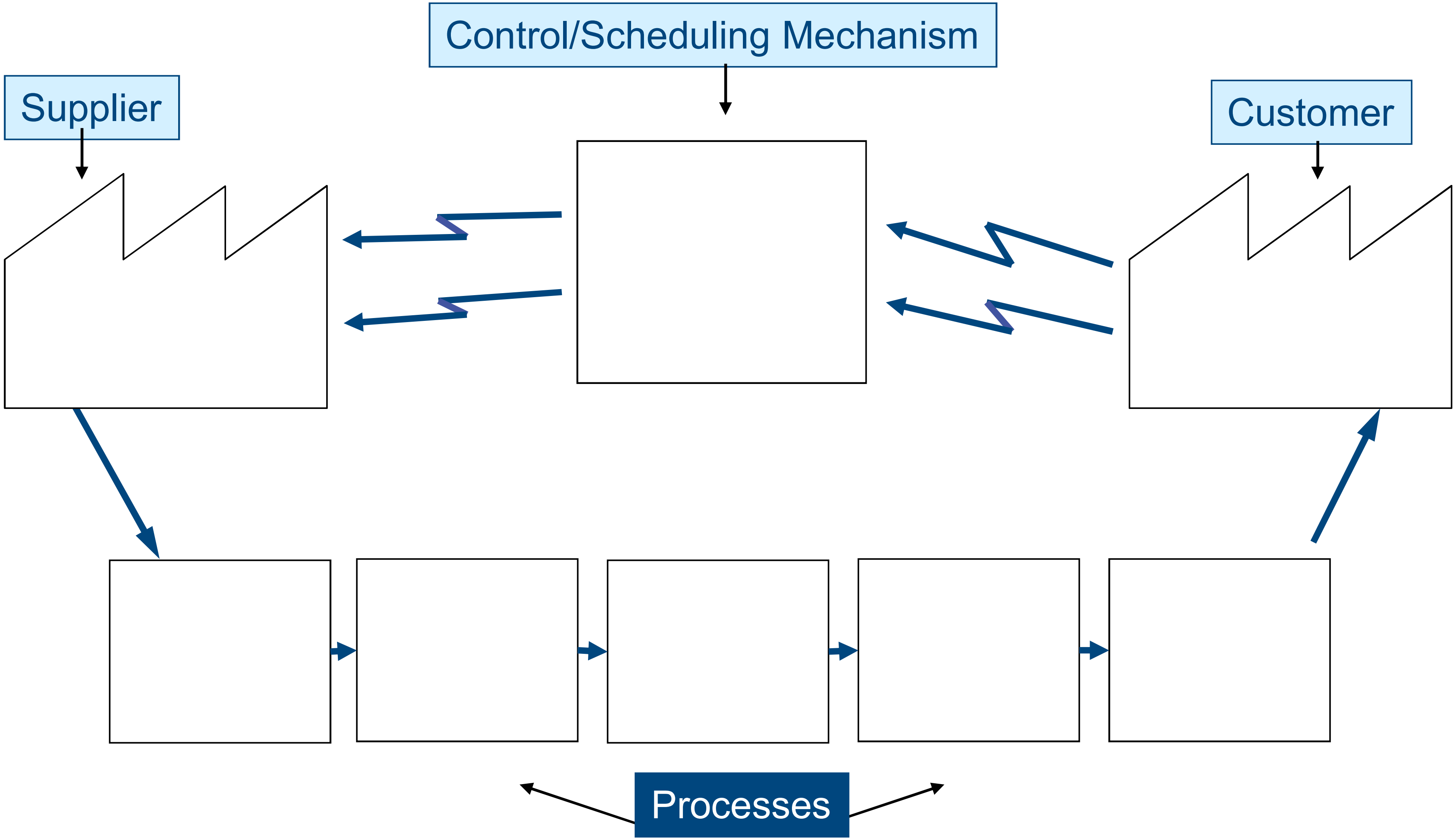
Origin of Value Stream Mapping

- Originated as part of Lean production concepts
- Originated in Japan as part of the Toyota Production System
- Originally called “material and information flow”
- Popularized in U.S. with the development of Toyota Supplier Support Centers (1990s–present)
- Method was documented and published in the U.S. in 1999 under the term “value stream mapping”

Exercise: Identifying a High-Level Value Stream

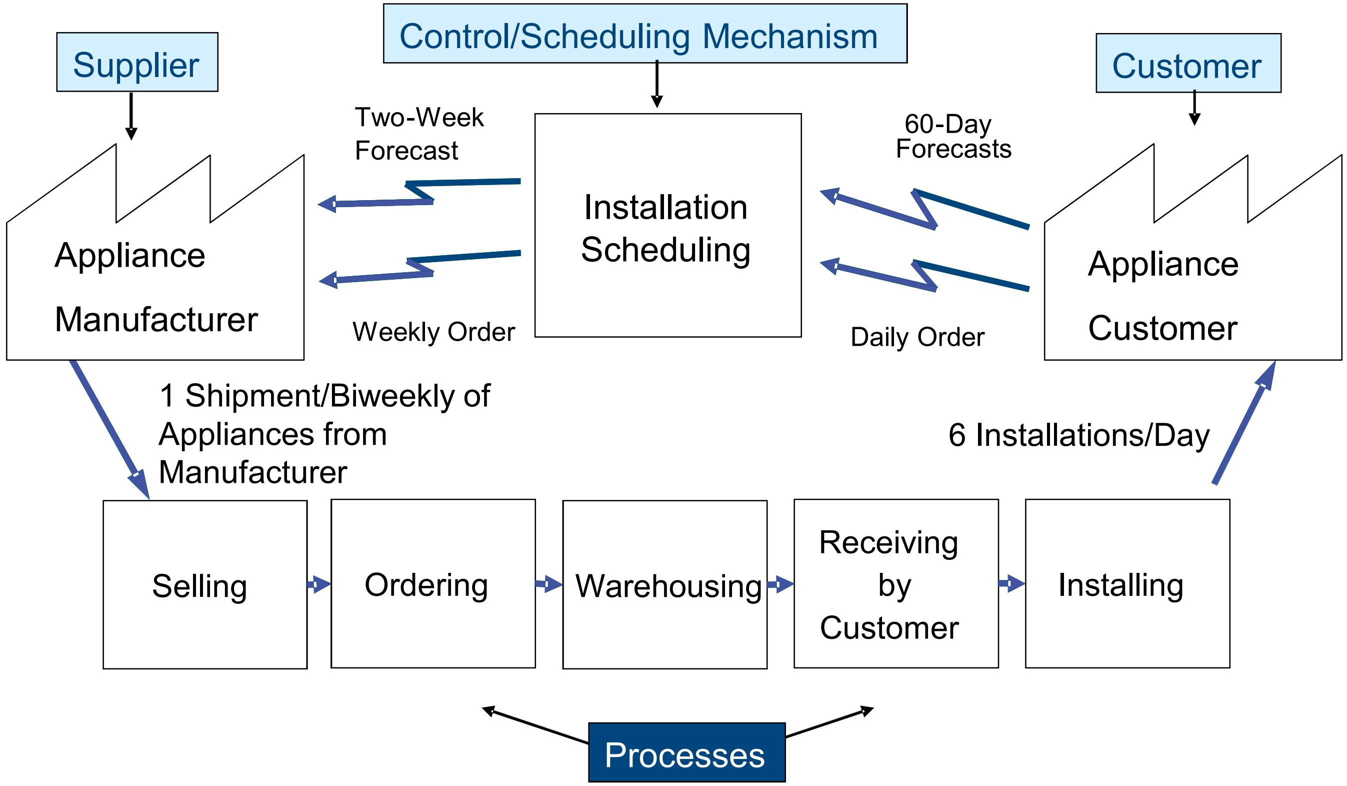
- **Objective:** Identify a value stream for your workplace
- **Instructions:**
  - Work individually
  - Select a product or service family in your work area, department, or enterprise
  - Use the template to document the value stream
  - Note that for this exercise, we are interested in identifying just the value stream itself, not all of the details we will add later
  - Be prepared to share with the larger group
- **Time:** 15 minutes

Exercise: Identifying a High-Level Value Stream, cont.



High-Level Value Stream

Can you identify waste and improvement opportunities from the high level?



More detail is needed in order to be useful.

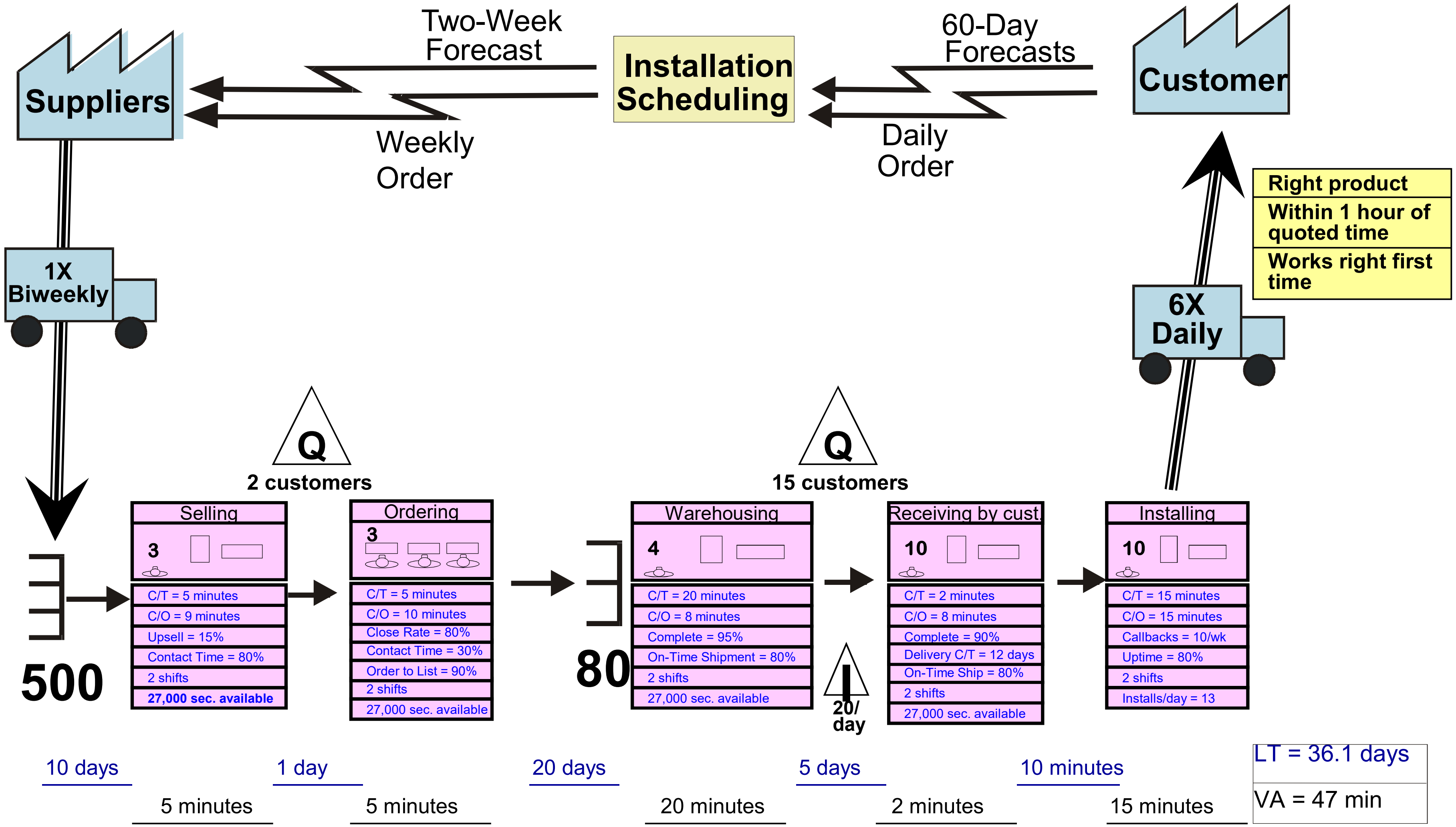
Anexas Consultancy Services

Comprehensive Value Stream Maps

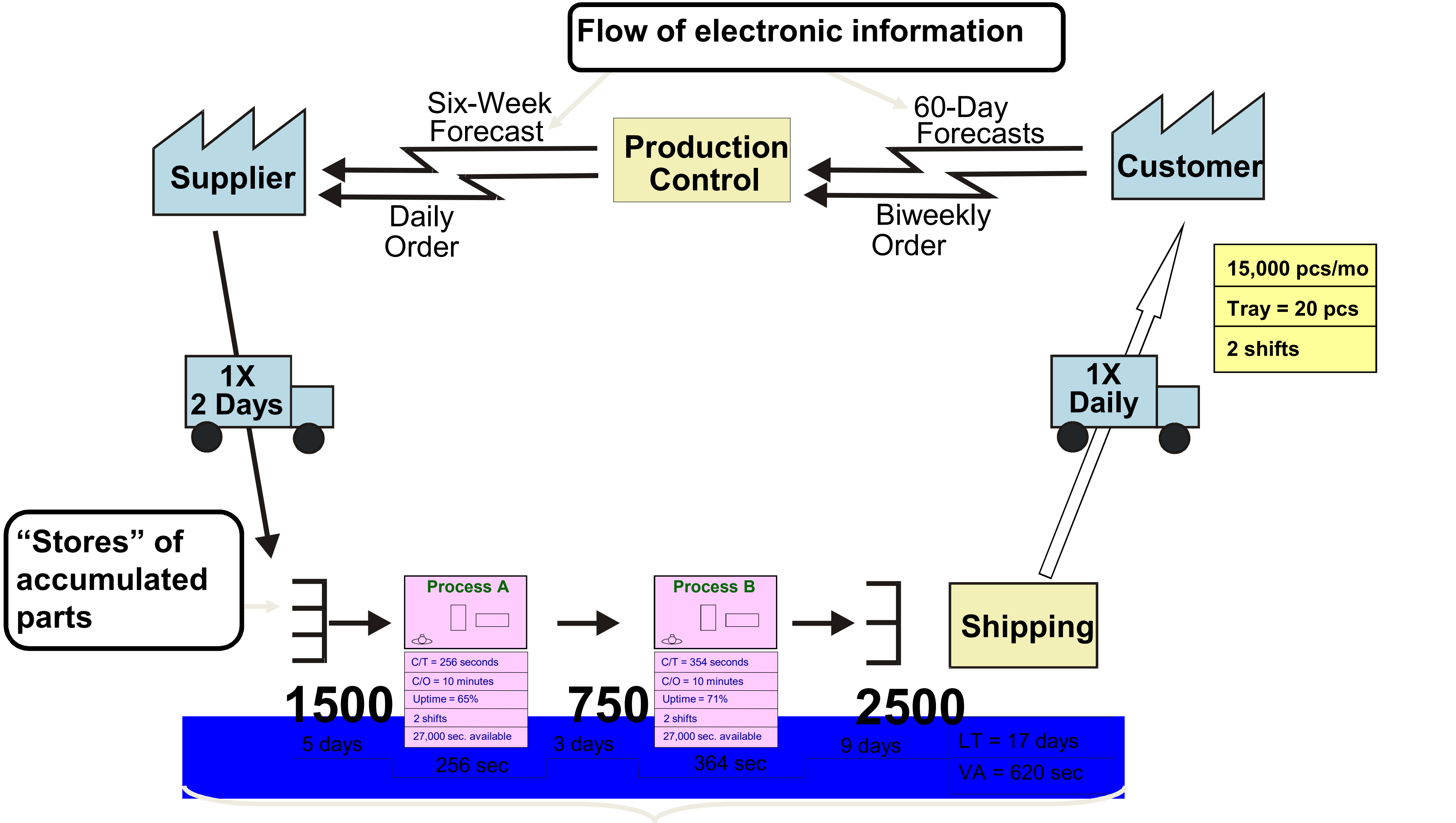
Elements of Comprehensive Value Stream Maps

- Supplier capabilities
- Process requirements and timing
- Process performance data
- Customer requirements
- Required production control/service scheduling information
- Indication of how the product/service flow is pulled and leveled through the processes
- Stated objectives of total efficiency

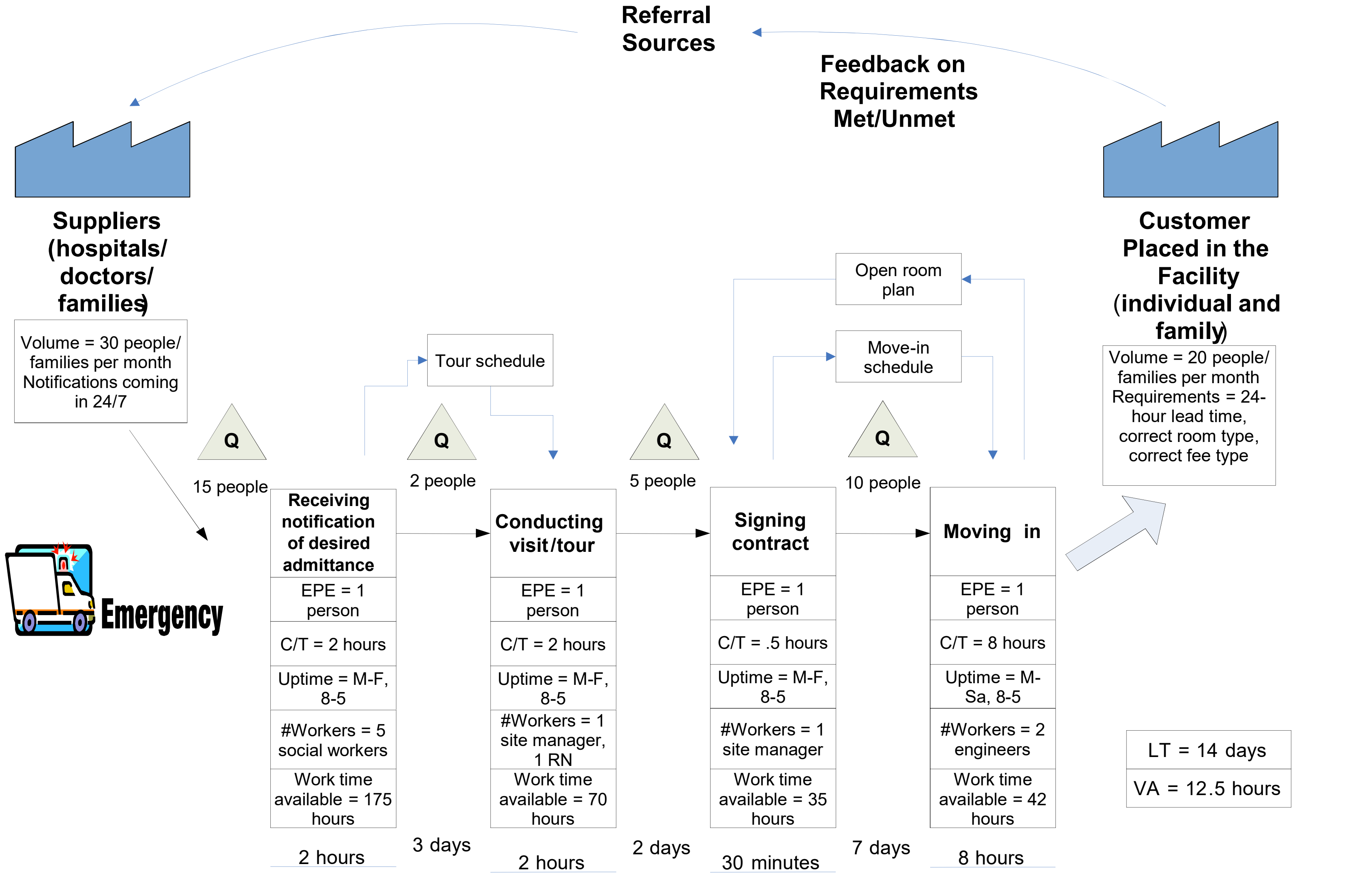
Example: Comprehensive VSM—Appliance Sales and Installation



Example: Manufacturing



Example: Healthcare



What's Different About Value Stream Mapping?

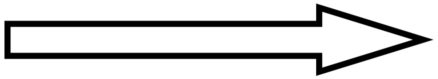
- Broader range of information gathered and displayed
- Broader scope (from door to door)
- Typically a higher level view than most process maps
- Future oriented
- Used as a strategic business planning tool to manage a change process

Basic Symbols for Value Stream Maps

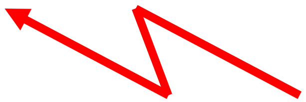
- Value stream maps use symbols as abbreviations
- Basic symbols can be used for any value stream, whether manufacturing, administrative, transactional, etc.
- Some symbols may be generic for a particular type of industry
- Some organizations have symbols that are specific to that organization

Basic Symbols for Value Stream Maps, cont.

Use arrows on all lines to show clear direction of flow

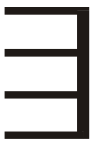


Use a wide arrow to show finished goods or services to the customer

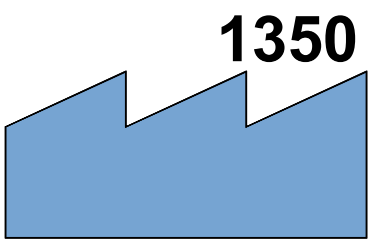


Indicates electronic communication

Indicates process (i.e., assembling, underwriting, etc.); each box represents one process

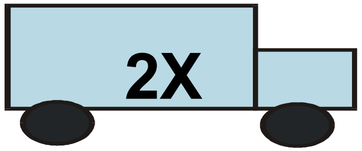


Indicates “stores” of shelves; accumulation location for parts/materials, documents, or emails directly following a process or operation with predetermined quantity requirements

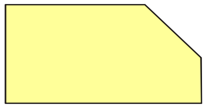


Icon may be used to represent customer or supplier

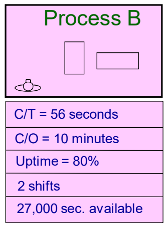
Basic Symbols for Value Stream Maps, cont.



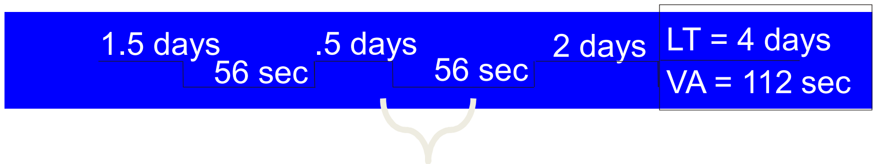
Transportation, shipping, or delivery icon: information inside box designates frequency of delivery



Signaling cards (kanban): signaling pull of work from process downstream

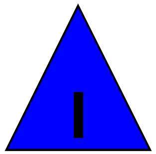


Data box: contains performance data for the particular process

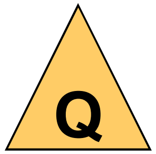


Indicates the timeline: the total time the product or service flows through system—lead time

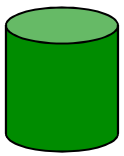
Basic Symbols for Value Stream Maps, cont.



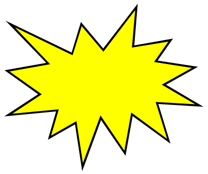
Denotes inventory waiting for the next process



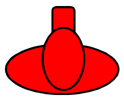
Denotes work waiting in queue for the next process



Denotes electronic storage



Denotes opportunity for improvement



Represents a person

Benefits of Value Stream Mapping

- Forces improvement on the whole, not just on optimizing individual processes
- Provides a common language for talking about processes
- Creates common understanding of how value is produced
- Helps employees see how their function or process fits into the overall value stream
- Visually identifies where waste occurs
- Helps to focus improvement efforts
- Shows linkage between product/service flow and information flow
- Shows performance data

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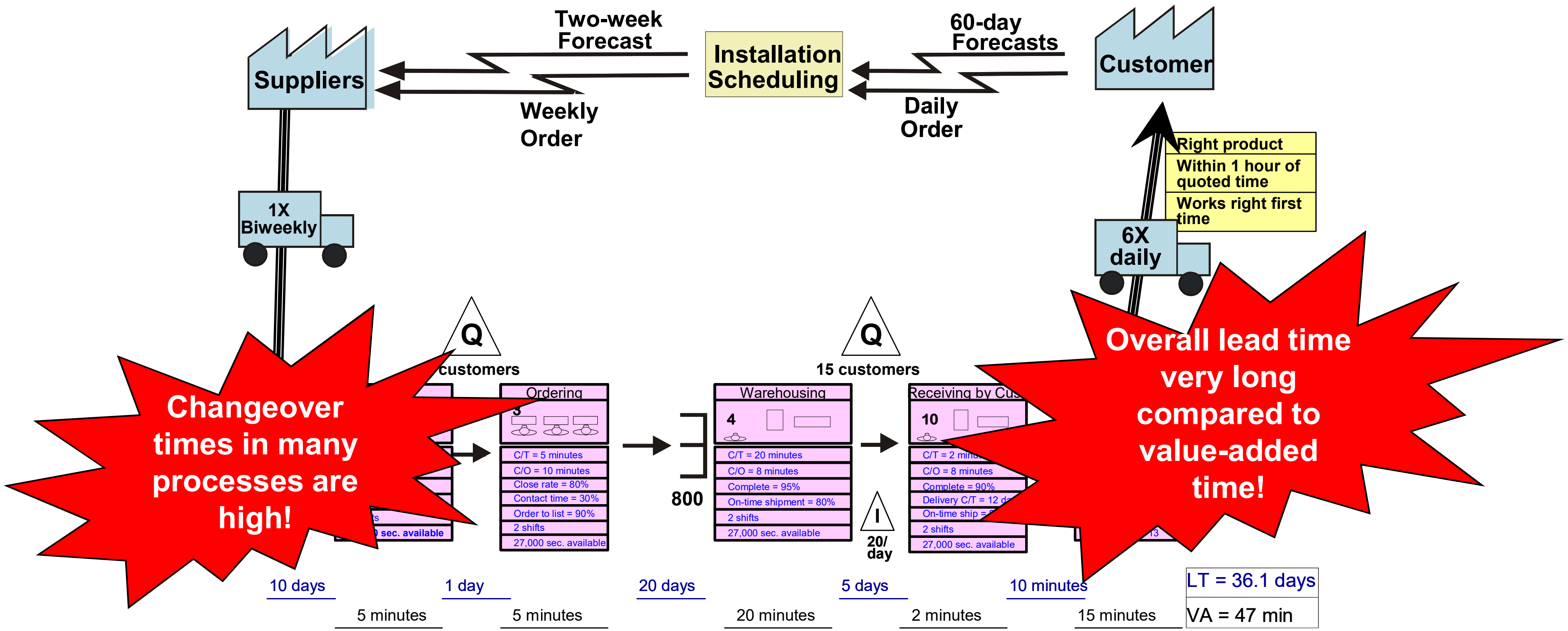
See the Waste in the Value Stream

What to Look for

- When you are analyzing your current state map, you are looking for opportunities to reduce or eliminate the waste
- Many issues become apparent just by creating a visual



Exercise: See the Waste

- **Objective:** Practice identifying waste using a current state value stream map
- **Instructions:**
  - Use either:
    - A value stream map from your own organization
    - The example provided by the instructor
  - Identify waste and opportunities for improvement
    - What, if anything, can you see with a value stream map you could not see using the types of waste?
  - Be prepared to report out
- **Time:** 15 minutes

Summary

- The value stream is the entire set of activities required to bring a product or service into the hands of the customer[1]
- Value streams are typically created for a single product or service family
- A current state map makes the flow of work visible and helps you see the waste

[1]From *Lean Thinking*, Womack and Jones, 1996.

Summary, cont.

- Value stream maps may look very different depending on the value stream and the industry
- Future state value stream maps are used after specific Lean approaches or solutions have been identified

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ANALYZE: Analyze to Identify Causes

Review

You Are Here—ANALYZE

ANALYZE Phase Deliverables

- Cause-and-effect analysis to identify potential causes (inputs or X's)
- Analysis of inputs to identify and prioritize the key inputs or X's affecting the process output(s) Y
- Data collected to validate key inputs or X's
- Graphical (and statistical) analysis of data to determine relationships
- Reduced list of potential key inputs that affect the output(s) Y (refined cause-and-effect analysis)

ANALYZE Phase Deliverables, cont.

- Evidence linking the key inputs to the outputs
- ANALYZE section of storyboard completed
- ANALYZE phase discussed and agreed on with sponsor and coach
- ANALYZE deliverables completed and phase approved

ANALYZE Checklist

- By the end of the ANALYZE phase, you should be able to show your sponsor which causes you will focus on in IMPROVE by being able to answer the following questions. Please check!:
  - What potential causes (X's) have you identified for each focused problem statement?
  - Which potential causes have you decided to investigate, and why?
  - How have you verified causes?
  - What data has been used? How, when and where was it collected?
  - What is the data showing?

ANALYZE Checklist, cont.

- By the end of the ANALYZE phase, you should be able to show your sponsor which causes you will focus on in IMPROVE by being able to answer the following questions. Please check!, cont.:
  - Do findings agree with process knowledge?
  - What are the root causes, and how do they affect the process output (Y)?
  - Which of the root causes are within the team's control? Is team makeup still appropriate?
  - What are the proven root causes (critical few) to be tackled in the IMPROVE phase?

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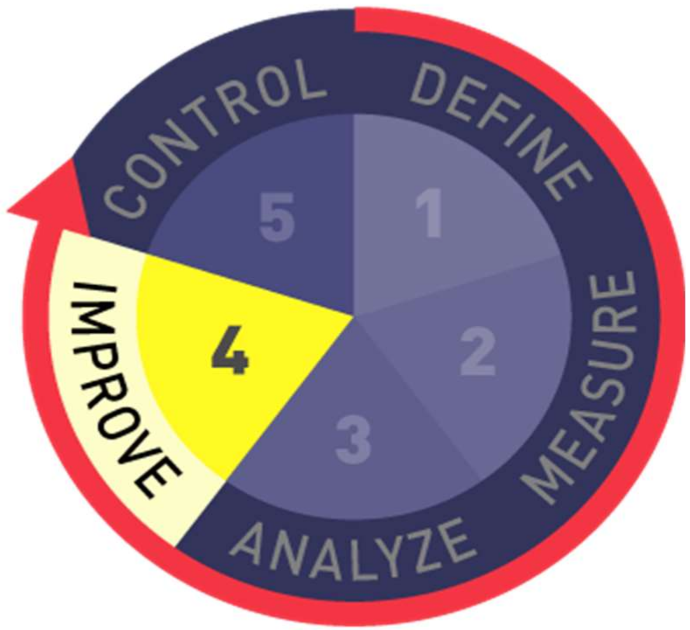
IMPROVE: Implement Solutions and Evaluate Results

Overview

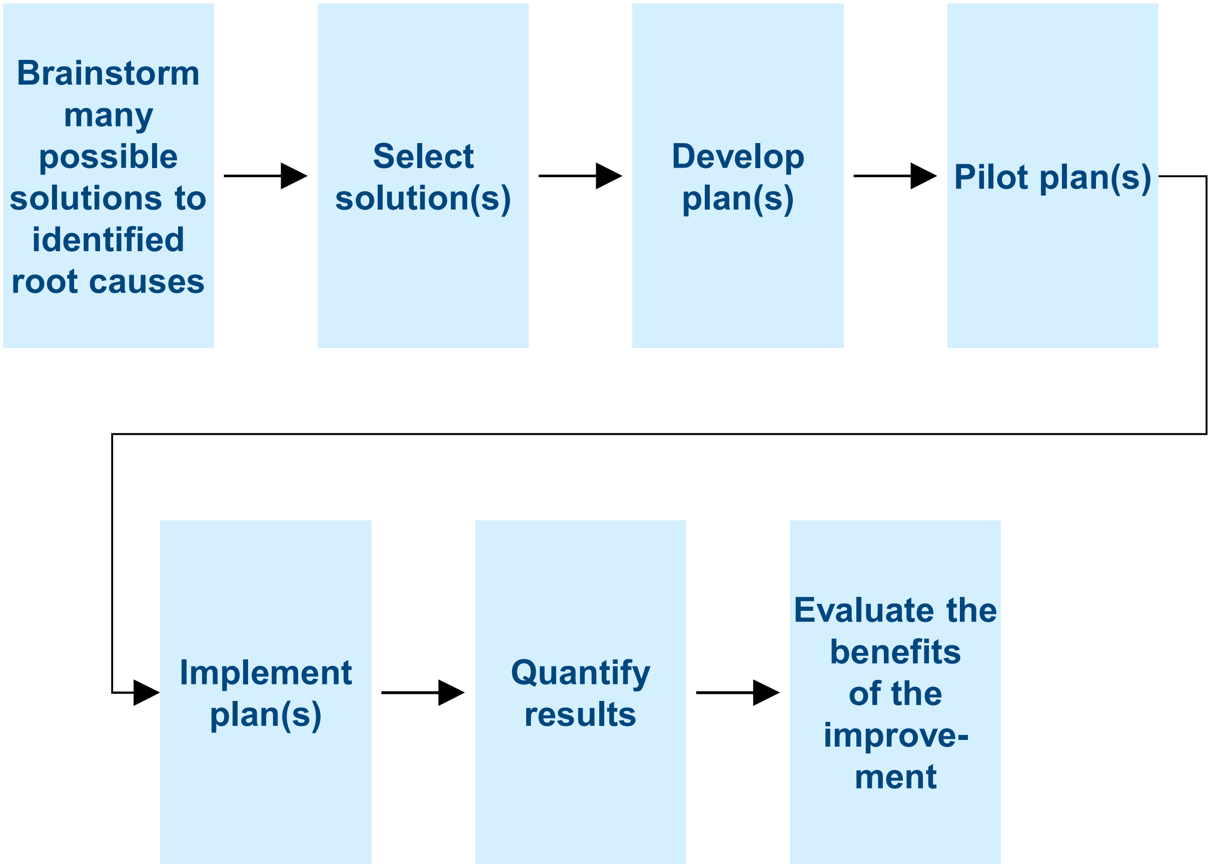
You Are Here—IMPROVE

IMPROVE: Implement Solutions and Evaluate Results

- **Goal:**
  - Develop, try out, and implement solutions that address root causes
  - Use data to evaluate both the solutions and the plans used to carry them out
- **Output:**
  - Planned, tested actions that eliminate or reduce the impact of the identified root causes
  - Before and after data analysis that shows how much of the initial gap was closed
  - A comparison of the plan to actual implementation



Approach to IMPROVE



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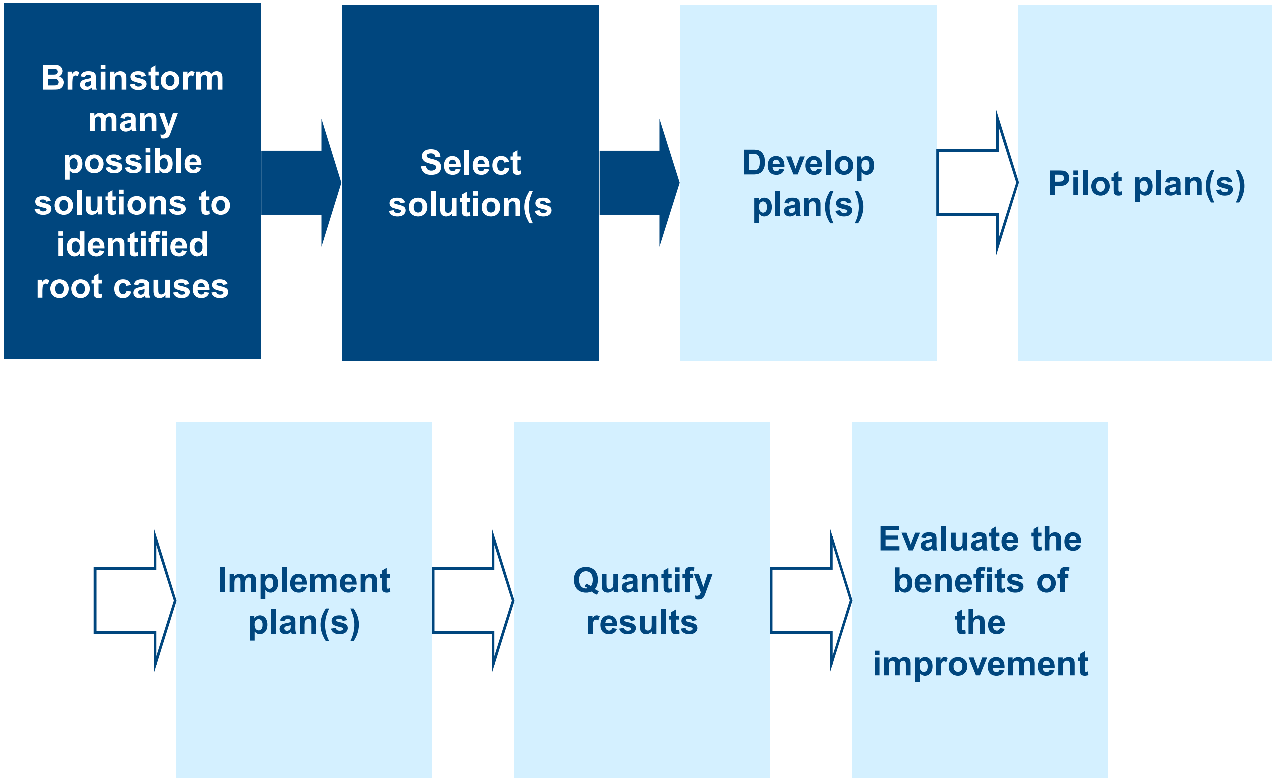
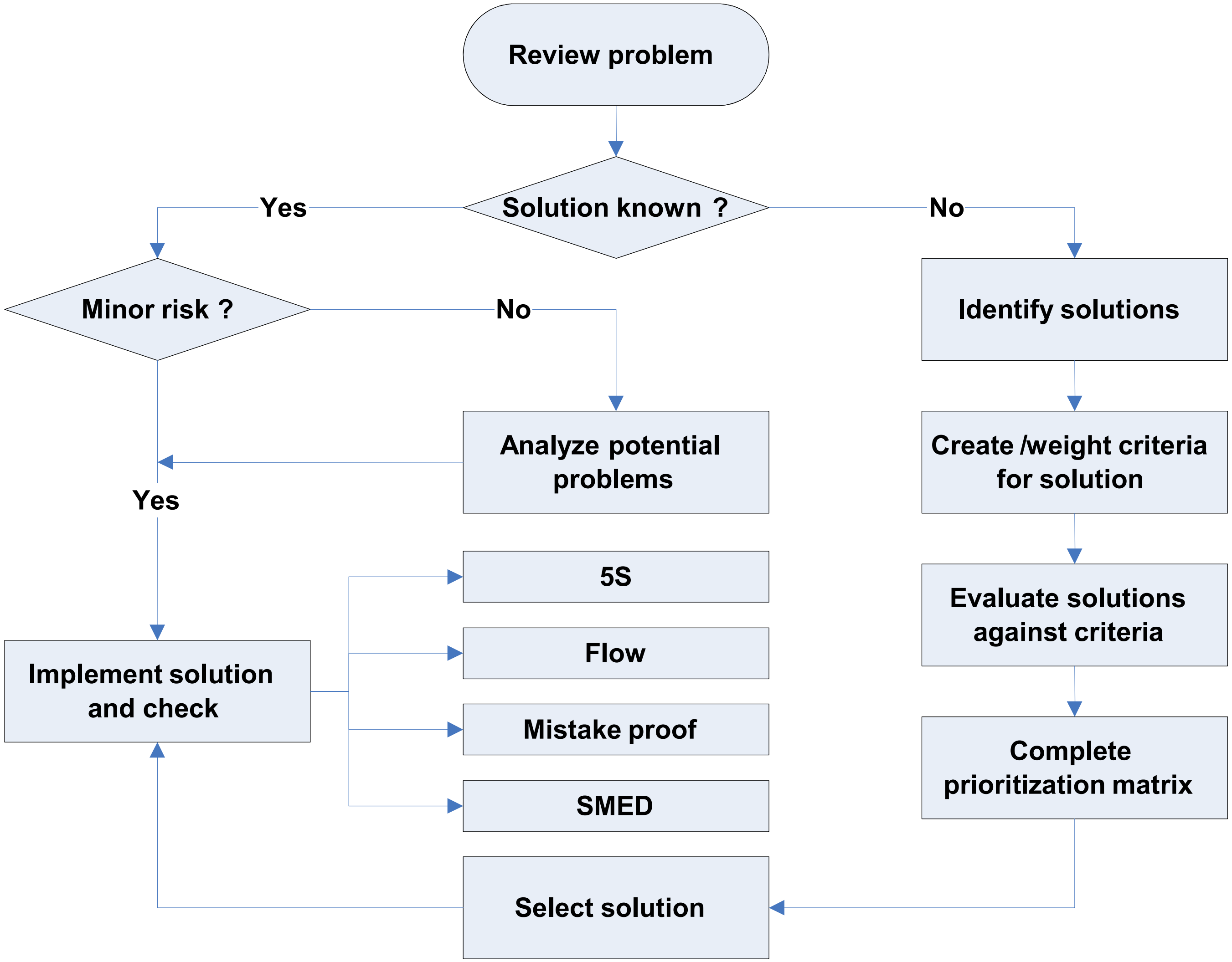
Generating and Selecting Solutions

You Are Here


Brainstorm many possible solutions to identified root causes
Select solution(s
Develop plan(s)
Pilot plan(s)
Implement plan(s)
Quantify results
Evaluate the benefits of the improvement

Generating and Selecting a Solution Roadmap



Involving People in Developing Solutions

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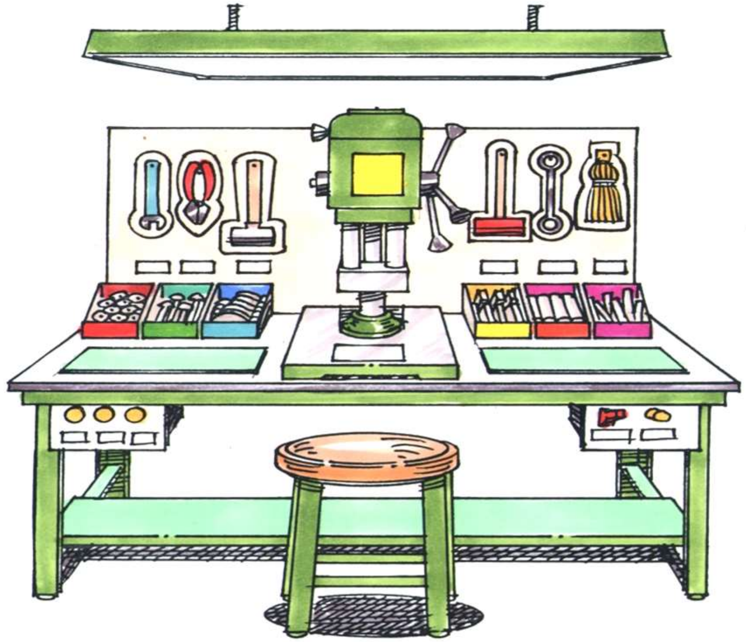
Lean Solutions

Process Improvements: **5S,** Flow, Mistake-Proofing, and SMED

5S

- Sort
- Straighten
- Sweep, wash, clean, and tag abnormalities
- Standardize
- Sustain (housekeeping and tagging)

Keep It Tidy!



Workplace Readiness (5S) Actions and Outcomes Plan

Organization and Safety Worksheet Workplace Readiness (5S) Actions and Outcomes Plan		
Category	**Required Action**	**Desired Outcomes**
Sort	Remove unneeded and unused items from the workplace.	A safe and uncluttered worksite, free of hazards and workarounds.
Straighten	Arrange worksite tools, equipment, and materials in the most convenient location for process use. Identify, label, color code. **Note:** Follow the *Principles of Safe Human Motion.*	Tools, equipment, and materials are located within safe and easy reach of use. Waste of motion is at a minimum.
Sweep, Wash, and Clean	Clean the work area, tools, and equipment – tag equipment abnormalities.	The worksite, required tools, equipment, and materials are clean, defect free, and ready for use.
Standardize	Document worksite layout, location of tools, equipment, and materials. Establish a plan and team assignments to maintain operational readiness.	A plan with documented graphic layout of the worksite showing the proper location and amounts of all required tools, equipment, and materials, including visual controls and coding, with required team member actions and assignments.
Sustain	Follow the plan. Improve the plan and worksite.	A continuously ready operational worksite; excellent housekeeping.

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Lean Solutions

Process Improvements: 5S, **Flow,**
Mistake-Proofing, and SMED

Takt Time: The Pulse of One-Piece Flow

- **Takt time** is defined as the amount of time available to produce one unit (one-piece flow is paced to takt time):
  - Usually measured in seconds
  - Used to synchronize the process and establish uniform production flow
  - Based on:
    - Anticipated customer demand
    - Time available or scheduled to produce the right amount of product to meet the sales demand

- Takt time = $\dfrac{\text{Total production time available}}{\text{Number of units required to meet customer demand}}$

Workload Balancing

- The balancing of work performed at and between operations is based on human motion and takt time
- The aim is to:
  - Equalize the workload fairly and safely
  - Eliminate unevenness and overburden
  - Facilitate the ability to easily increase or decrease the flow of production based on customer requirement

Benefits of a Balanced Workload

- A balanced workload makes redistribution of work safer, easier, and faster:
  - Manpower and cycle time can be increased or decreased while keeping production smooth and uninterrupted
  - Workload balancing facilitates standardization:
    - Where there is no standard, there can be no sustained improvement
  - Balancing provides a safe and consistent workload
  - Supports level production objectives

ESCAP Analysis

All the process steps are evaluated based ESCAP criteria.

It is checked if following can be done to any of the steps:

- Eliminate
- Simplify
- Combine
- Automate
- Parallel

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Lean Solutions

Process Improvements: 5S, Flow,
Mistake-Proofing, and SMED

Continuum of Devices

Preventative → Reactive

	Control Device	Warning Device	Shutdown Device
Possible Error	Prevents the cause of an error from occurring	Warns that an error has occurred	Shuts process down when defect occurs
Possible error is the wrong password entered for an ATM transaction	ATM machine only accepts a set number of digits	ATM notifies users that password has been incorrectly entered	ATM transaction is deactivated if user incorrectly enters the password more than three times
Cut wood strips don't meet specifications	Wood strip cutting machine has a stop mechanism that prevents overloading feed material	Alarm sounds if overloading occurs	Machine stops if cut length and width deviate from specifications

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Lean Solutions

Process Improvements: 5S, Flow, Mistake-Proofing, and **SMED**

SMED—Rapid Changeover

- Rapid changeover means performing changeovers or operations setup in less than 10 minutes
- Sometimes you will hear this referred to as SMED, for Single Minute Exchange of Die
- Although the concept originated in manufacturing, it can also be applied to services

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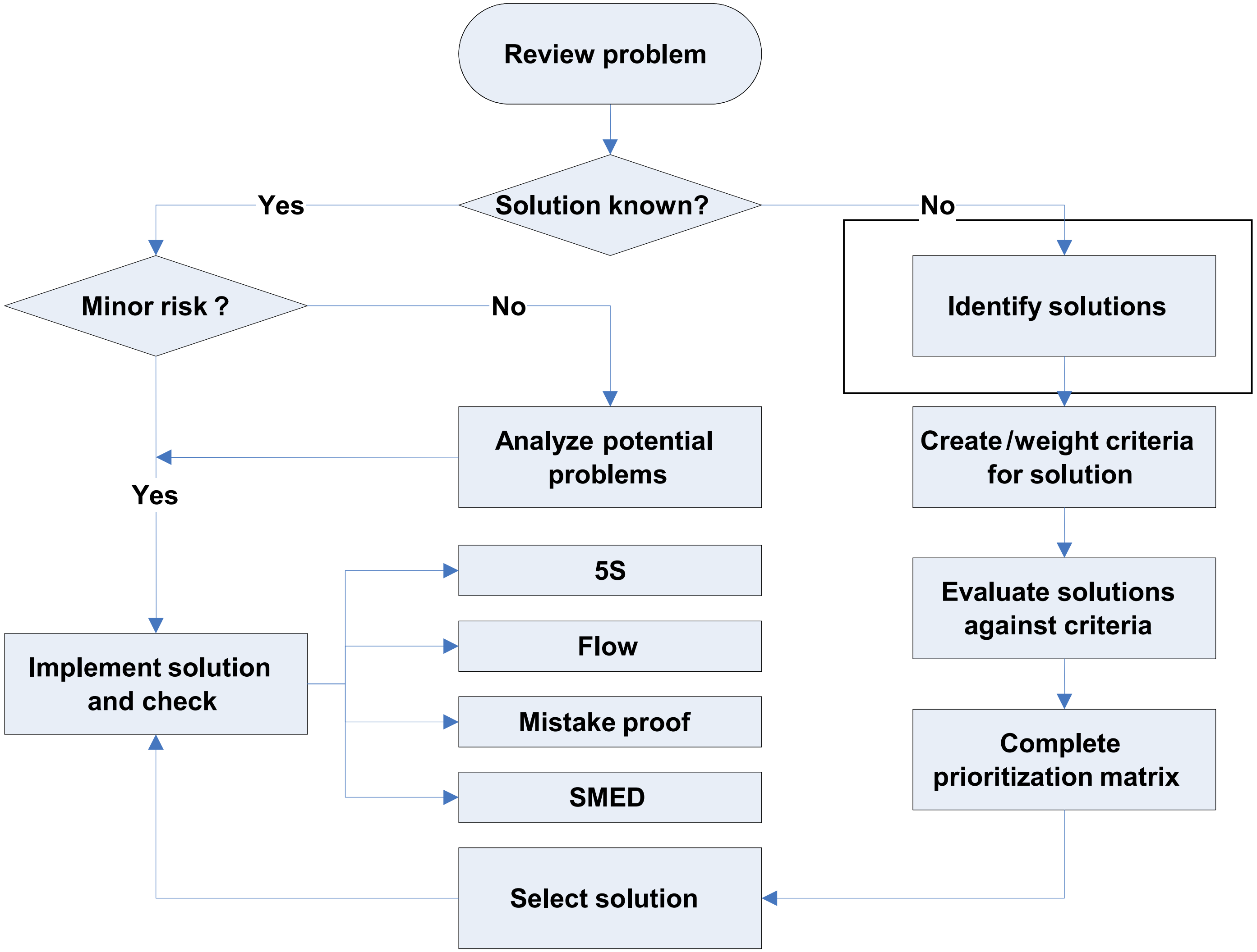
Generating Solution Alternatives

Generating and Selecting Solution Roadmap

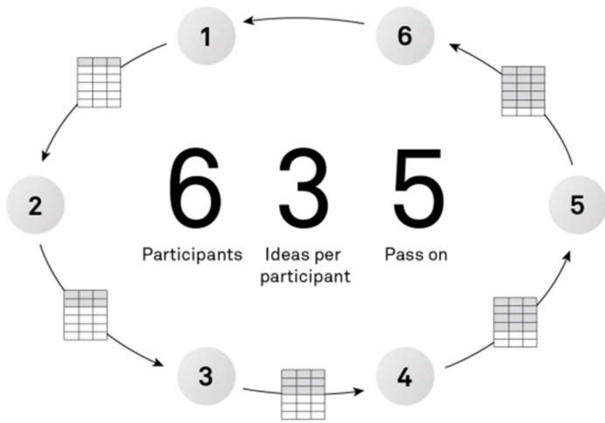


Generating Solution Ideas

- Review what you know about the process and the verified cause
- Brainstorm solution ideas; use creativity techniques
- Combine ideas into solutions

Brainwriting 6-3-5

- Team members brainstorm ideas on a written form:
  - Take 5 minutes to write down three solution ideas on the first row of your form
  - Pass your form to the right
  - On the form you have just received from your team member, add another three ideas on the next row
  - Add ideas by:
    - Enhancing an idea already on the sheet
    - Adding a variation of an idea on the sheet
    - Adding a completely new idea
  - Repeat for as many rounds as you have team members



Round Robin and Anti Solution

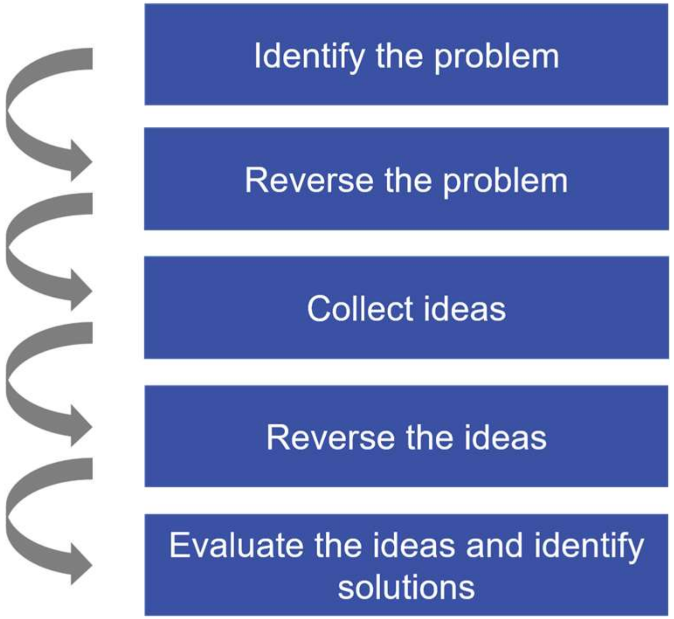
Round Robin

- Everyone gets a chance to put forth his/her idea If they do not have to contribute an idea, they just say pass.
- This goes on till all the participants have exhausted their ideas.

Round Robin and Anti Solution

Anti Solution

- Team brainstorms on how to increase the problem rather than solving it.
- The brainstormed ideas are reversed to get the solution.



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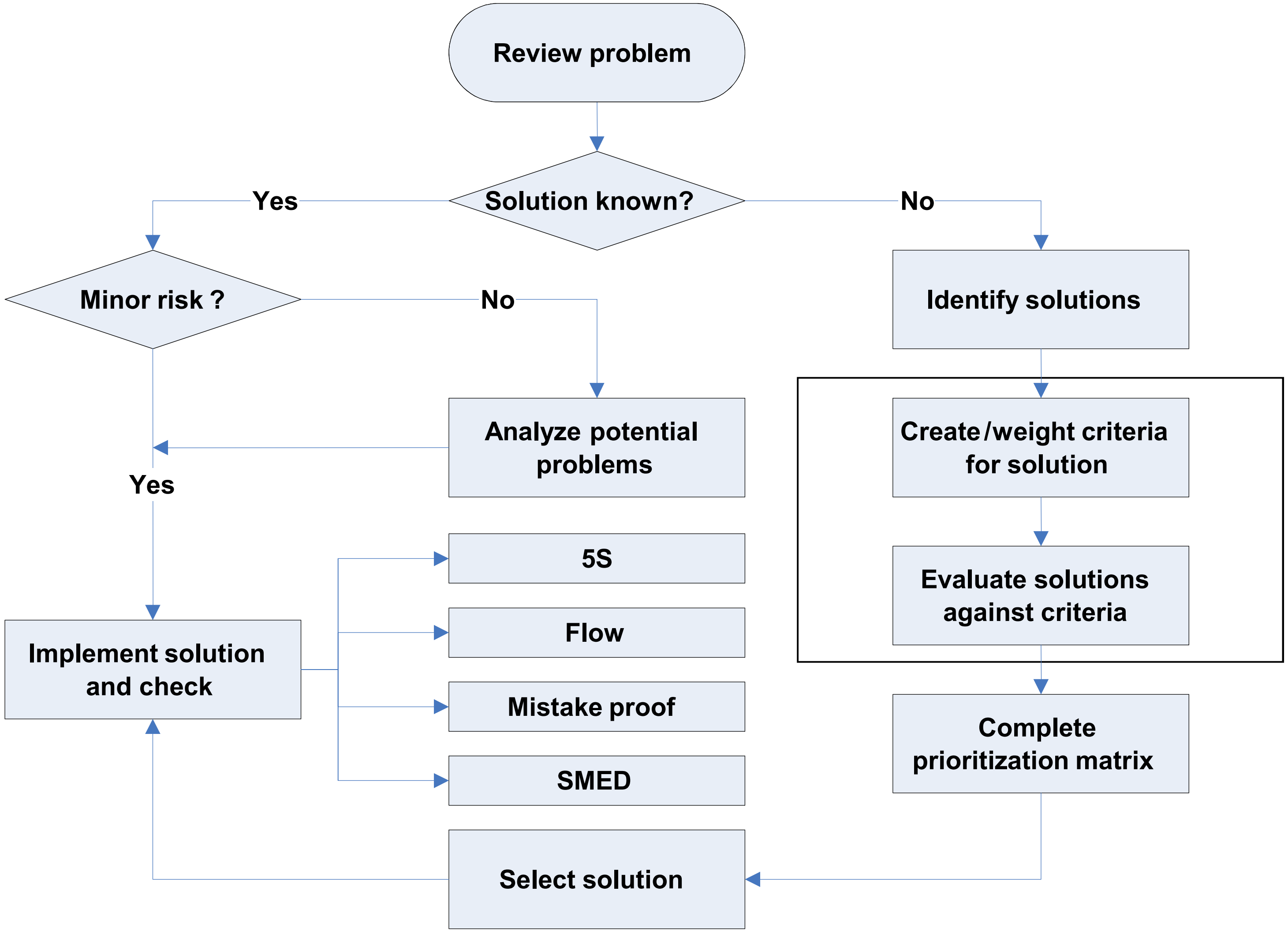
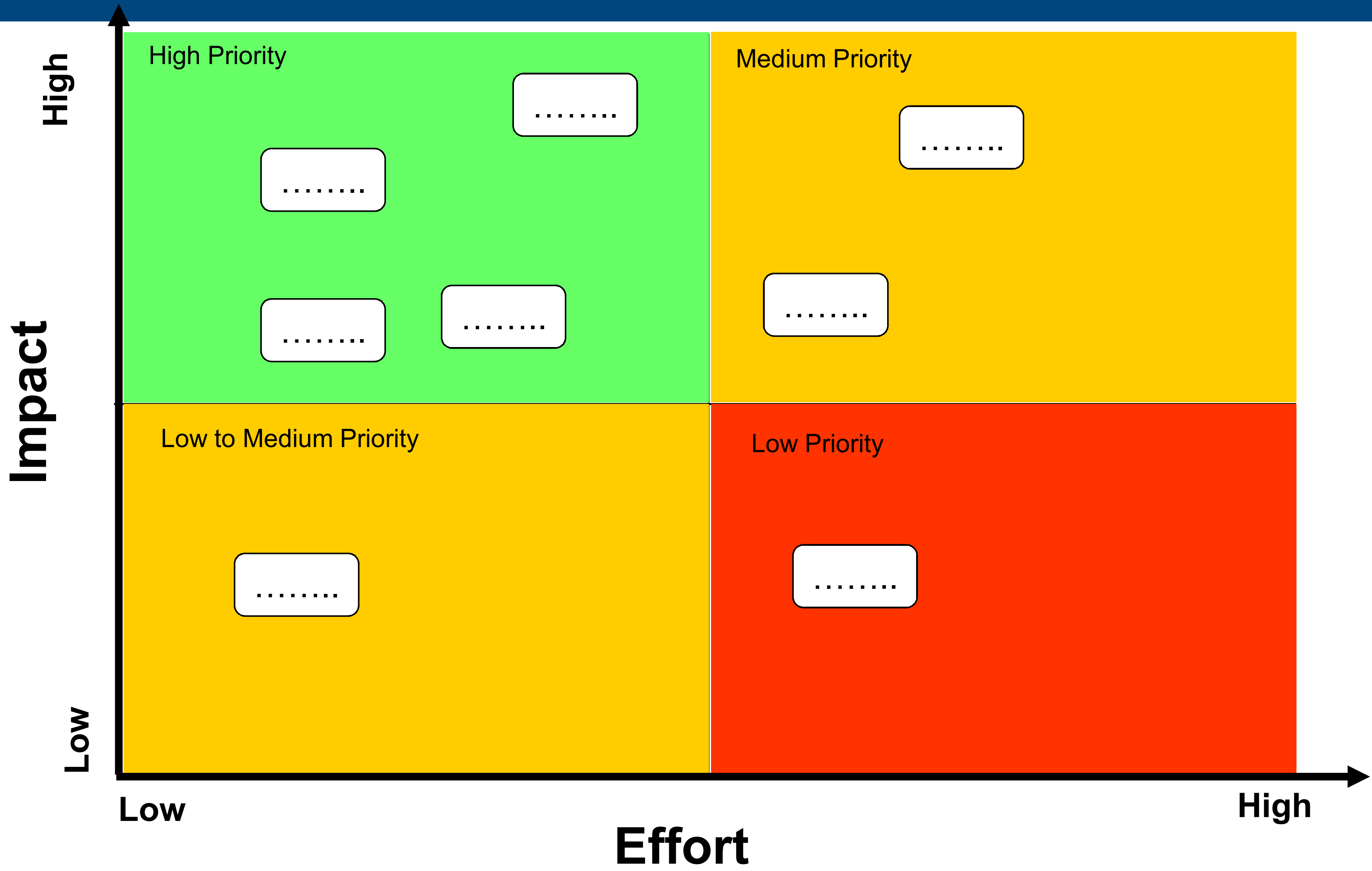
Evaluating Solution Alternatives

Generating and Selecting Solution Roadmap



Prioritization Tool — Solutions



Solution Selection Matrix

	Criteria	Weight	Solution A		Solution B		Solution C	
			Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
1	cheap solution	3	3	9	9	27	9	27
2	quick to implement	3	9	27	1	3	3	9
3	high impact on CTQs	9	9	81	9	81	9	81
4	compliant	9	1	9	9	81	9	81
5	change management	3	1	3	3	9	9	27
6	resource required	1	9	9	3	3	3	3
TOTAL				**138**		**204**		**228**

Where **weight** and **scores** on following scale : High = 9, Medium = 3 and Low = 1.

Example :

Solution A = outsource all data processing

Solution B = development of our own software

Solution C = buy a software and adapt to our needs

It seems here that solution C is the most satisfying. B also can be considered as an option.

Summary

- Involve people
- Use creativity techniques to generate alternatives
- Generate and weight criteria
- Evaluate each alternative against the criteria
- Be creative in finding ways to get additional information about a potential solution
- If no clear choice emerges, use consensus decision making

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Introduction to the Design of Experiments (DOE)

Module Objectives

By the end of this module, the participant will:

- Understand the strategy behind Design of Experiments (DOE)
- Create a design matrix
- Code factors
- Understand the limitations of OFAT experiments
- Interpret interactions

Why Learn About Design of Experiments?

- Properly designed experiments will improve
- Efficiency in gathering information
  - Planning
  - Resources
- Predictive knowledge of the process
- Ability to optimize process
  - Response
  - Control input costs
- Capability of meeting customer CTQs

What is Design of Experiments ?

- A DOE is a planned set of tests on the response variable(s) (KPOVs) with one or more inputs (factors) (PIVs) each at two or more settings (levels) which will:

- Determine if any factor is significant
- Define prediction equations
- Allow efficient optimization
- Direct activity to rapid process improvements
- Create significant events for analysis

DOE Terminology

- Response (Y, KPOV): the process output linked to the customer CTQ
- Factor (X, PIV): uncontrolled or controlled variable whose influence is being studied
- Level: setting of a factor (+, -, 1, -1, hi, lo, alpha, numeric)
- Treatment Combination (run): setting of all factors to obtain a response
- Replicate: number of times a treatment combination is run (usually randomized)
- Repeat: non-randomized replicate
- Inference Space: operating range of factors under study

DOE Objectives

- Learning the most from as few runs as possible; efficiency is the objective of DOE
- Identifying which factors affect mean, variation, both or none
- Screening a large number of factors down to the vital few
- Modeling the process with a prediction equation:
  $Y = f(A,B,C \ldots)$
- Optimizing the factor levels for desired response
- Validating the results through confirmation

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DOE Strategy

Strategy of Experimentation

Planning Phase

- Define the problem
- Set the objective
- Select the response(s), Ys
- Select the factors(s), Xs
- Select the factor levels
- Select the DOE design
- Determine sample size
- Run the experiment

Execution Phase

- Collect data
- Analyze data
- Validate results
- Evaluate conclusions
- Revise SOPs
- Train affected workforce
- Document results
- Consider next experiment

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Planning Phase

The purpose of an experiment is to better understand the real world, not to understand the experimental data…

William Diamond
Statistician, IBM

Define the Problem
Step 1

- The problem statement should:
- Be complete and detailed
- Contain no conclusions
- Contain no solutions
- Contain no causes
- Be specific

Well begun is half done…

Mary Poppins

Issues With Problem Definition

- Common problem definition issues
- Response not well defined
- Response not quantifiable
- Response does not link to CTQs
- Specifications not customer focused
- Quantification not based upon data
- Stated as a predetermined solution

Guide your team to unambiguous, executable experiments

Set the Objectives Step 2

- The upfront objectives should
- Define what you want to learn from the experiment
- Support screening, modeling or both
- Look at main effects, interactions or both
- Set boundaries for optimization
- Know resource requirements

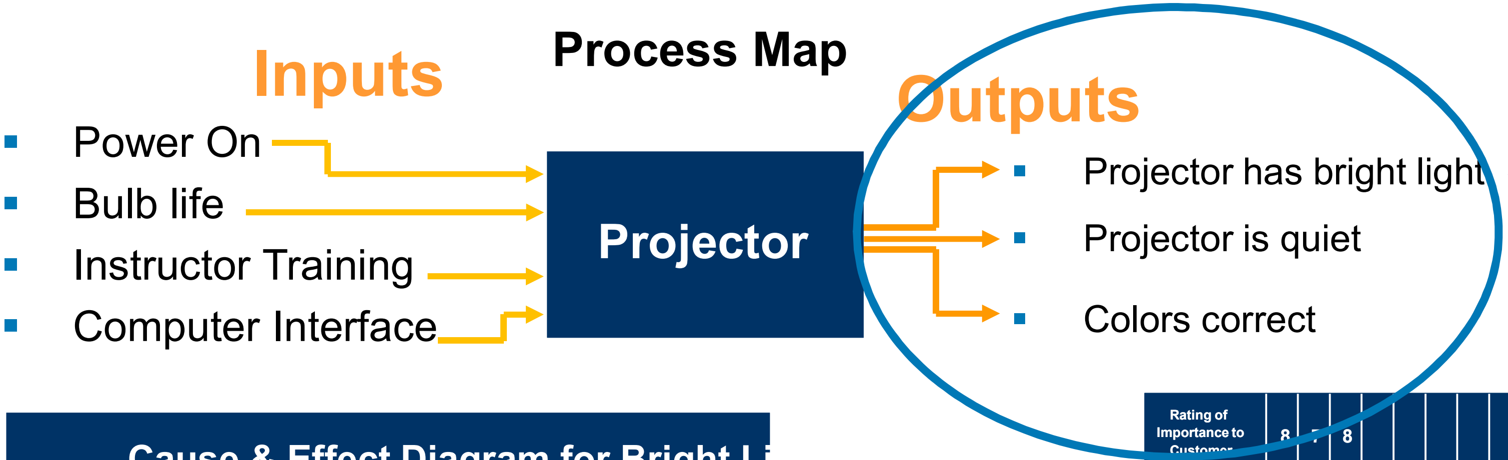
Do not use all of your resources on the first experiment

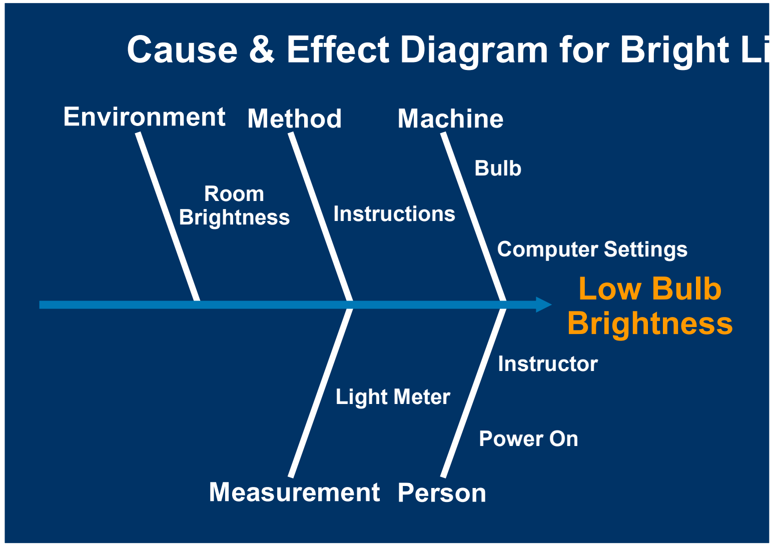
Selecting the Response
Step 3

A response is the output linked to the customer CTQ

- Usually quantitative (continuous)
  - Yield
  - Level of purity
  - Effort Variance
  - Energy consumed
- May be qualitative (discrete)
  - Bubbles in glass plate
  - Defective Coding
- Comes from Define and Measure Phase
  - Voice of the Customer
  - C&E, FMEA, process map and other

Response Relationship to Other Tools





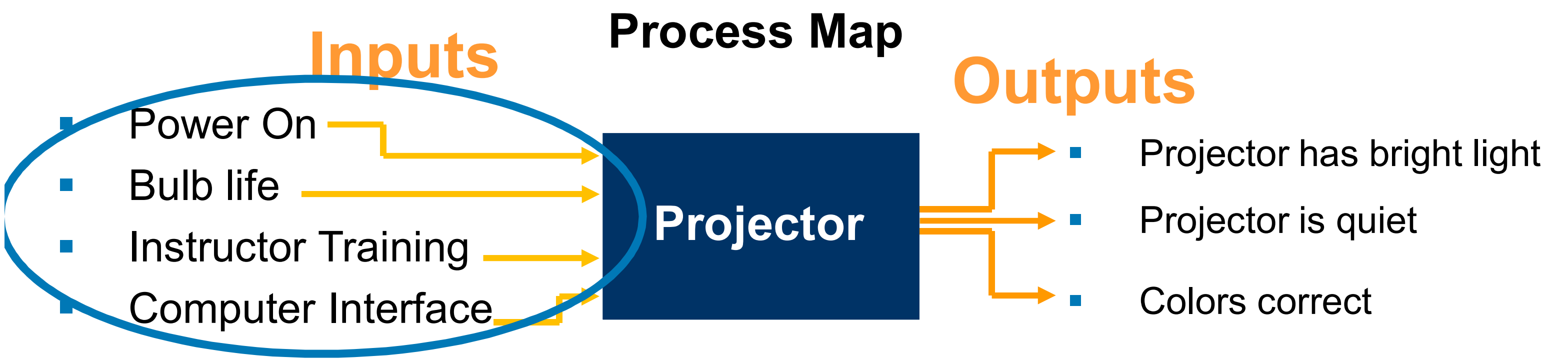
	Rating of Importance to Customer	8	7	8													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
	Process Inputs	Bright Light	Quiet	Color Correct													Total
1	Power on	9	3	2													119
2	Bulb Life	8	1	3													95
3	Instructor	1	1	1													23
4	Computer	2	1	9													95
5																	
6																	
7																	

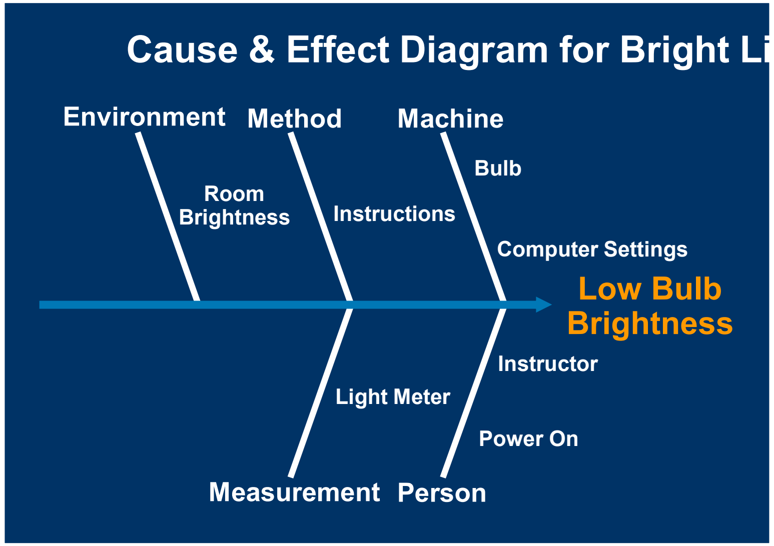
Selecting the Factors
Step 4

A factor is one of the inputs suspected of influencing the response

- May be qualitative (discrete)
  - Different operators
  - Different shifts
  - Different Resources
- May be quantitative (continuous)
  - Pressure
  - Pull back angle
- Comes from Measure and Analyze Phase
  - C&E, FMEA, process map and other
  - Hypothesis testing

Response Relationship to Other Tools





	Rating of Importance to Customer	8	7	8													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
	Process Inputs	Bright Light	Quiet	Color Correct													Total
1	Power on	9	3	2													119
2	Bulb Life	8	1	3													95
3	Instructor	1	1	1													23
4	Computer	2	1	9													95
5																	
6																	
7																	

Selecting the Factor Levels
Step 5

The factor levels are the range of values of the input under study

- Qualitative (discrete) inputs
  - operator 1, operator 2, operator 3…
  - shift 1, shift 2, shift 3 …
  - pin loc 1, 2
- Quantitative (continuous) inputs
  - 50 , 75, 100 psi
  - 160, 170, 180 degrees
- Process knowledge/inference space

Consider what works, what could work and what won’t hurt

Select the DOE Design
Step 6

The selected design should align with the objectives of the experiment and resource commitment

- OFAT (One Factor at a Time)
- 2k-n Fractional Factorial Designs
- 2k Full Factorial
- Full Factorial (replication)
- RSM (response surface method)

Experimental Design Considerations

Many K P I V 's **Few**

Experimental Objective	**Experimental Design Types**
Screen	OFAT (One Factor at a Time) Fractional Designs 2^k Full Factorial
Optimize *Model*	2^k Full Factorial (w center points/replication) Full Factorial (replication) RSM (Response Surface Method)

Less **K N O W L E D G E** ***More***

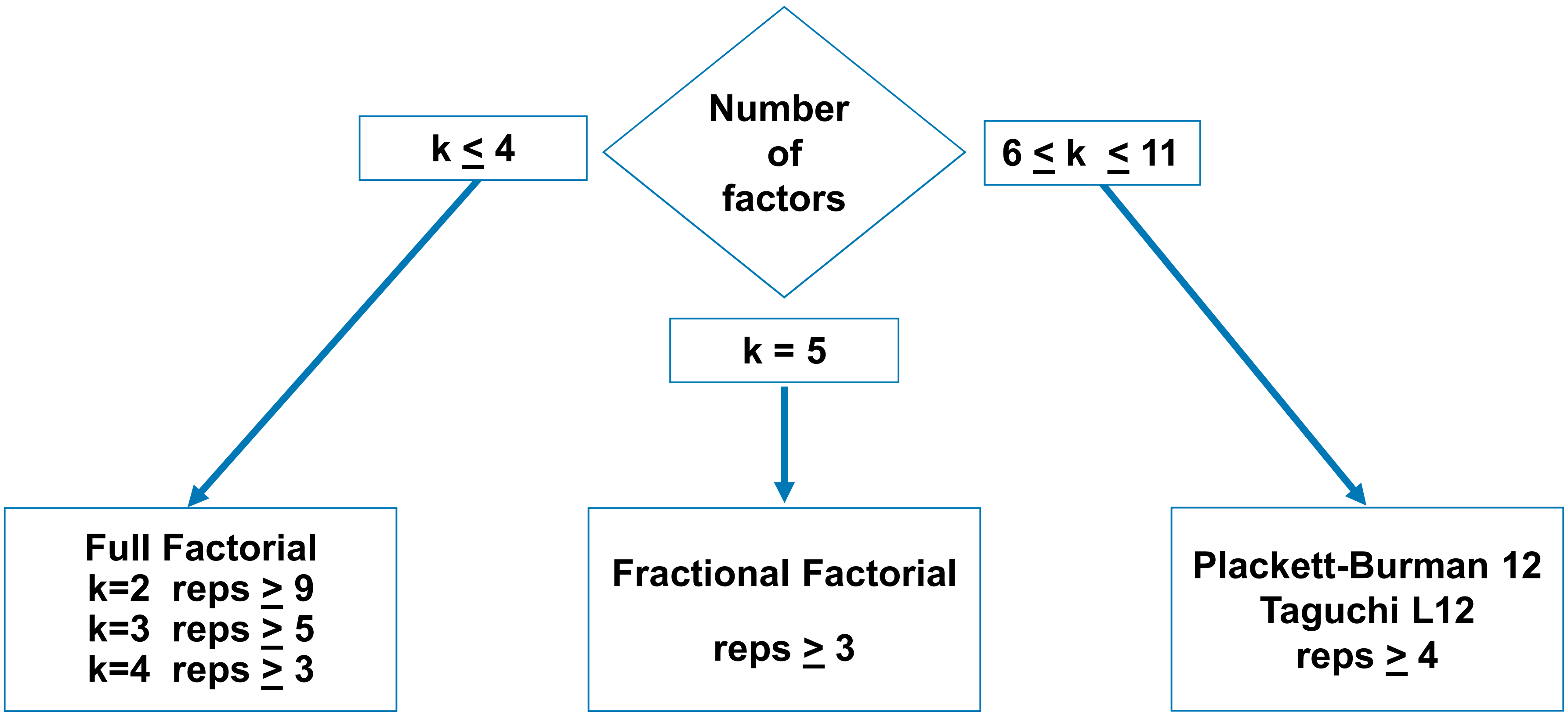
Less **C O S T** ***More***

Higher complexity designs offer greater knowledge at a higher price

Determine Sample Size
Step 7

- The type of design determines minimum number of samples (replicates/repeats). Considerations for replicates
  - Multiple runs help identify data and measurement errors
  - Screening for main effects requires fewer replicates
  - Modeling designs require more replicates to have confidence in prediction models
  - Detectable effect
  - Resources

Two Level Sample Size



Provides greater than 99% confidence in mean and 95% confidence in variance prediction models

Run the Experiment
Step 8

- Manage resources
  - Assign tasks
  - Stage supplies
- Have contingency plan
  - Personnel changes
  - Business changes
  - Botched runs
- Statistical common sense
  - Randomize runs if possible
  - Replicate and/or repeat

DOE Strategy Exercise

- Break into table teams. Select two projects at each table (one industrial process and one business process). Using flip charts list the Planning Phase elements for each project.

- Be prepared to discuss your learnings.

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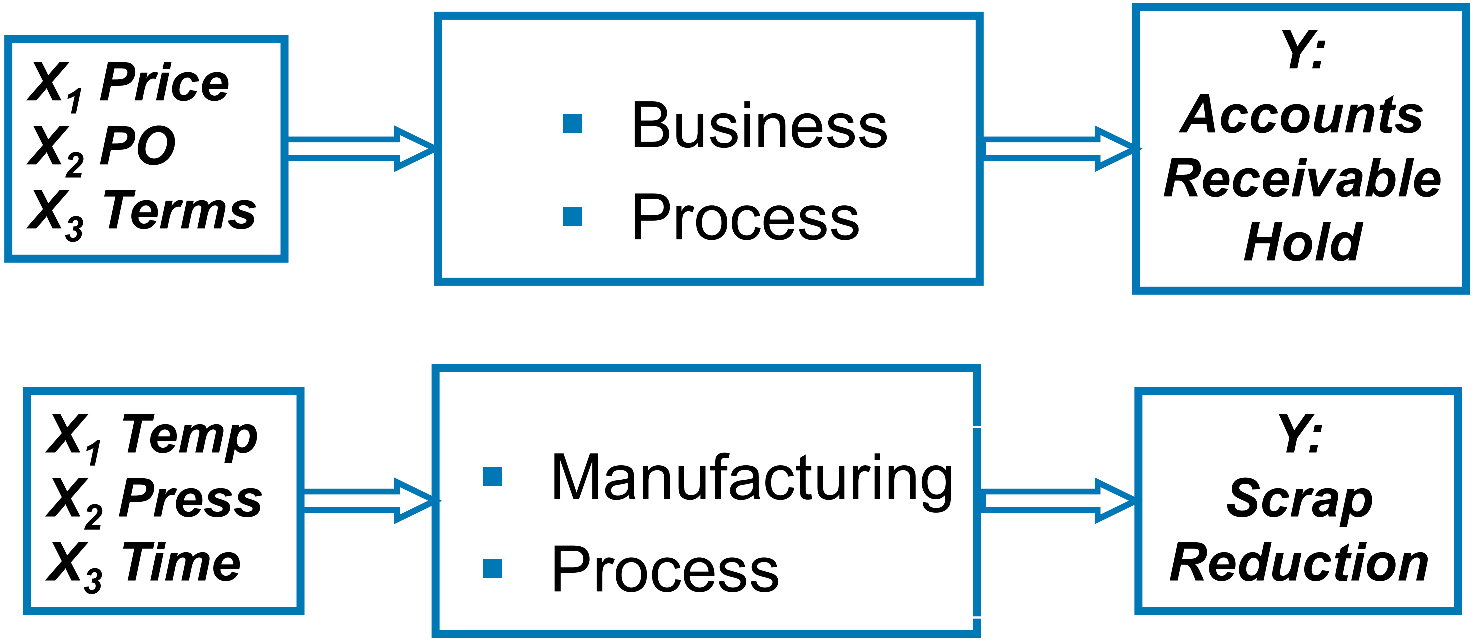
Factors

Factors and the Process



DOE can be applied to both business and industrial processes

Organizing the Factors

- The best conceived experiment will fail if executed poorly. Defining the factor settings and capturing the process response(s) properly is paramount to a successful DOE.

	INPUT FACTORS			OUTPUT RESPONSE REPLICATES					STATISTCAL ANALYSIS	
RUN	X_1	X_2	X_3	Y_1	Y_2	-	-	Y_n	Ybar	s
1										
2										
3										
4										
-										
-										
-										
n										

A matrix that clearly defines the input settings to the output response showing the flow of the experiment is a must

Factors at Two Levels

Many experiments will be quite successful when only two levels of each factor are studied.

	INPUT FACTORS			OUTPUT RESPONSE REPLICATES					STATISTCAL ANALYSIS	
RUN	X_1	X_2	X_3	Y_1	Y_2	-	-	Y_n	Ybar	s
1	234	1	0.0345						11	1.46
2	116	1	0.0737						14	2.03
3	234	2	0.0737						9	2.18
4	116	2	0.0345						16	4.22
-										
-										
-										
n										

Experimental Data Placed Here

The matrix of inputs should be arranged to reduce or eliminate correlation between factors

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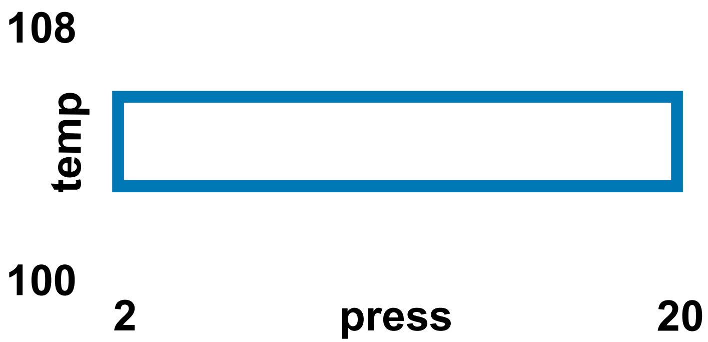
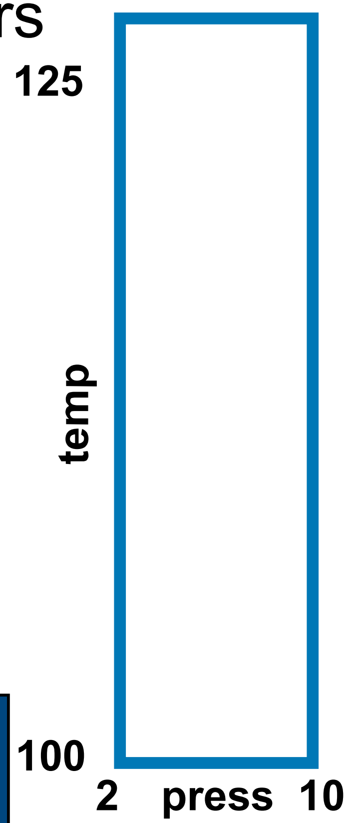
Coding

Factors and Scale of Units

Representation of the inference space is often related to the linear scale of units of the factors





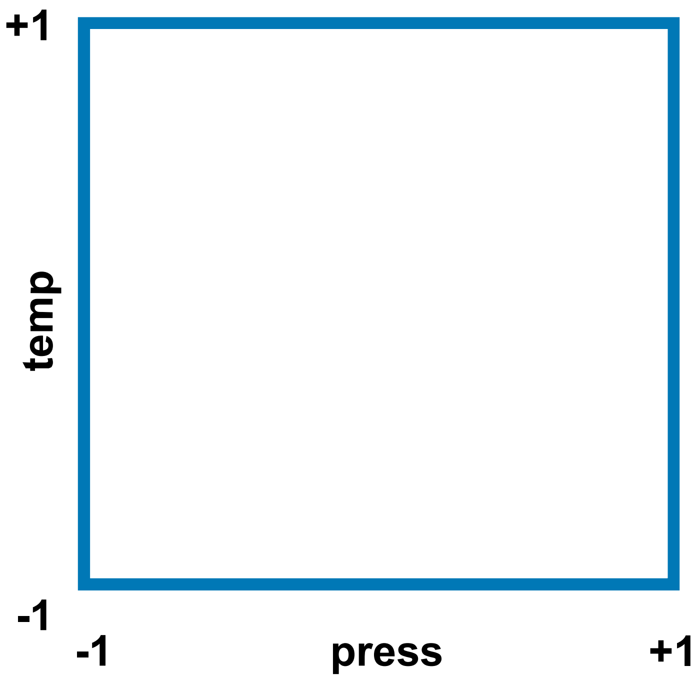
It would be advantageous to normalize the range of factors to a common scale

Concept of Coding

Low **-1** — **High** **+1**

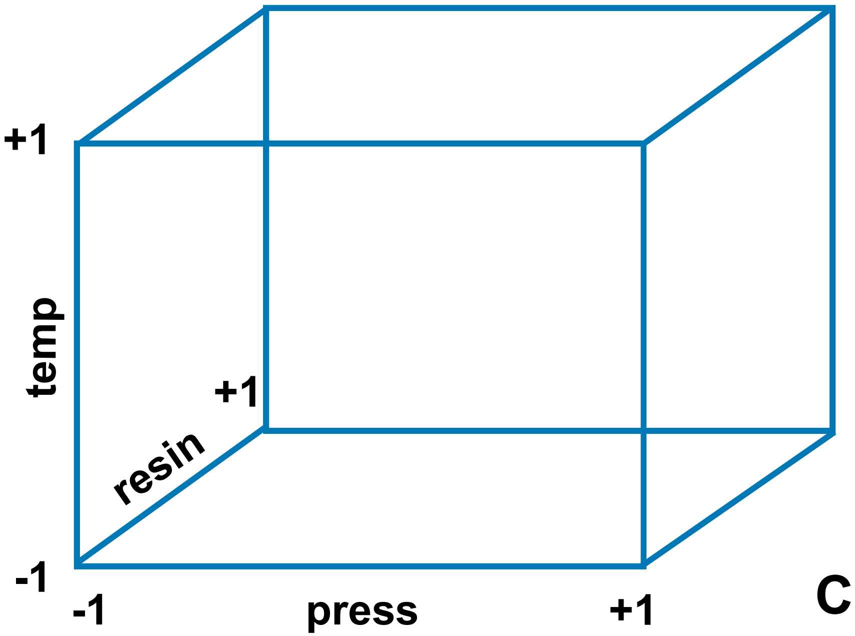
Press = 2 — **Press = 10**

Temp = 10 — **Temp = 125**



Coding Three Factors

Low -1	High +1
Press = 2	Press = 10
Temp = 10	Temp = 125
Resin = 56	Resin = 3560



Coding convention often uses "+" for high and "-" for low

Class Coding Exercise

Transform the uncoded factor levels to coded factor levels using "+" and "-"

	UNCODED INPUT FACTORS			CODED INPUT FACTORS			OUTPUT RESPONSE			STATISTCAL ANALYSIS	
RUN	X_1	X_2	X_3	X_1	X_2	X_3	Y_1	Y_2 …	Y_n	Ybar	s
1	234	1	0.0345							11	1.46
2	116	1	0.0737							14	2.03
3	116	2	0.0737							9	2.18
4	234	2	0.0345							16	4.22
-											
-											
-											
n											

Why Code?

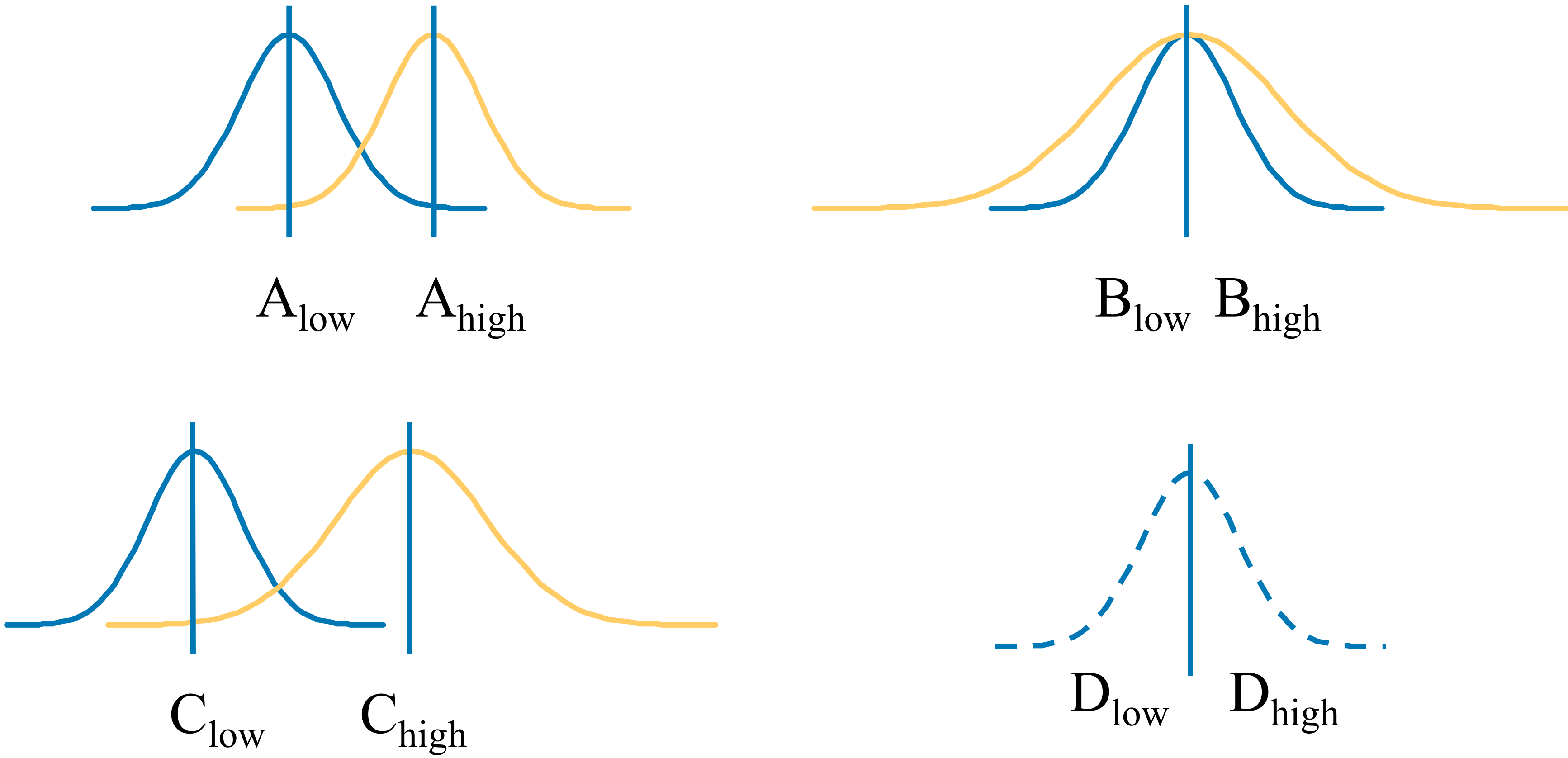
- Allows experimenter to focus on the design
- Shows the design generation clearly
- Permits easier mathematical analysis
- Produces fewer data entry errors
- Reduces analysis errors
- Manages magnitude of scale

Coding is the standard practice for experimental design

Anexas Consultancy Services

Exploring Factor Effects

How Factors Affect a Response



Which factors affect mean or variation?

Anexas Consultancy Services

One Factor at a Time (OFAT) Experiments

One Factor at a Time

- A process has two variable inputs: flow and temperature. Historically the process has run with flow = 18 and temp = 160 with a yield of 81.7%.

Flow	Temp	Yield
18	140	71.4
18	145	74.8
18	150	78.3
18	155	79.4
18	160	81.7
18	165	82.8
18	170	84.0
18	175	84.5
18	180	84.2
18	185	83.3
18	190	80.5
18	195	78.3
18	200	76.0

One Factor at a Time Data Analysis First Step

Old setting → (Temp 160, Yield 81.7)

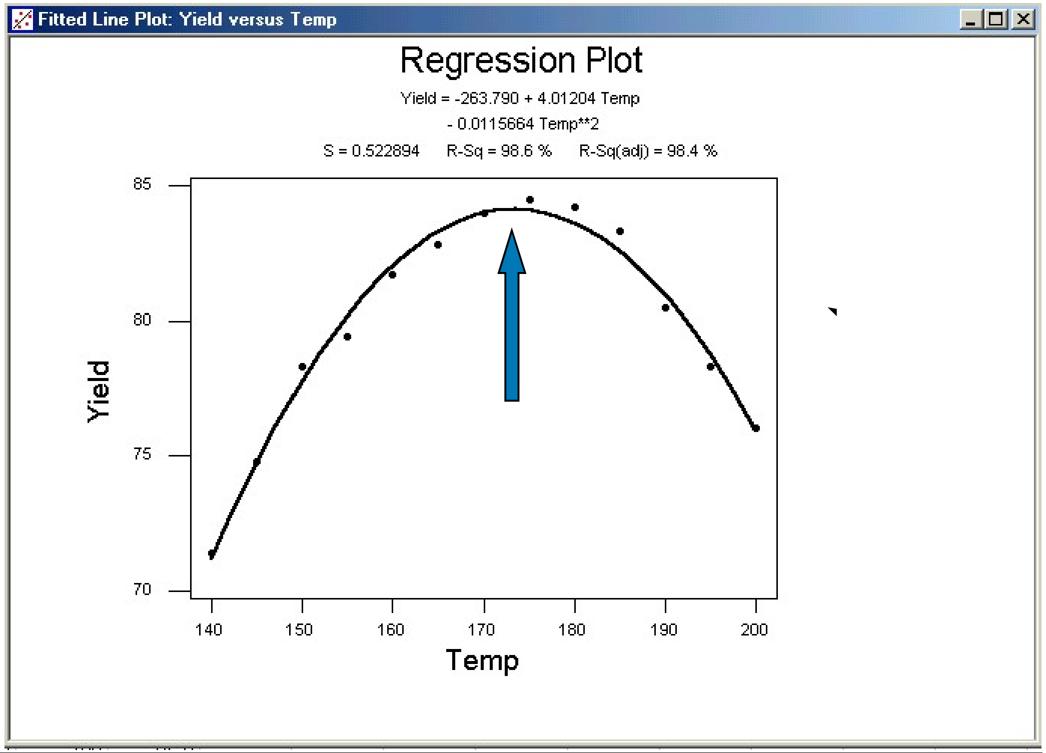
New setting → (Temp 175, Yield 84.5)

Flow	Temp	Yield
18	140	71.4
18	145	74.8
18	150	78.3
18	155	79.4
18	160	81.7
18	165	82.8
18	170	84.0
18	175	84.5
18	180	84.2
18	185	83.3
18	190	80.5
18	195	78.3
18	200	76.0

Higher yield is obtainable, but at a higher temperature (cost)

Data is used for a regression analysis

One Factor at a Time Data Analysis Second Step



$$Y = -263.79 + 4.012Temp - 0.011566Temp^2$$

Regression analysis provides an equation which can be solved for temperature

Another test is planned to study flow at the “optimum” temperature of 174.4^{0}C

One Factor at a Time Data Analysis Third Step

Flow	Temp	Yield
2	174.4	65.5
4	174.4	65.5
6	174.4	77.8
8	174.4	84.8
10	174.4	90.8
12	174.4	91.8
14	174.4	89.8
16	174.4	88.8
18	174.4	84.5
20	174.4	82.8
22	174.4	74.2
24	174.4	58.8
26	174.4	40.8

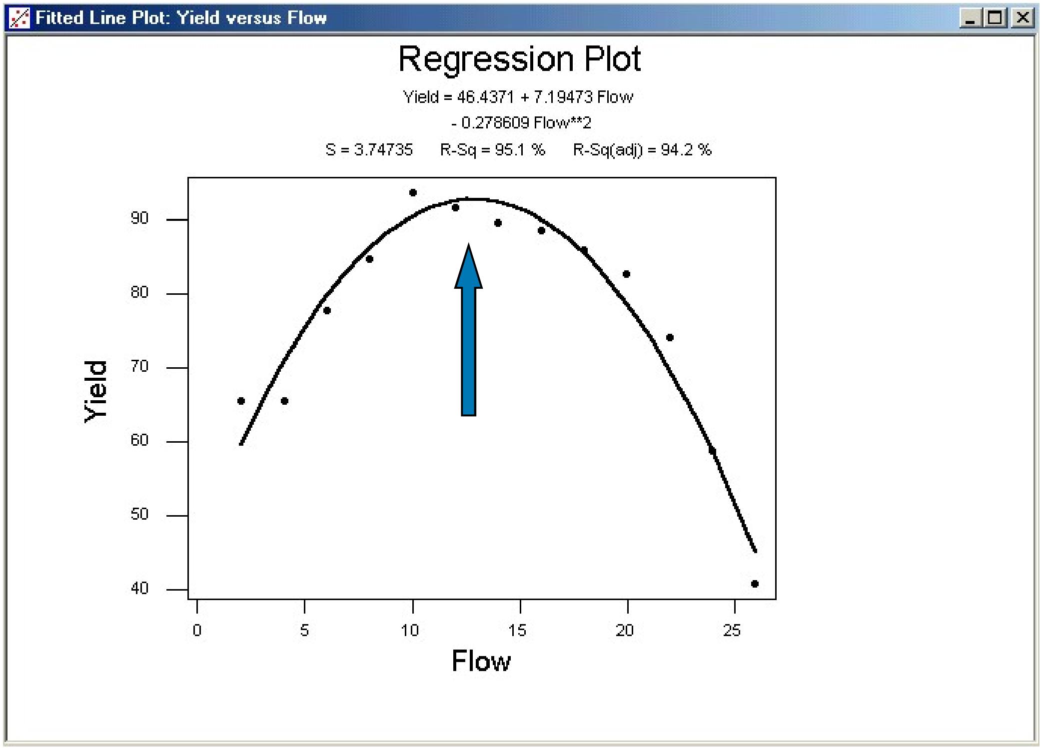
New setting (Flow 12, Yield 91.8)

Old setting (Flow 18, Yield 84.5)

Higher yield at lower flow is found, but is this the true optimum?

Data is used for a regression analysis

One Factor at a Time Data Analysis Fourth Step



Regression analysis provides equation which can be solved for flow

$$Y = 46.437 + 7.195 Flow - 0.2786 Flow^2$$

Another test is planned to study temp at the "optimum" flow of 12.9 lpm

One Factor at a Time Data Analysis Fifth Step

- Repeat steps 1 – 4 until satisfied "optimum" is found
- Each cycle will produce an equation for yield versus temperature
- Each cycle will produce an equation for yield versus flow
- Solve equations iteratively
- Repeat cycle, obtaining NEW equations

OFAT Equations

- Each cycle produces a set of independent, simultaneous equations describing the process
- First cycle:

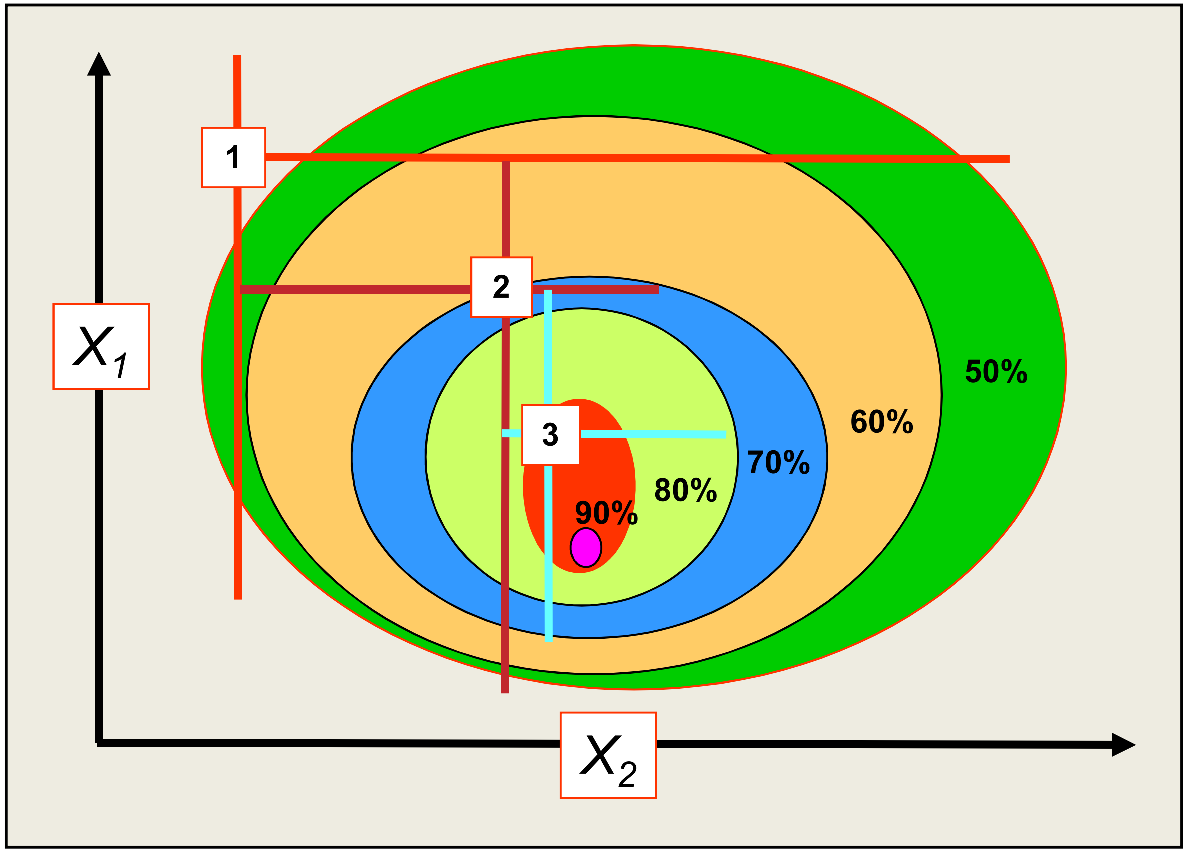
$$Y = -263.79 + 4.012Temp - 0.011566Temp^2$$
$$Y = 46.437 + 7.195Flow - 0.2786Flow^2$$

- Subsequent cycles:

$$Y = f(Temp)$$
$$Y = f(Flow)$$

OFAT will generate a family of independent prediction equations that do not readily lead to the optimum solution

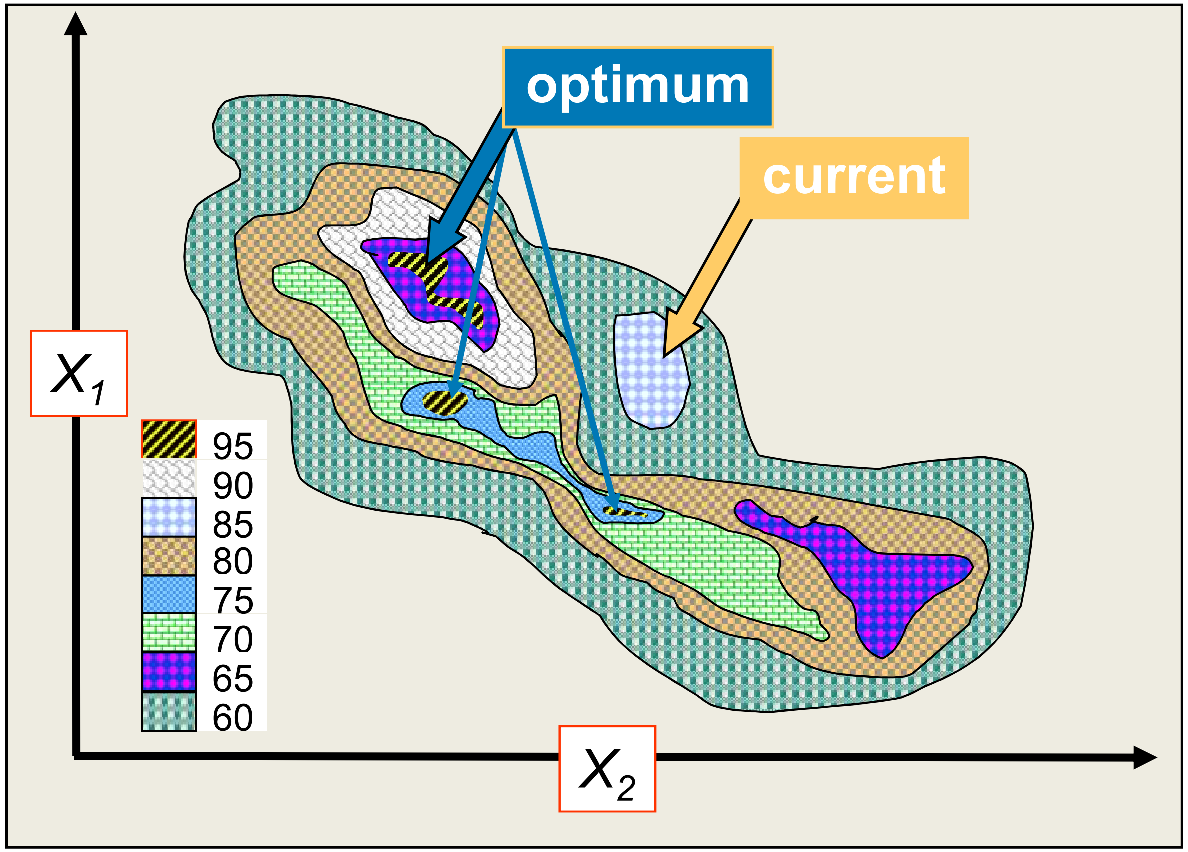
OFAT Prediction Contours



One factor at a time presumes a nested family of responses

Factor interactions are missed with OFAT

Process Response Contours



More often than not, the response contours of a process contain many peaks and valleys created by the interaction of factors

OFAT optimization can become inefficient and sometimes misleading

Prediction Equations

- More useful and efficient is one equation that predicts the output as a function of all factors

$$\hat{Y} = f(temp, press)$$

$$\hat{Y} = f(A, B, C\ldots)$$

- This type of equation has multiple factors. It will contain:
  - Main effects
  - Interactions

General Form of DOE Prediction Equations

- The general full equation has all combinations and power terms

$$\hat{Y} = b_0 + b_1 Flow + b_2 Temp + b_3 Flow * Flow + b_4 Flow^2 + \ldots$$

- Most DOE experiments will use the linear solution of the general equation to define the response

$$\hat{Y} = b_0 + b_1 A + b_2 B + b_3 C + b_4 AB + b_5 AC + \ldots + b_7 ABC$$

DOE equations will deal with a linear subset of the general equation

Capturing Interactions

Statistically based designs provide information about factors and interactions

- 2k-n Fractional Factorial Designs
- 2k Full Factorial
- Full Factorial (replication)
- RSM (response surface method)

Revealing information about main effects and interactions is key to process understanding

Prepared to Explore DOE

DoE 3 Factor 2 Level ***

↓	C1	C2	C3	C4	C5	C6	C7	C8
	StdOrder	RunOrder	CenterPt	Blocks	A	B	C	
1	6	1	1	1	1	-1	1	
2	3	2	1	1	-1	1	-1	
3	2	3	1	1	1	-1	-1	
4	1	4	1	1	-1	-1	-1	
5	8	5	1	1	1	1	1	
6	7	6	1	1	-1	1	1	
7	4	7	1	1	1	1	-1	
8	5	8	1	1	-1	-1	1	
9								

Minitab will be the tool for creating and analyzing DOE experiments in the Breakthrough Strategy ™

Key Learning Points

-
-
-
-
-
-
-

Objectives Review

By the end of this module, the participant should:

- Understand the strategy behind Design of Experiments (DOE)
- Create a design matrix
- Code factors
- Understand the limitations of OFAT experiments
- Interpret interactions

Anexas Consultancy Services

Full Factorial Design of Experiments

Module Objectives

By the end of this module, the participant will:

- Generate a full factorial design
- Look for factor interactions
- Develop coded orthogonal designs
- Write process prediction equations (models)
- Set factors for process optimization
- Create and analyze designs in Minitab™
- Evaluate residuals
- Develop process models from Minitab™ analysis
- Determine sample size

Why Learn About Full Factorial DOE?

- A Full Factorial Design of Experiment will
- Provide the most response information about
  - Factor main effects
  - Factor interactions
- Provide the process model's coefficients for
  - All factors
  - All interactions
- When validated, allow process to be optimized

What is a Full Factorial DOE

- A full factorial DOE is a planned set of tests on the response variable(s) (KPOVs) with one or more inputs (factors) (PIVs) with all combinations of levels
- ANOVA analysis will show which factors are significant
- Regression analysis will provide the coefficients for the prediction equations
  - Mean
  - Standard deviation
- Residual analysis will show the fit of the model

DOE Terminology

- **Response** (Y, KPOV): the process output linked to the customer CTQ
- **Factor** (X, PIV): uncontrolled or controlled variable whose influence is being studied
- **Level**: setting of a factor (+, -, 1, -1, hi, lo, alpha, numeric)
- **Treatment Combination** (run): setting of all factors to obtain a response
- **Replicate**: number of times a treatment combination is run (usually randomized)
- **Repeat**: non-randomized replicate
- **Inference Space**: operating range of factors under study

Full Factorial DOE Objectives

- Learning the most from as few runs as possible..
- Identifying which factors affect mean, variation, both or have no effect
- Modeling the process with prediction equations,

$$\hat{Y} = f(A, B, C\ldots)$$

$$\hat{s} = f(A, B, C\ldots)$$

- Optimizing the factor levels for desired response
- Validating the results through confirmation

Anexas Consultancy Services

Linear Combinations of Factors for Two Levels

Combinations of Factors and Levels

- A process whose output Y is suspected of being influenced by three inputs A, B and C. The SOP ranges on the inputs are
  - A 15 through 25, by 1
  - B 200 through 300, by 2
  - C 1 or 2
- A DOE is planned to test all combinations

Is testing all combinations possible, reasonable and practical?

Combinations of Factors and Levels cont'd

- Setting up a matrix for the factors at all possible process setting levels will produce a really large number of tests.
- The possible levels for each factor are

  A = 11

  B = 51

  C = 2
- How many combinations are there?

A	B	C
15	200	1
16	200	1
17	200	1
18	200	1
19	200	1
20	200	1
21	200	1
22	200	1
23	200	1
24	200	1
25	200	1
15	202	1
16	202	1
17	202	1
.	.	.
.	.	.
.	.	.
.	.	.
22	300	2
23	300	2
24	300	2
25	300	2

We must make assumptions about the response in order to manage the experiment

Linear Response for Factors at Two Levels

- The team decides, from process knowledge, that the response is close to being linear throughout the range of factor level settings (inference space).
- A reasonable assumption for most processes
- The levels of the factors for the test would then be
  - A 15 and 25
  - B 200 and 300
  - C 1 and 2

The design becomes much more manageable!

The Three Factor Design at Two Levels

- The revised experiment consists of all possible combinations of A, B and C each at the chosen low and high settings:

A	B	C
15	200	1
15	200	2
15	300	1
15	300	2
25	200	1
25	200	2
25	300	1
25	300	2

This is a 2^3 full factorial design (pronounced two to the three). It consists of all combinations of the three factors each at two levels

Naming Conventions

- The naming convention for full factorial designs has the level raised to the power of the factor:

$$\textit{level}^{(\text{factor})}$$

- and is called "a (level) to the (factor) design"

- What would a two level, four factor design be called?
- How many combinations (runs) are in a 23 design?

Class Exercise

- Write the total number of combinations for the following designs

  2^3

  2^4

A	B	C	D

- Assume factors are named A, B, C, D, etc. and the levels are low “-” and high “+”.

Did we all generate the same designs?

Anexas Consultancy Services

The Yates Standard Order

A method to generate experimental designs in a consistent and logical fashion was developed by Frank Yates.

The Yates Standard Order
Step 1

Create a matrix with factors along the top, runs down the left side (2^3 example shown)

	Factors		
Runs	A	B	C
1			
2			
3			
4			
5			
6			
7			
8			

For a 2^3 there will be 8 runs

The Yates Standard Order
Step 2

Starting with the first factor, insert its low value in the first row followed by its high value in the second row. Repeat through the last row.

	Factors		
Runs	A	B	C
1	15		
2	25		
3	15		
4	25		
5	15		
6	25		
7	15		
8	25		

The Yates Standard Order
Step 3

Move to the next factor and place its low value in the first two rows, followed by its high value in the next two rows. Repeat through the last row.

	Factors		
Runs	**A**	**B**	**C**
1	15	200	
2	25	200	
3	15	300	
4	25	300	
5	15	200	
6	25	200	
7	15	300	
8	25	300	

The Yates Standard Order
Step 4

Move to the next factor and place its low value in the first four rows, followed by its high value in the next four rows. Repeat through the last row.

	Factors		
Runs	A	B	C
1	15	200	1
2	25	200	1
3	15	300	1
4	25	300	1
5	15	200	2
6	25	200	2
7	15	300	2
8	25	300	2

The Yates Standard Order
Step N

Continue the pattern until all factors are included

Yates Design Generator

Factor	Row	Pattern
1st	1 low	1 high
2nd	2 low	2 high
3rd	4 low	4 high
	•	
	•	
nth	2n-1 low	2n-1 high

The Yates Standard Order Summary

- The Yates design generator yields all possible combinations of factor levels.
- This is a full factorial two level design for three factors.

	Factors		
Runs	A	B	C
1	15	200	1
2	25	200	1
3	15	300	1
4	25	300	1
5	15	200	2
6	25	200	2
7	15	300	2
8	25	300	2

Class Exercise

- Write the total number of combinations for the following designs using the Yates Standard order design generator.
- **2^3**
- **2^4**
- Assume factors are named A, B, C, D, etc. and the levels are low = "-" and high ="+".

Did we all generate the same designs?

Anexas Consultancy Services

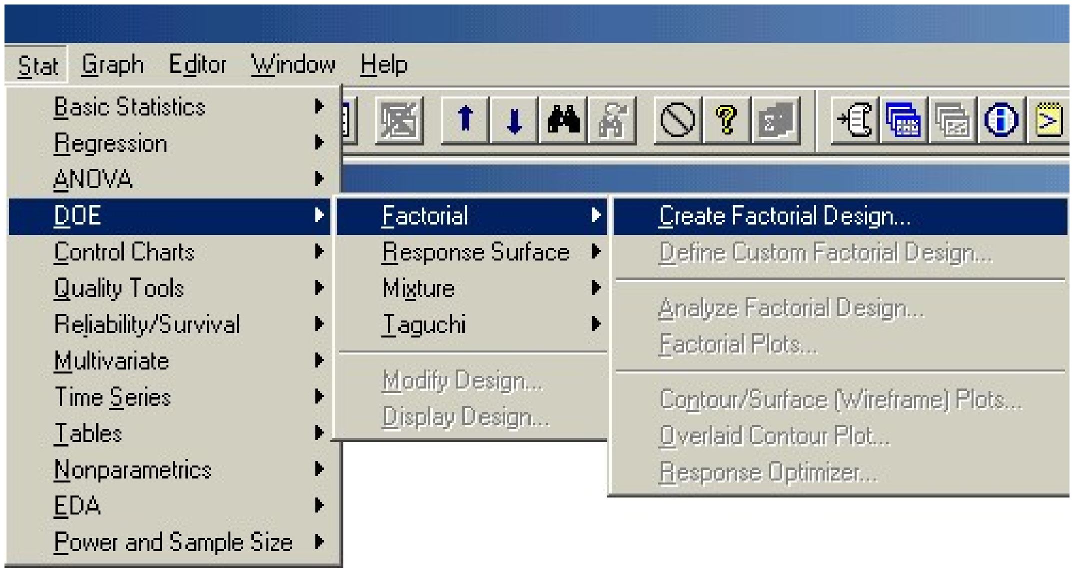
Creating a Full Factorial Design in Minitab®

Creating a Full Factorial Design in Minitab Step 1

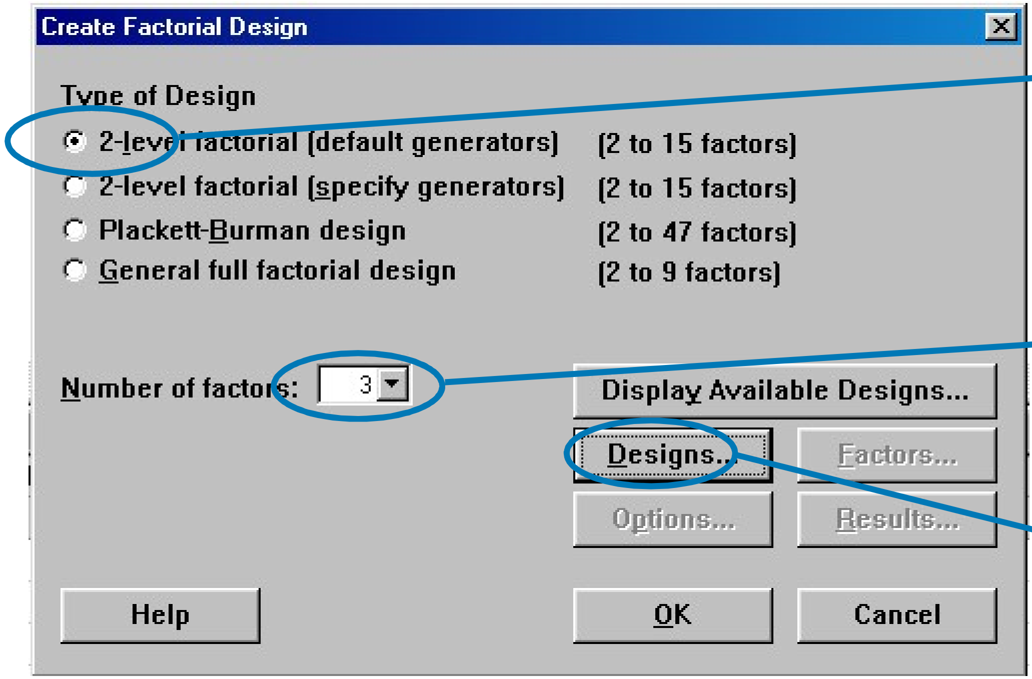
Tool Bar Menu > Stat > DOE > Factorial > Create Factorial Design

- Create a Minitab® design for
  - A - pressure
  - B - temperature
  - C - material vendor

2^3 design



Creating a Full Factorial Design in Minitab Step 2

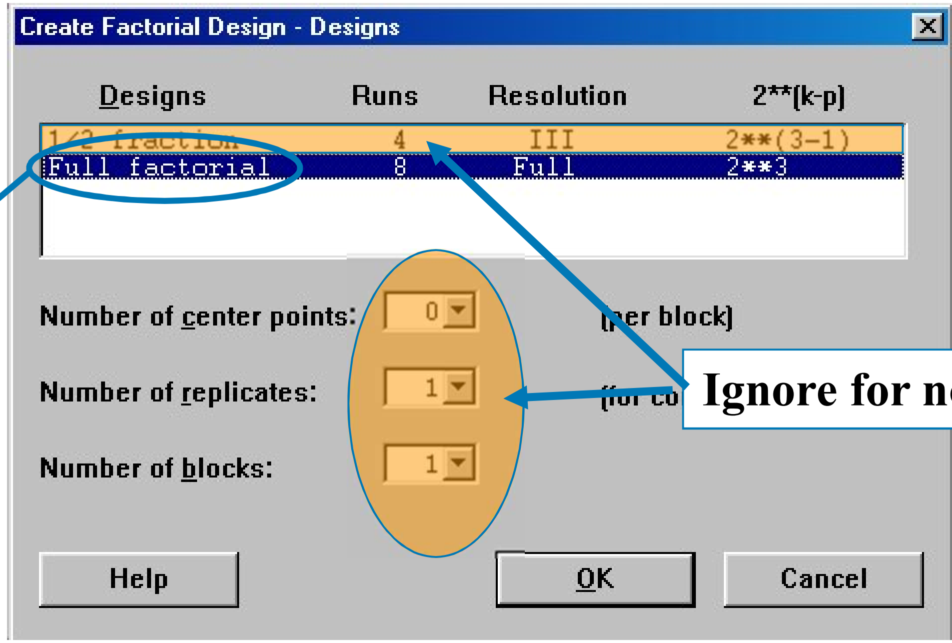


1. Select default generators (Yates is default)

2. Set number of factors to three

3. Go to Designs

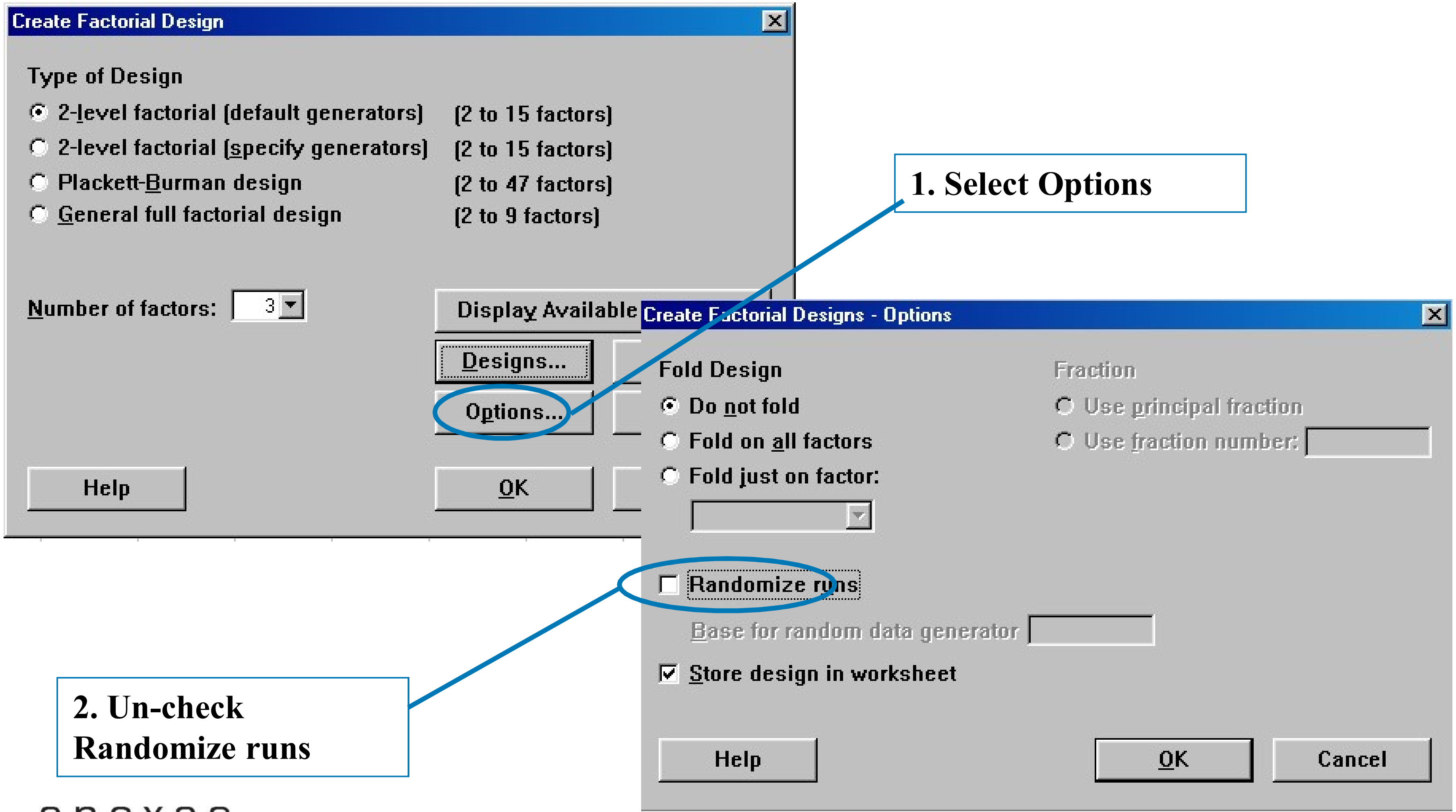
Creating a Full Factorial Design in Minitab Step 3



Select Full factorial

Ignore for now

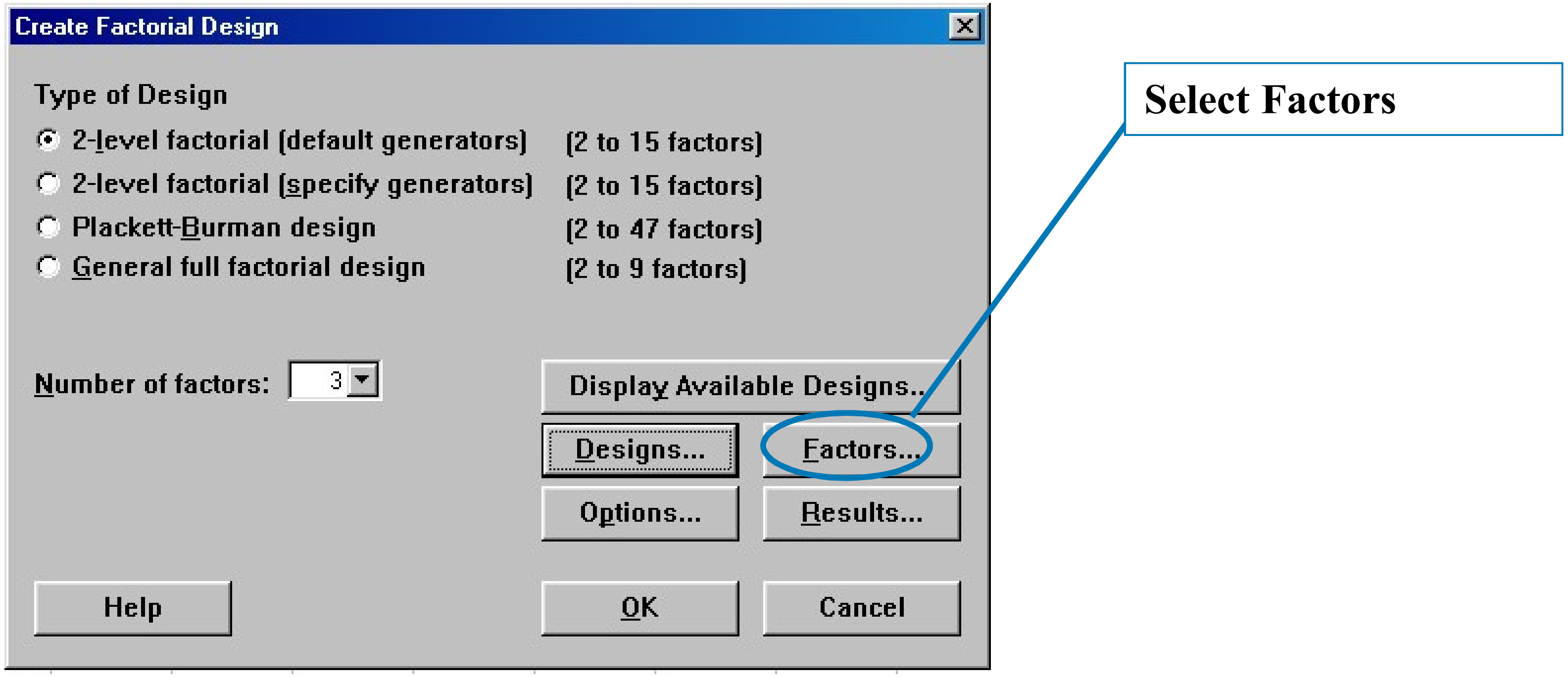
Creating a Full Factorial Design in Minitab Step 4



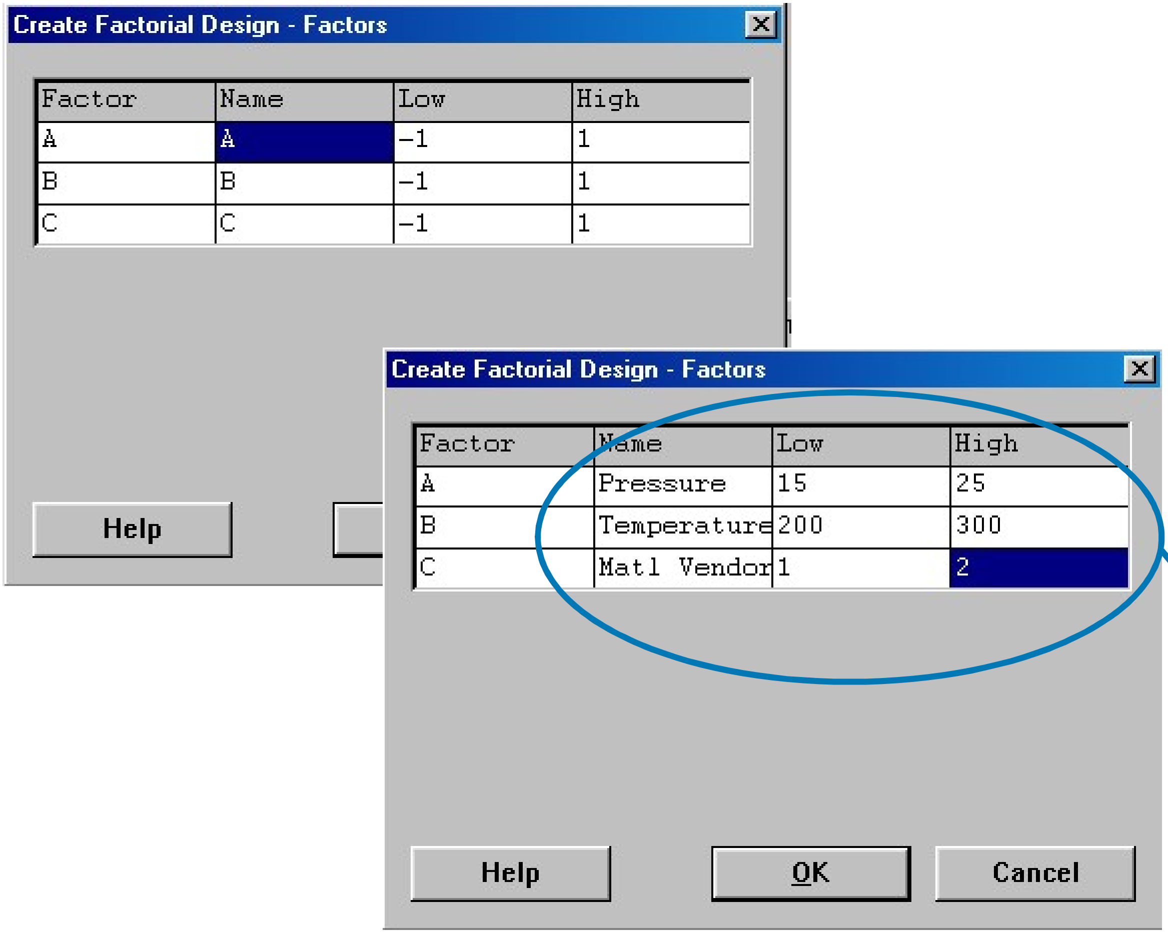
1. Select Options

2. Un-check Randomize runs

Creating a Full Factorial Design in Minitab Step 5

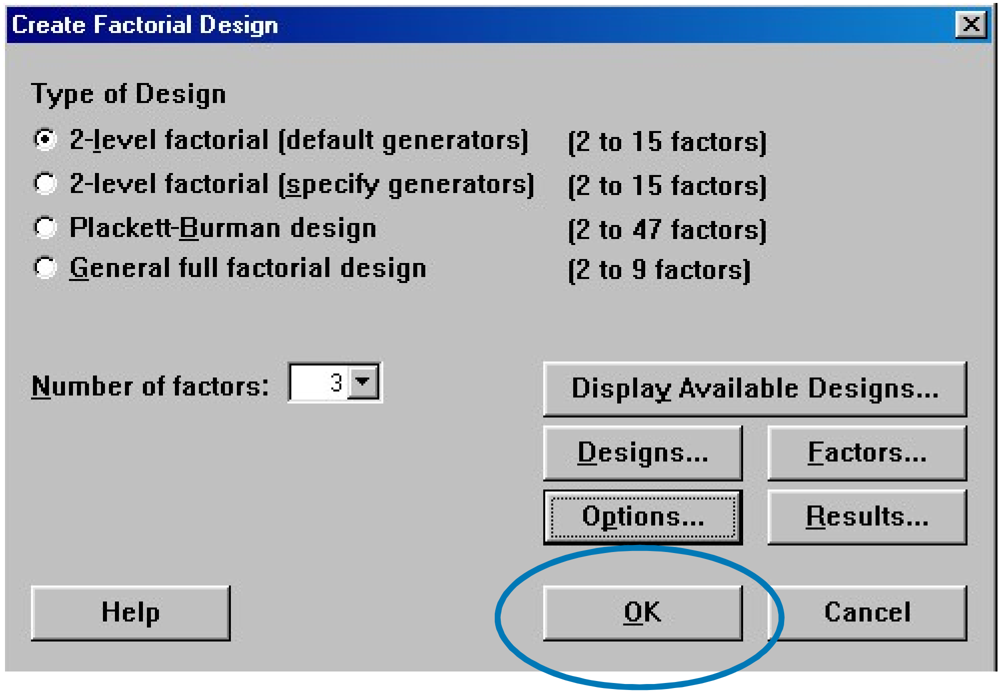


Creating a Full Factorial Design in Minitab Step 6



Input the Factor Names and Levels

Creating a Full Factorial Design in Minitab Step 7



Design parameters are entered; ready to create the design in the worksheet.

Creating a Full Factorial Design in Minitab Step 8

Worksheet 1 ***

↓	C1	C2	C3	C4	C5	C6	C7	C8
	StdOrder	RunOrder	CenterPt	Blocks	Pressure	Temperature	Matl Vendor	
1	1	1	1	1	15	200	1	
2	2	2	1	1	25	200	1	
3	3	3	1	1	15	300	1	
4	4	4	1	1	25	300	1	
5	5	5	1	1	15	200	2	
6	6	6	1	1	25	200	2	
7	7	7	1	1	15	300	2	
8	8	8	1	1	25	300	2	
9								

This is the Yates Standard order for a 2^3 uncoded design

Std Order Column of Minitab Design

Worksheet 1 ***

↓	C1	C2	C3	C4	C5	C6	C7	C8
	StdOrder	RunOrder	CenterPt	Blocks	Pressure	Temperature	Matl Vendor	
1	1	1	1	1	15	200	1	
2	2	2	1	1	25	200	1	
3	3	[illegible]	[illegible]	1	15	300	1	
4	4	[illegible]	[illegible]	1	25	300	1	
5	5	[illegible]	[illegible]	1	15	200	2	
6	6	[illegible]	[illegible]	1	25	200	2	
7	7	[illegible]	[illegible]	1	15	300	2	
8	8	8	1	1	25	300	2	
9								

The StdOrder Column is the Yates Standard Order

Run Order Column of Minitab Design

Worksheet 1 ***

↓	C1	C2	C3	C4	C5	C6	C7	C8
	StdOrder	RunOrder	CenterPt	Blocks	Pressure	Temperature	Matl Vendor	
1	1	1			15	200	1	
2	2	2			25	200	1	
3	3	3			15	300	1	
4	4	4			25	300	1	
5	5	5			15	200	2	
6	6	6			25	200	2	
7	7	7			15	300	2	
8	8	8			25	300	2	
9								

RunOrder Column is the sequence of the runs

StdOrder is created by the design choice RunOrder is created by randomize runs choice

Class Exercise Part 1

- Generate the previous design with the randomize runs tic box selected
- Compare results with your neighbors

Class Exercise Part 2

Create a non random Minitab design for the following:
The factors are

	NAME	LEVEL (Low	High)
A	Customer Type	Retail	Consumer
B	System	Legacy	SAP
C	Warehouse	Atlanta	Dallas
D	Overtime Hours	0	100

The response is on-time delivery.

Be prepared to present your results.

Anexas Consultancy Services

Replicates and Repeats

What are Replicates and Repeats?

- Replicate
- Total run of all treatment combinations
  - Usually in random order
- Requires factor level change between runs
- All experiments will have one replicate
  - Two replicates are two complete experiment runs
- Statistically best experimental scenario

Repeat (also repetition)

- Additional run without factor level change

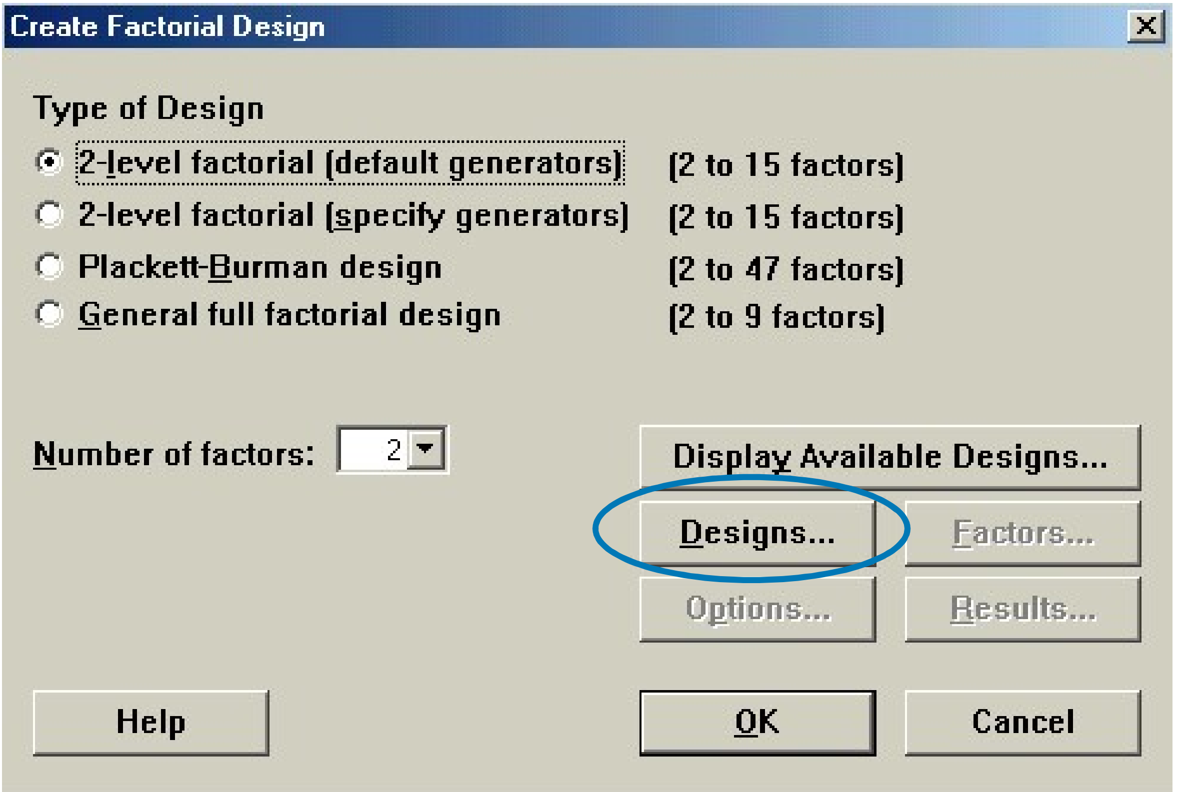
Minitab Design Replication

- Minitab easily handles replicating the design
- Replicate or repeat is treated same in design
- Actual factor level change between runs is at the discretion of the experimenter
  - Minitab provides treatment combination
  - Randomization or information needed is part of strategy of experiment

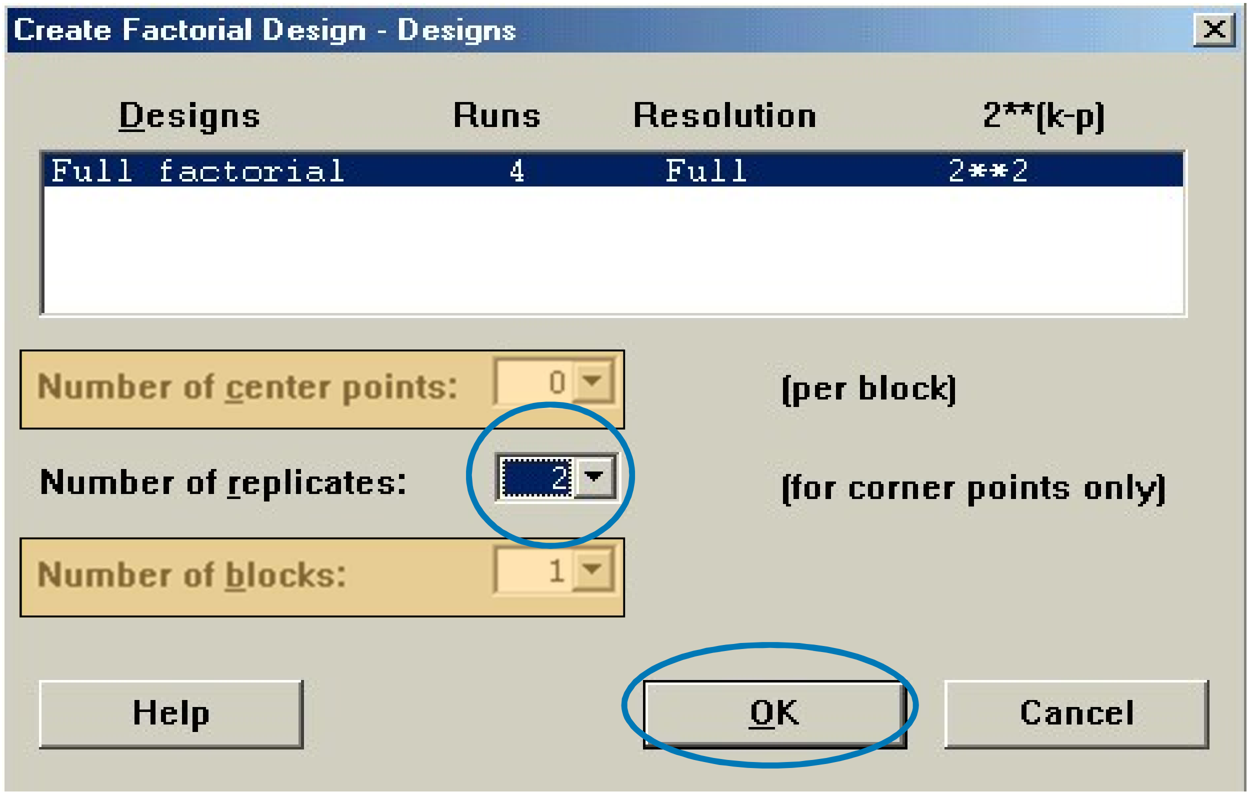
Replication in Minitab
Step 1

Tool Bar Menu > Stat > DOE > Factorial > Create Factorial Design

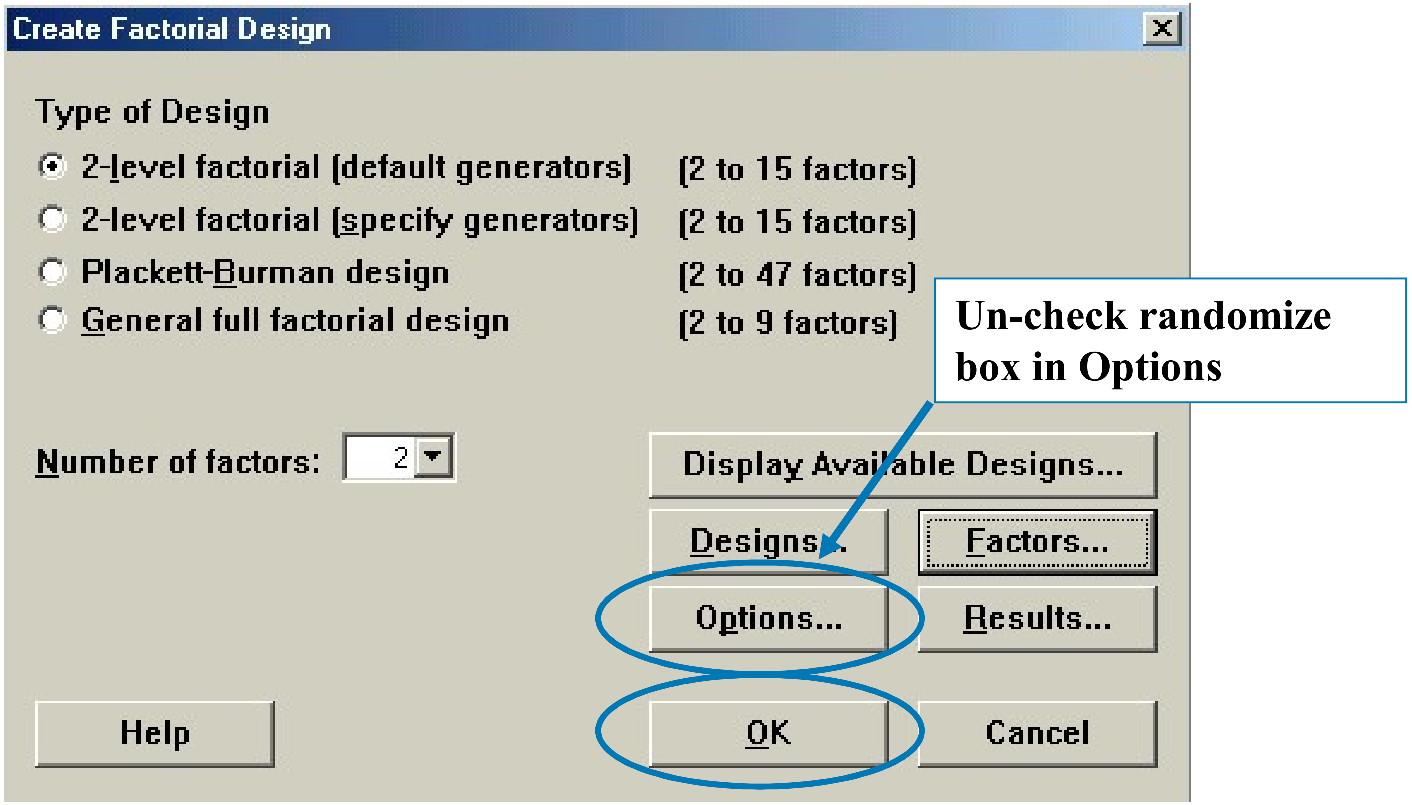
Create a 2^2 with two non randomized replicates



Replication in Minitab
Step 2



Replication in Minitab
Step 3



Skip the other dialog options

Replication in Minitab
Step 4

Worksheet 1 ***

↓	C1	C2	C3	C4	C5	C6	C7
	StdOrder	RunOrder	CenterPt	Blocks	A	B	
1	1	1	1	1	-1	-1	
2	2	2	1	1	1	-1	
3	3	3	1	1	-1	1	
4	4	4	1	1	1	1	
5	5	5	1	1	-1	-1	
6	6	6	1	1	1	-1	
7	7	7	1	1	-1	1	
8	8	8	1	1	1	1	
9							

First Replicate (rows 1–4)

Second Replicate (rows 5–8)

Response Y would be placed in C7

Randomized Replication in Minitab for Step 4

Worksheet 2 ***

↓	C1	C2	C3	C4	C5	C6	C7
	StdOrder	RunOrder	CenterPt	Blocks	A	B	
1	7	1	1	1	-1	1	
2	4	2	1	1	1	1	
3	5	3	1	1	-1	-1	
4	3	4	1	1	-1	1	
5	8	5	1	1	1	1	
6	2	6	1	1	1	-1	
7	1	7	1	1	-1	-1	
8	6	8	1	1	1	-1	
9							

Response Y would be placed in C7

Coding the Design

Coding the design by transforming the low factor level to a “-1” and the high factor level to a “+1” offers analysis advantages

Coding Review Exercise

Fill in the coded design based upon the uncoded design

	Uncoded Factors			Coded Factors		
Runs	A	B	C	A	B	C
1	15	200	1			
2	25	200	1			
3	15	300	1			
4	25	300	1			
5	15	200	2			
6	25	200	2			
7	15	300	2			
8	25	300	2			

Any uncoded design can be transformed into a coded design

Requirement of Factor Independence

- Factors are mathematically independent when only the response is a function of the factors
- A factor is not a function of another factor
- The coded design is orthogonal
  - Factors will be independent

DOE analysis requires that the factors be independent

Anexas Consultancy Services

Orthogonal Designs

Determining Orthogonality

Consider the 2^2 design

	Coded Factors		OutPut
Runs	X_1	X_2	Y
1	-1	-1	(y_1)
2	1	-1	(y_2)
3	-1	1	(y_3)
4	1	1	(y_4)

The run outputs, Y_n, can be described by

where b and c are coded settings of the factors

It can be shown that for X_1 to be independent of X_2

$$\sum_{i=1}^{n} b_i c_i = 0$$

Calculating Orthogonality

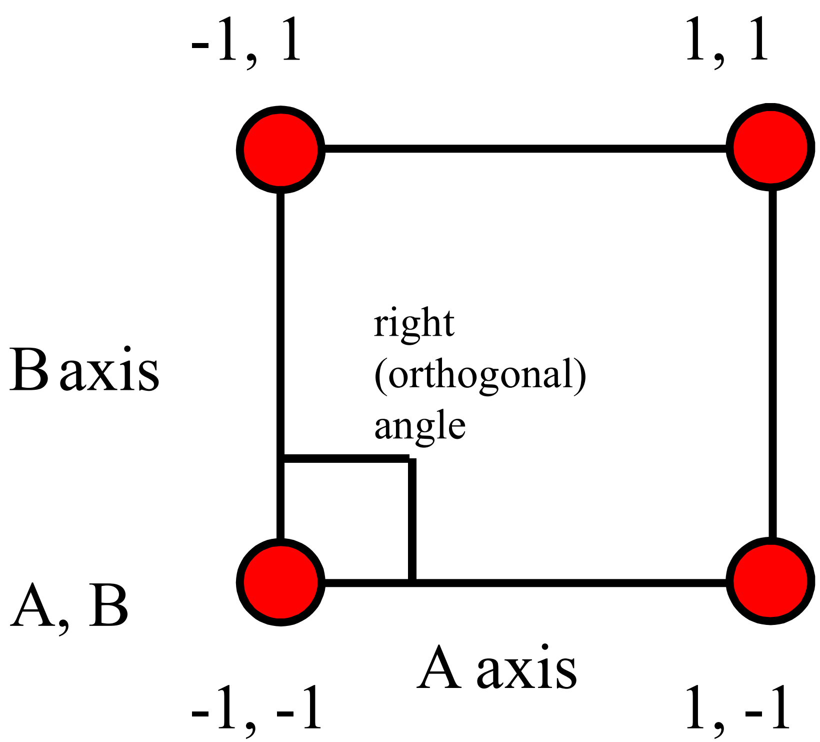
	Coded Factors		Coef1*coeff2
Runs	X1	X2	X1*X2
1	-1	-1	1
2	1	-1	-1
3	-1	1	-1
4	1	1	1
		$\sum$	0

Satisfies

$$\sum_{i=1}^{n} b_i c_i = 0$$

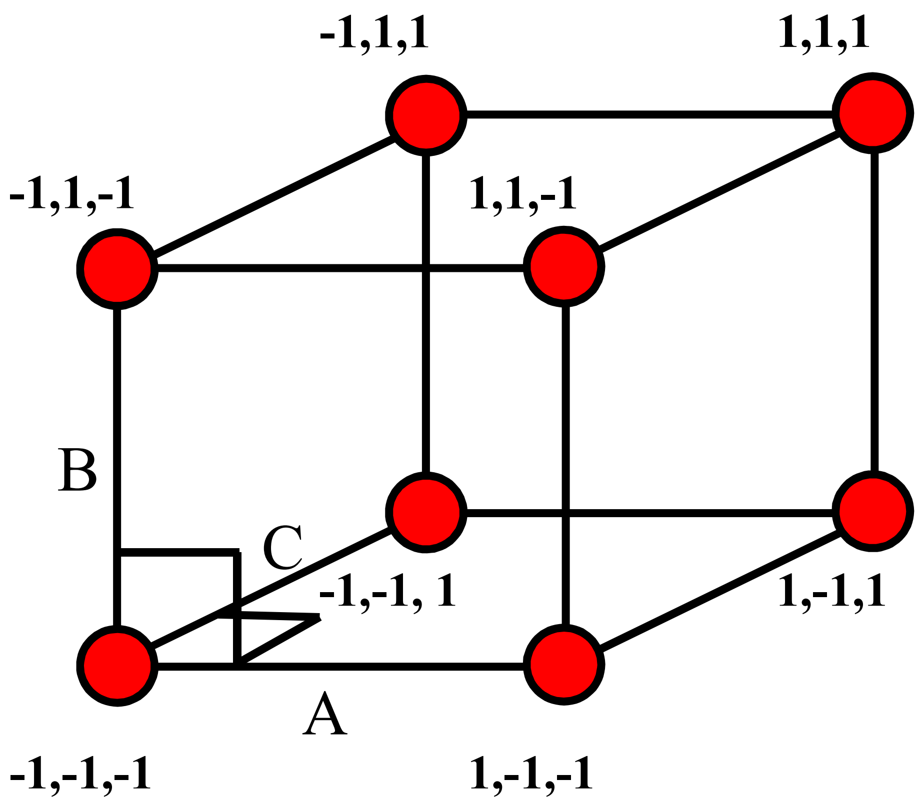
Therefore orthogonal and independent

Coding and Orthogonality for a 2^2 Design



Orthogonal designs can be represented as a geometric (mathematical) figure

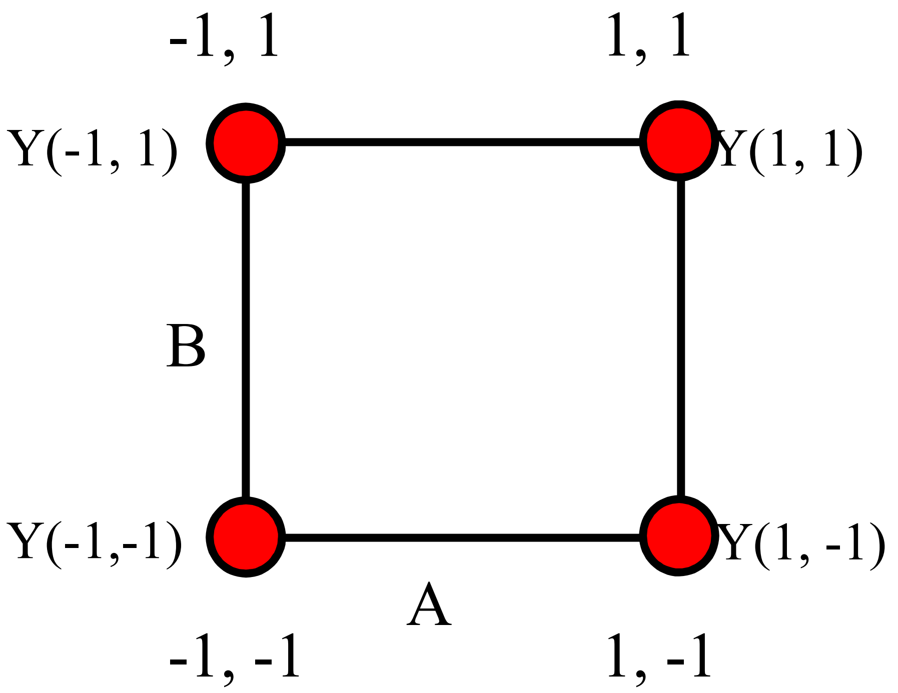
Coding and Orthogonality for a 2^3 Design



The vertices are the response measurement points; the volume within is the inference space

Response and Orthogonality

The response can be measured at each corner of the design, as represented by Y(A,B).



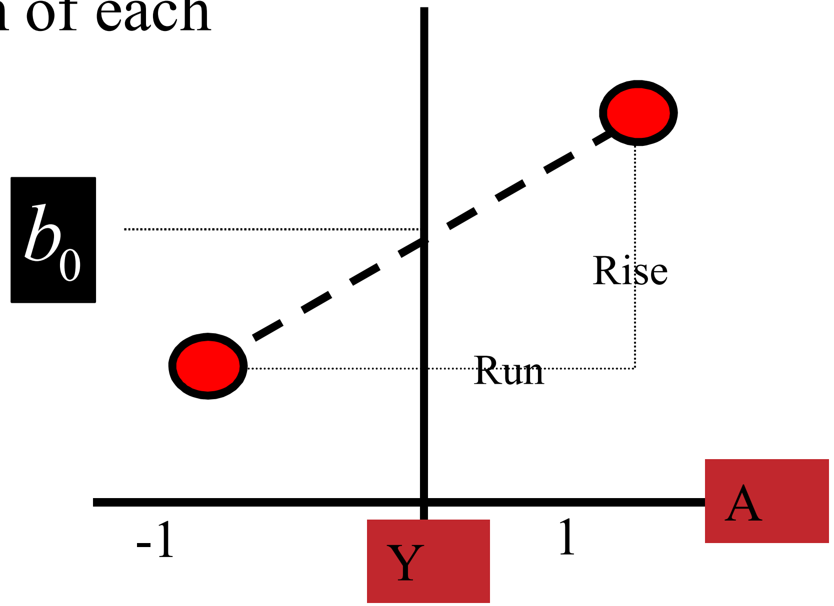
Coding and the Linear Model

Since the factors are orthogonal, Y is a linear combination of each factor

The linear equation,

$$Y = b_0 + b_1 A$$

describes the line between the points



b_0 = Intercept

b_1 = Rise/Run

Fitting a linear model to the coded design becomes very easy

Anexas Consultancy Services

Main Effects and Interactions

Calculating Main Effects

A DOE is run:

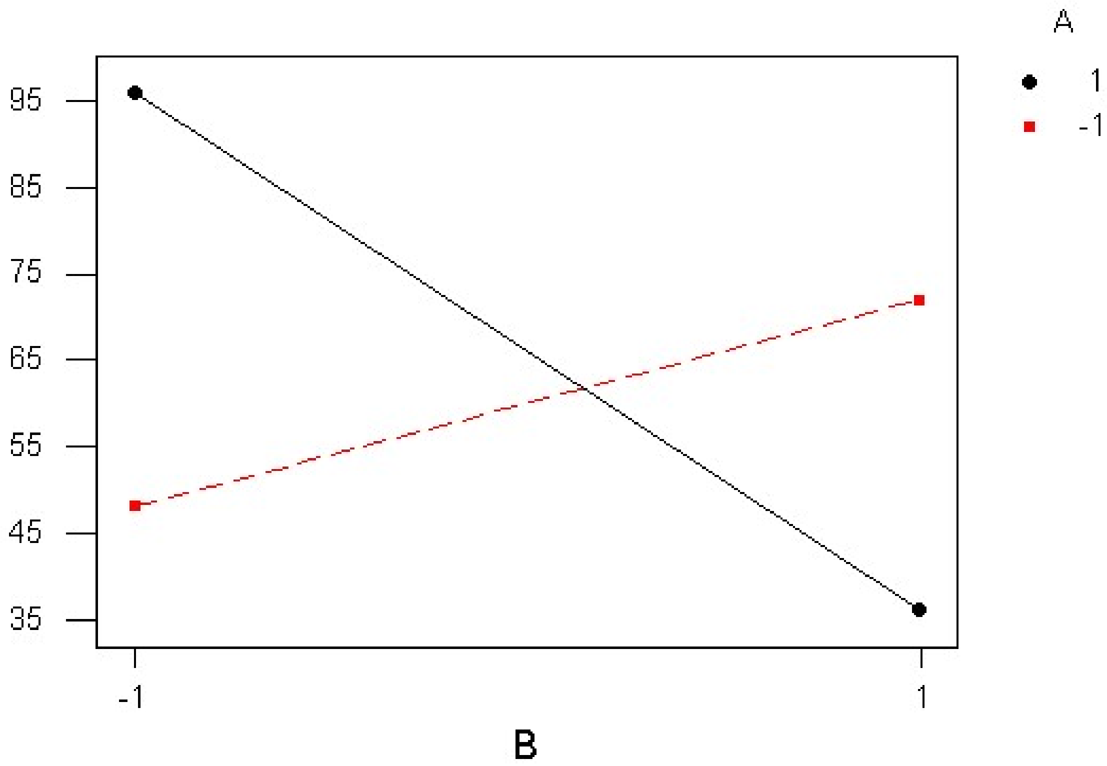
	Coded Factors		Response
	A	B	Y
	-1	-1	48
	1	-1	96
$\frac{96+36}{2}=66$	-1	1	72
	1	1	36
Y_{ave} at $FACTOR_{high}$	66	54	
Y_{ave} at $FACTOR_{low}$	60	72	
Effect	6	-18	

What does a non-zero effect mean?

$$effect = \overline{Y}(@\ factorhigh) - \overline{Y}(@\ factorlow)$$

The factor (or main) effects are easily calculated

Discovering Interactions



A response change due to both A and B changing is called an interaction

Linear Prediction Equation With Interaction Term

- The interaction will add a term to the linear equation

$$Y = b0 + b1\ A + b2\ B + b3\ AB$$

- A and B are the main effects
- AB is the interaction
- b0 is the grand mean (intercept)
- b1, b2, and b3 are the term coefficients

Coded Values for Interactions

The coded value matrix for an interaction is the product of the factor coded values:

A	B
-1	-1
1	-1
-1	1
1	1

-1*-1 = 1
1*-1 = -1
-1*1 = -1
1*1 = 1

AB
1
-1
-1
1

Finding the interaction levels in a coded design is as simple as multiplying one times one

Calculating Interaction Effects

The DOE again

	Coded Factors		Interaction	Response
This is the Yates Standard Order for a 2^2 coded design with interaction	A	B	AB	Y
	-1	-1	1	48
	1	-1	-1	96
	-1	1	-1	72
	1	1	1	36
Y_{ave} at $FACTOR_{high}$	66	54	42	
Y_{ave} at $FACTOR_{low}$	60	72	84	
Effect	6	-18	-42	←

The interaction is set by the design (math) based upon the factor settings

Anexas Consultancy Services

Main Effects, Interactions and Cube Plots in Minitab

Create the Experiment

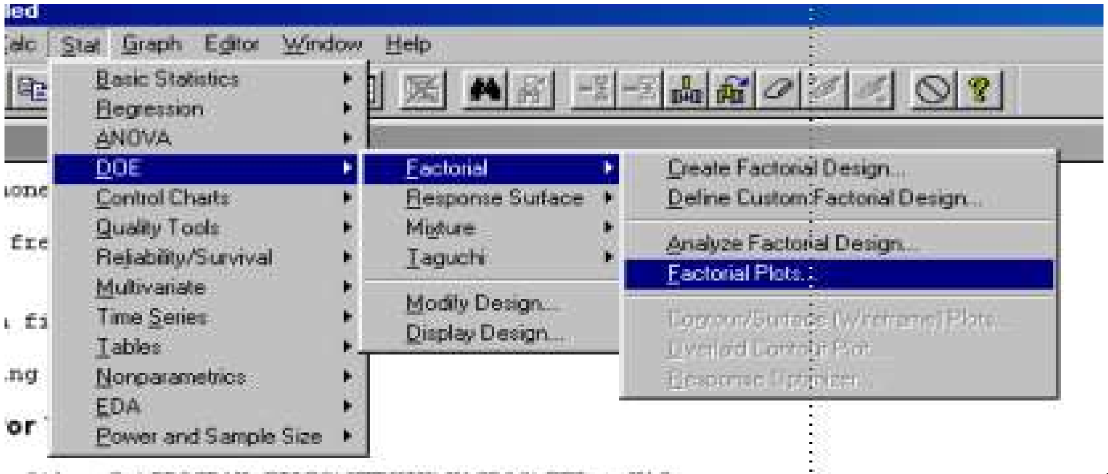
Tool Bar Menu > Stat > DOE > Factorial > Factorial Plots

Create a 2^2 coded design for factors A and B.

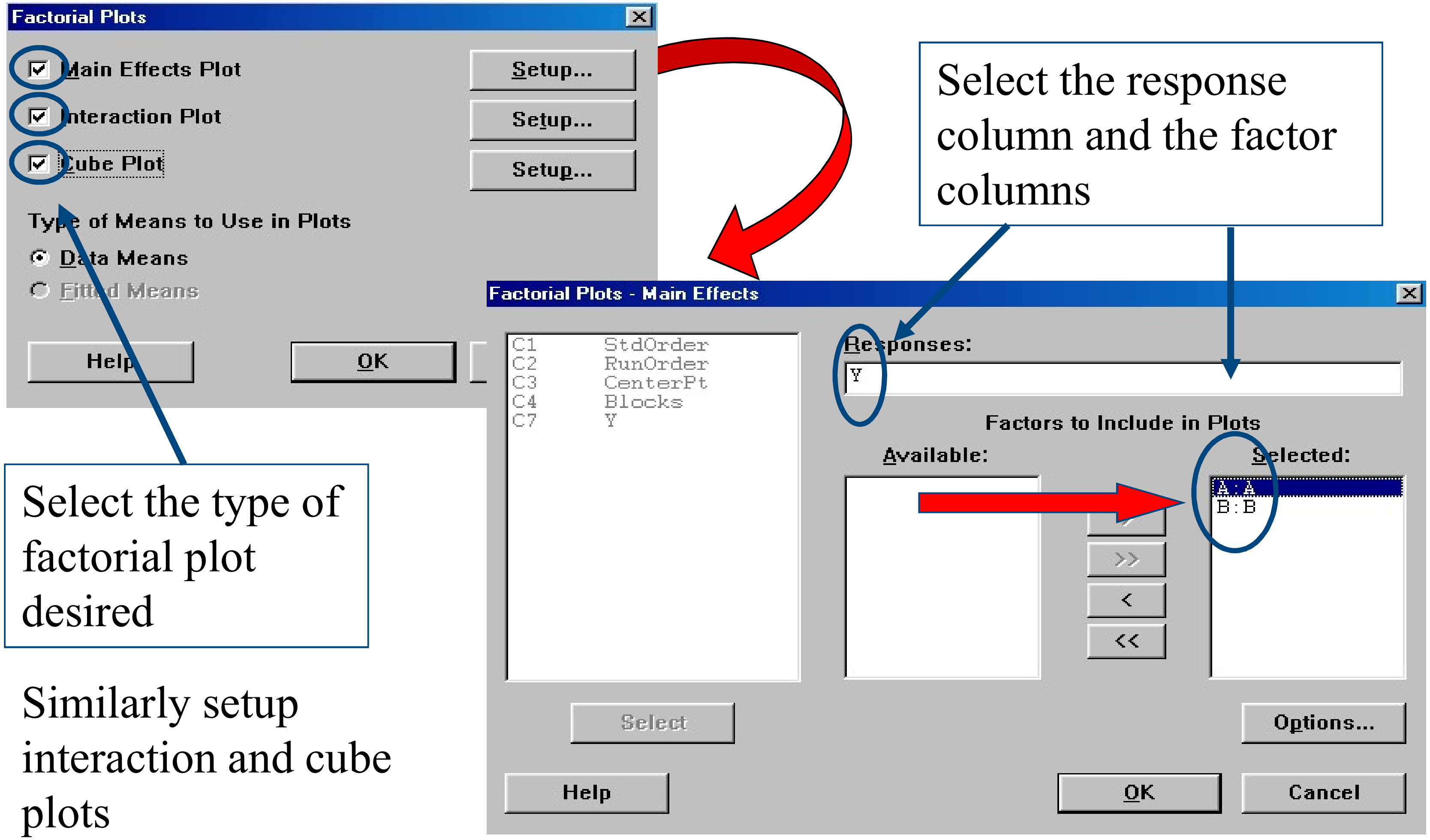
Worksheet 4 ***

↓	C1	C2	C3	C4	C5	C6	C7	C
	StdOrder	RunOrder	CenterPt	Blocks	A	B	Y	
1	1	1	1	1	-1	-1	48	
2	2	2	1	1	1	-1	96	
3	3	3	1	1	-1	1	72	
4	4	4	1	1	1	1	36	
5								

Input the Y response



Factorial Plots in Minitab
Step 1

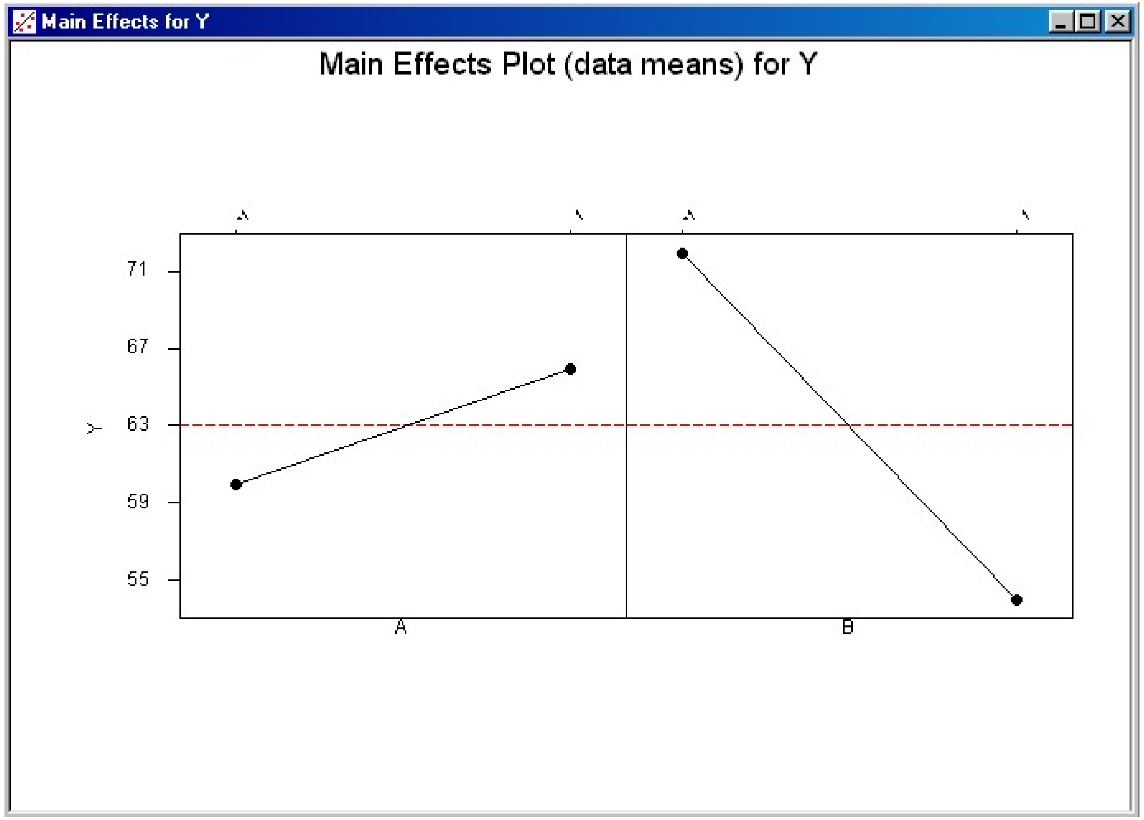


Select the response column and the factor columns

Select the type of factorial plot desired

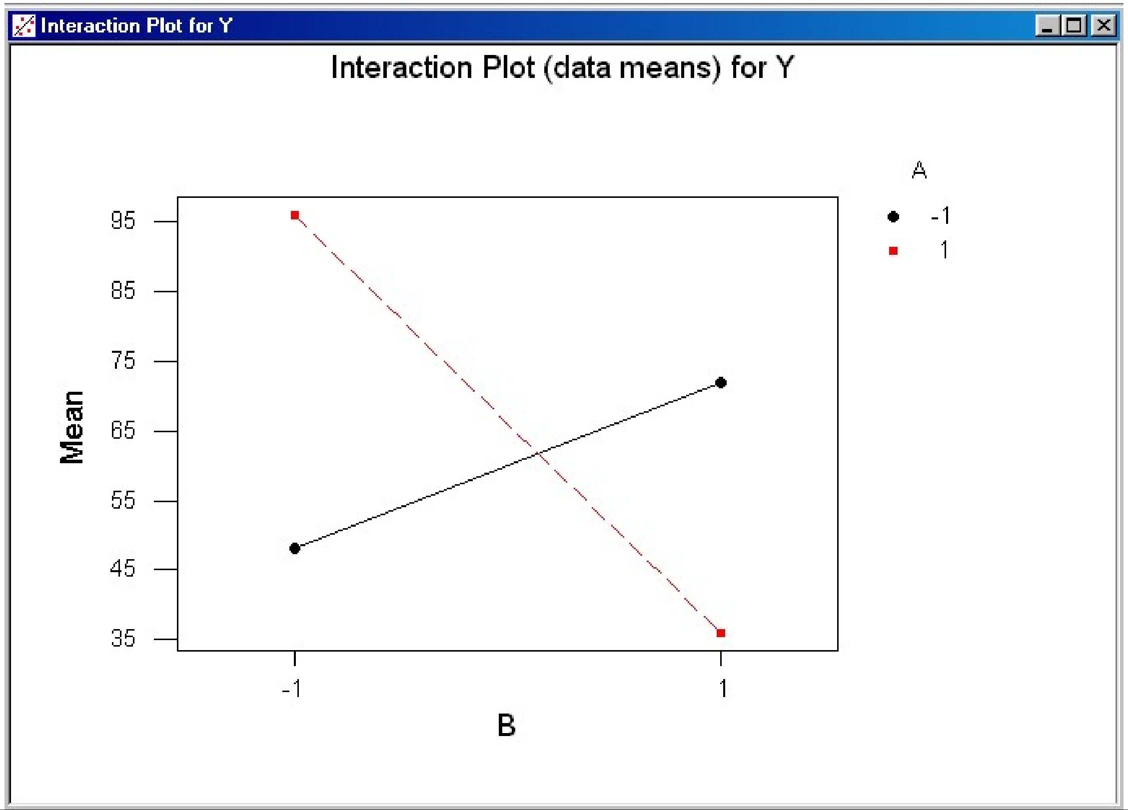
Similarly setup interaction and cube plots

Main Effects Plot



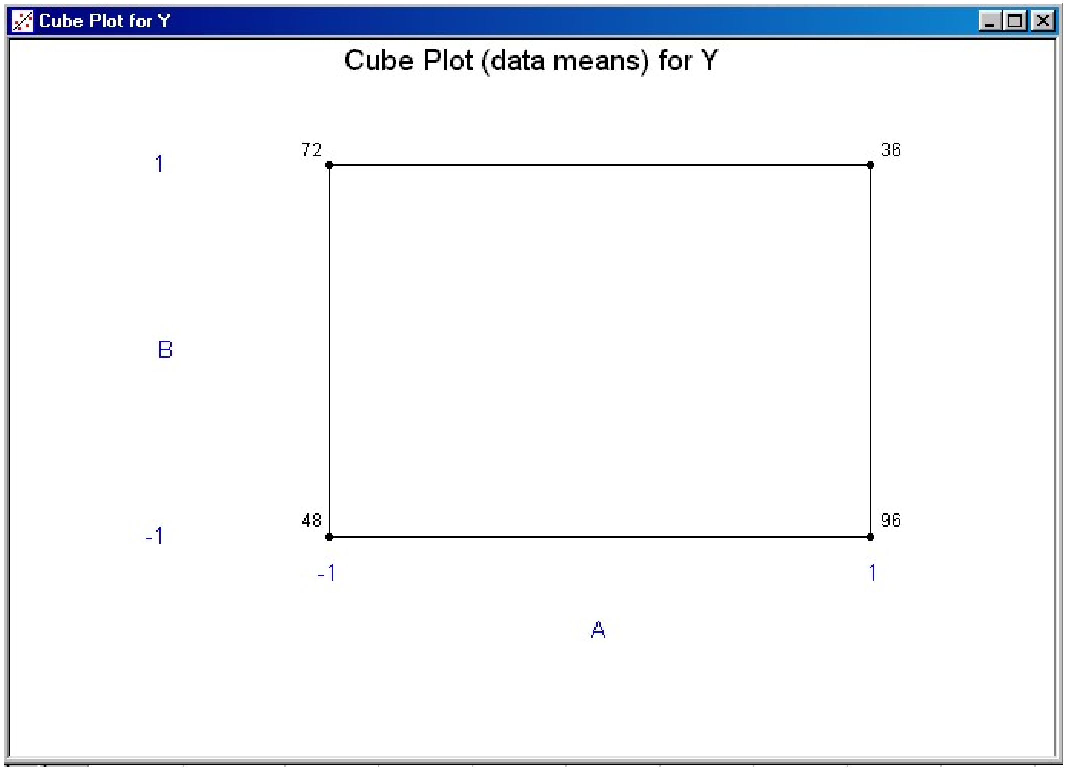
The response is plotted by factor from low level to high level

Interaction Plot



Parallel lines indicate no interaction; the less parallel, the higher the degree of interaction

Cube Plot



The response is plotted on the orthogonal factor axis

Class Exercise

Using the file *TWO CUBE EXERCISE.MTW* create all three factorial plots.

Be prepared to discuss your results.

The Prediction Equations

Developing the Prediction Equation

Knowing the design, responses and effect analysis the prediction equation can be found.

	Coded Factors		Interaction	Response
	A	B	AB	Y
	-1	-1	1	48
	1	-1	-1	96
	-1	1	-1	72
	1	1	1	36
Y_{ave} at $FACTOR_{high}$	66	54	42	
Y_{ave} at $FACTOR_{low}$	60	72	84	
Effect	6	-18	-42	

$$\hat{Y} = b_0 + b_1 A + b_2 B + b_3 AB$$

The Intercept – Constant – Grand Mean Relationship

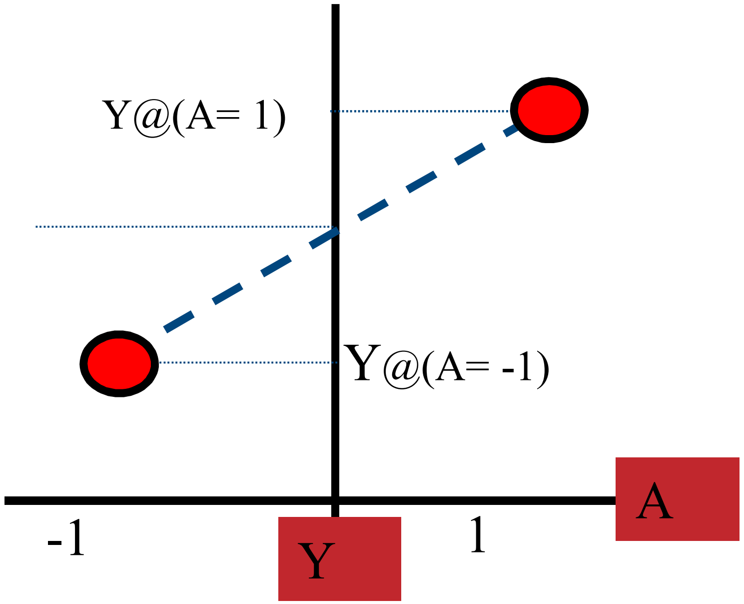
$$Y = b0 + b1\ A + b2\ B + b3\ AB$$

If we set all (coded) factors to equal zero, the equation becomes:
$Y = b0$
which is the overall average, or grand mean. The grand mean of the response is 63.

The regression constant is the grand mean of the responses for a coded design

Finding the Coefficients

$$\hat{Y} = 63 + b_1 A + b_2 B + b_3 AB$$



Looking at $b_1 A$ in coded units

when A = 1, Y_{ave} = 66
and
when A = -1, Y_{ave} = 60

The rise from –1 to +1 is 6 The run is 2
The slope is 6/2 = 3

The regression coefficients are the factor effects divided by two for a coded design

Finishing the Matrix

	Coded Factors		Interaction		Response
	A	B	AB		Y
	-1	-1	1		48
	1	-1	-1		96
	-1	1	-1		72
	1	1	1		36
Y_{ave} at $FACTOR_{high}$	66	54	42	Grand Mean	63
Y_{ave} at $FACTOR_{low}$	60	72	84		
Effect	6	-18	-42		
Coefficient	3	-9	-21		

$$Y = 63 + 3A - 9B - 21\,AB$$

Verify the equation for the coded A and B values in the matrix

Anexas Consultancy Services

DOE Analysis in Minitab™

Create the Experiment

Create or recall the 2^2 coded design for factors A and B.

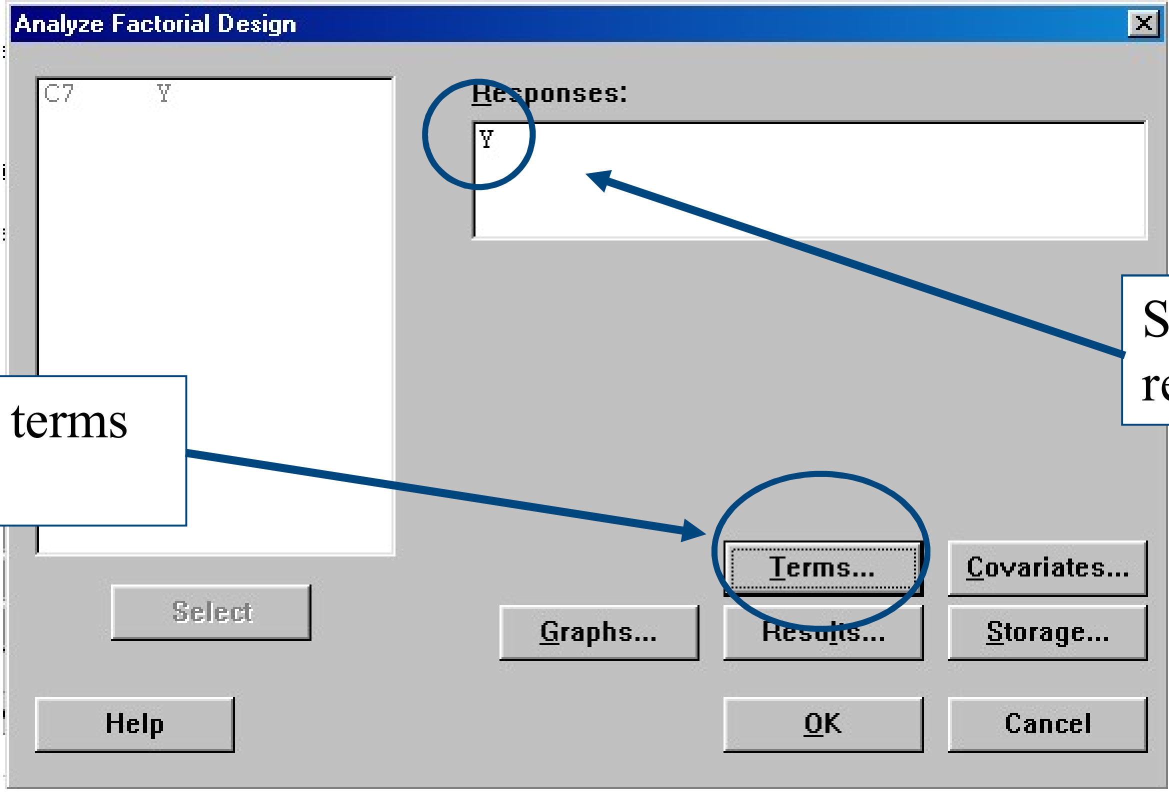
Worksheet 4 ***

↓	C1	C2	C3	C4	C5	C6	C7	C
	StdOrder	RunOrder	CenterPt	Blocks	A	B	Y	
1	1	1	1	1	-1	-1	48	
2	2	2	1	1	1	-1	96	
3	3	3	1	1	-1	1	72	
4	4	4	1	1	1	1	36	
5								

Input the Y response

Setting Up the Analysis

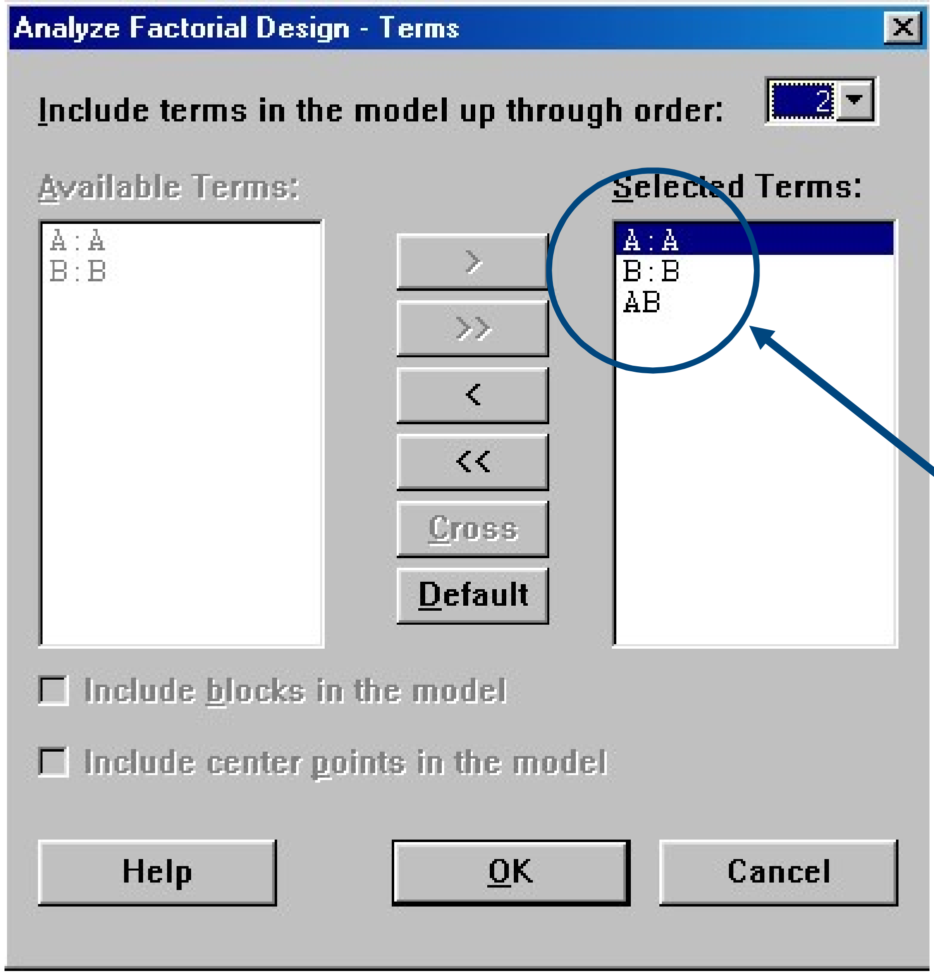
Tool Bar Menu > Stat > DOE > Factorial > Analyze Factorial Design



Select the Y response

Go to terms menu

Selecting Terms



Select all of the available terms note the AB interaction!

The Analysis

Fractional Factorial Fit: Y versus A, B

Estimated Effects and Coefficients for Y (coded units)

Term	Effect	Coef
Constant		63.00
A	6.00	3.00
B	-18.00	-9.00
A*B	-42.00	-21.00

Analysis of Variance for Y (coded units)

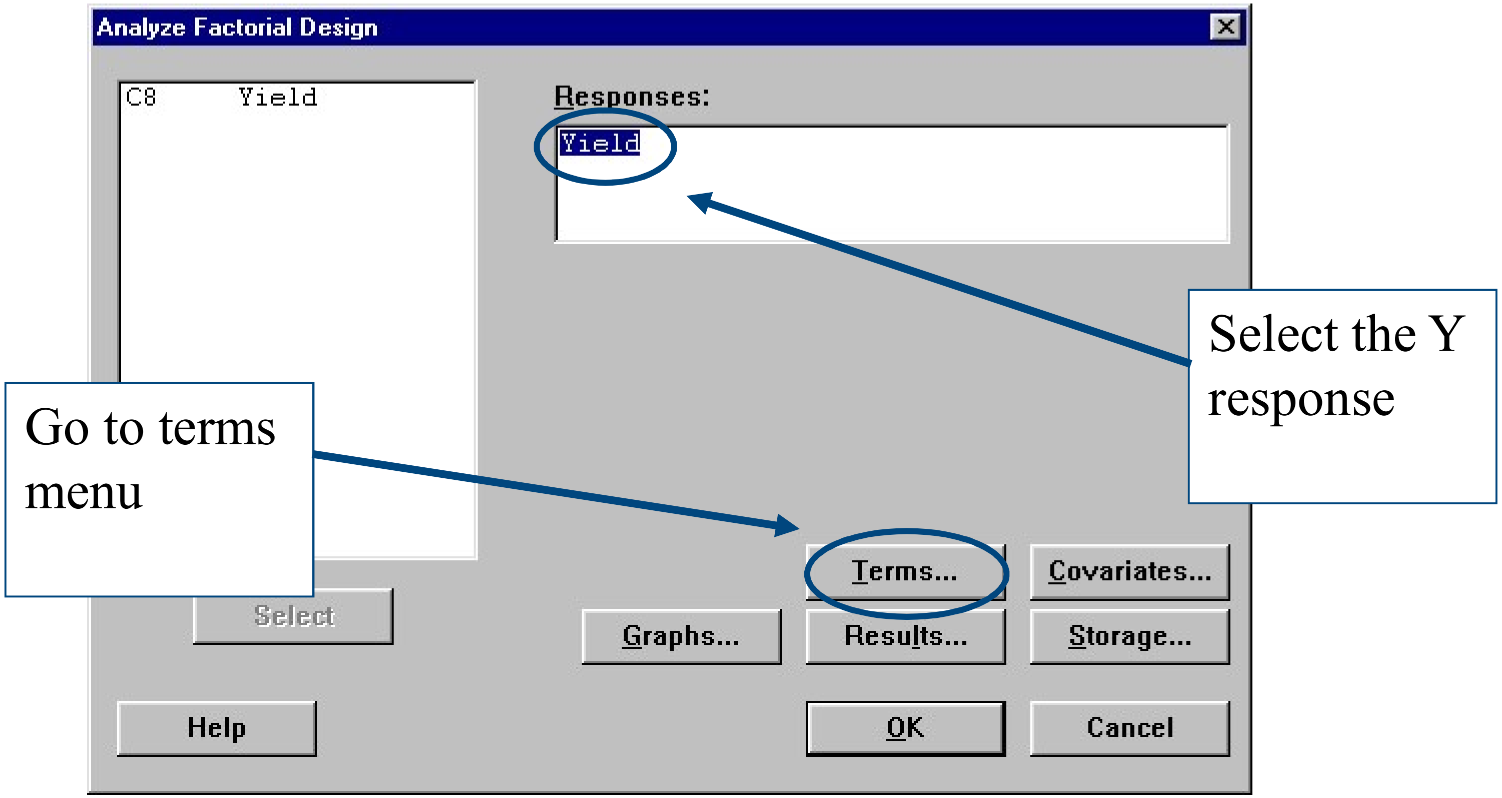
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	2	360.0	360.0	180.0	*	*
2-Way Interactions	1	1764.0	1764.0	1764.0	*	*
Residual Error	0	0.0	0.0	0.0		
Total	3	2124.0				

The coefficients are identical to manual analysis

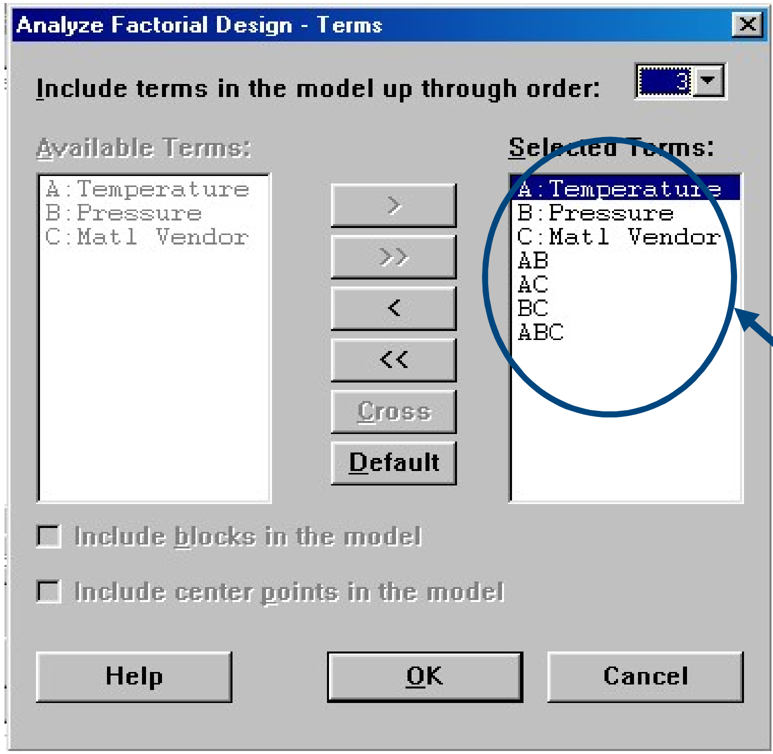
Another Analysis

Tool Bar Menu > Stat > DOE > Factorial > Analyze Factorial Design

Recalling the ***TWO CUBE EXERCISE.MTW*** file



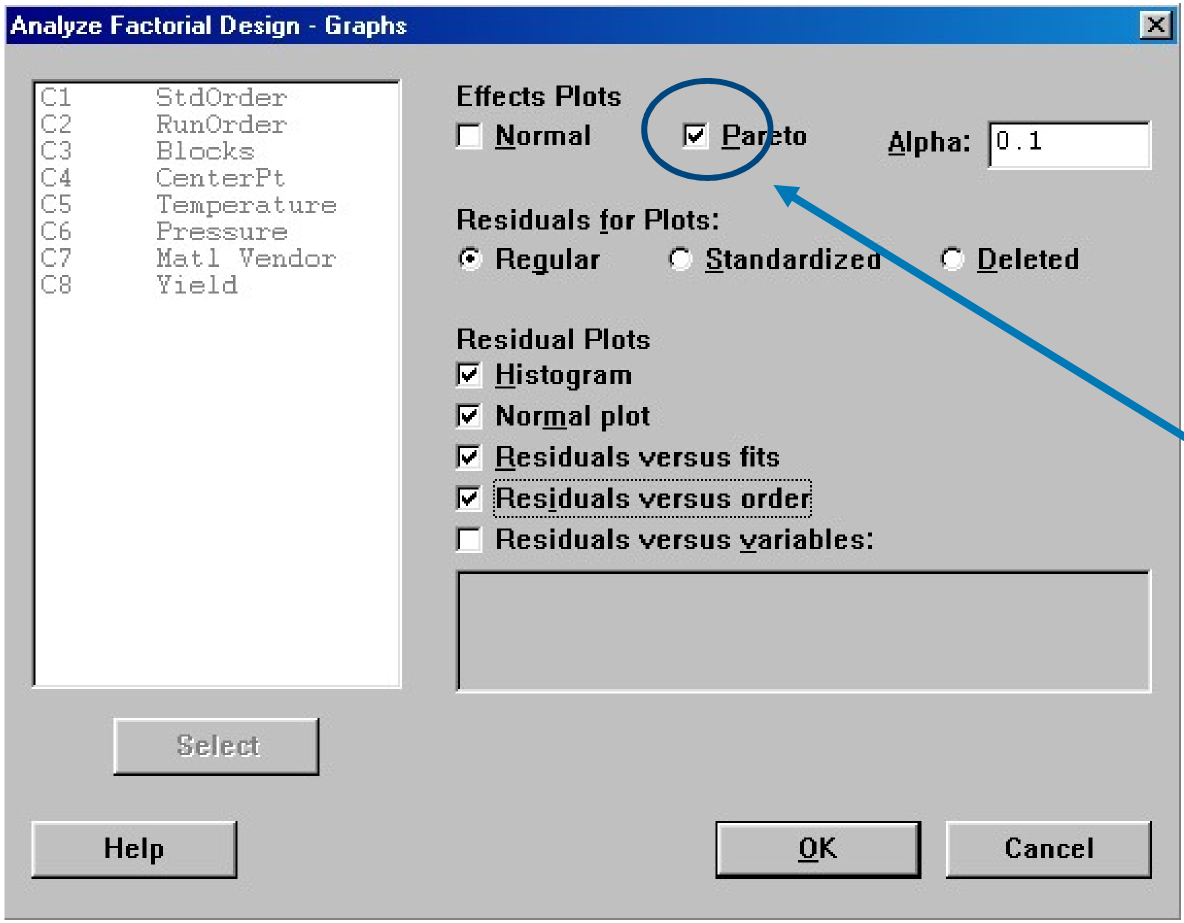
Setting Up the Analysis



Select all of the available terms
note interaction terms

What can be estimated with this model?
How many terms in the prediction equation?

Selecting Graph Options



From the Graphs menu select the graph shown

The ANOVA Results

Results for: TWO CUBE EXERCISE.MTW

Fractional Factorial Fit: Yield versus Temperature, Pressure, ...

Estimated Effects and Coefficients for Yield (coded units)

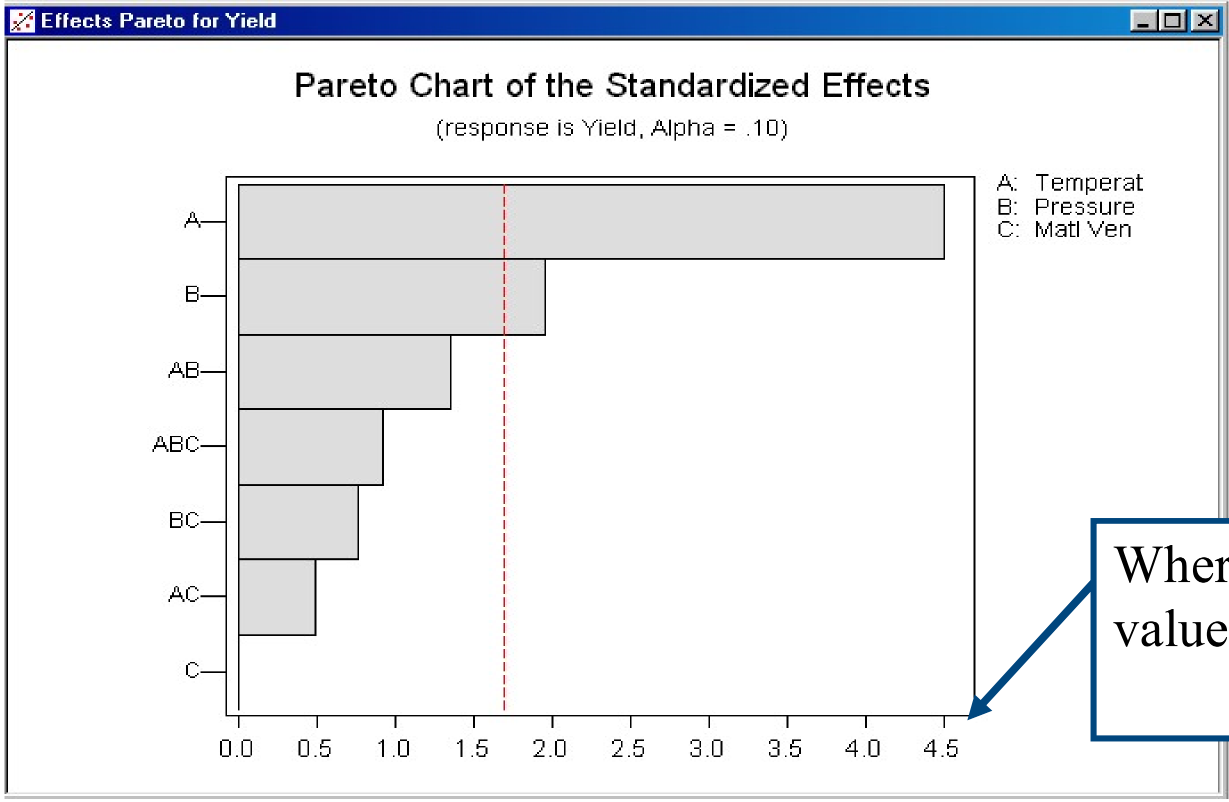
Term	Effect	Coef	SE Coef	T	P
Constant		0.66432	0.01356	49.01	0.000
Temperat	-0.12226	-0.06113	0.01356	-4.51	0.000
Pressure	-0.05303	-0.02651	0.01356	-1.96	0.059
Matl Ven	-0.00000	-0.00000	0.01356	-0.00	1.000
Temperat*Pressure	0.03682	0.01841	0.01356	1.36	0.184
Temperat*Matl Ven	0.01326	0.00663	0.01356	0.49	0.628
Pressure*Matl Ven	-0.02062	-0.01031	0.01356	-0.76	0.452
Temperat*Pressure*Matl Ven	0.02504	0.01252	0.01356	0.92	0.363

Analysis of Variance for Yield (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	0.177592	0.177592	0.059197	8.05	0.000
2-Way Interactions	3	0.019571	0.019571	0.006524	0.89	0.458
3-Way Interactions	1	0.006271	0.006271	0.006271	0.85	0.363
Residual Error	32	0.235199	0.235199	0.007350		
Pure Error	32	0.235199	0.235199	0.007350		
Total	39	0.438632				

The ANOVA Table shows temperature and pressure are significant; regression coefficients are listed

The Pareto of Standardized Effects



Where did the axis values come from?

The Pareto of effects shows the ranking of the variation identified by each source; note the "line of significance"

The Prediction Equation from Minitab™

Term	Effect	Coef
Constant		0.66432
Temperat	-0.12226	-0.06113
Pressure	-0.05303	-0.02651
Matl Ven	-0.00000	-0.00000
Temperat*Pressure	0.03682	0.01841
Temperat*Matl Ven	0.01326	0.00663
Pressure*Matl Ven	-0.02062	-0.01031
Temperat*Pressure*Matl Ven	0.02504	0.01252

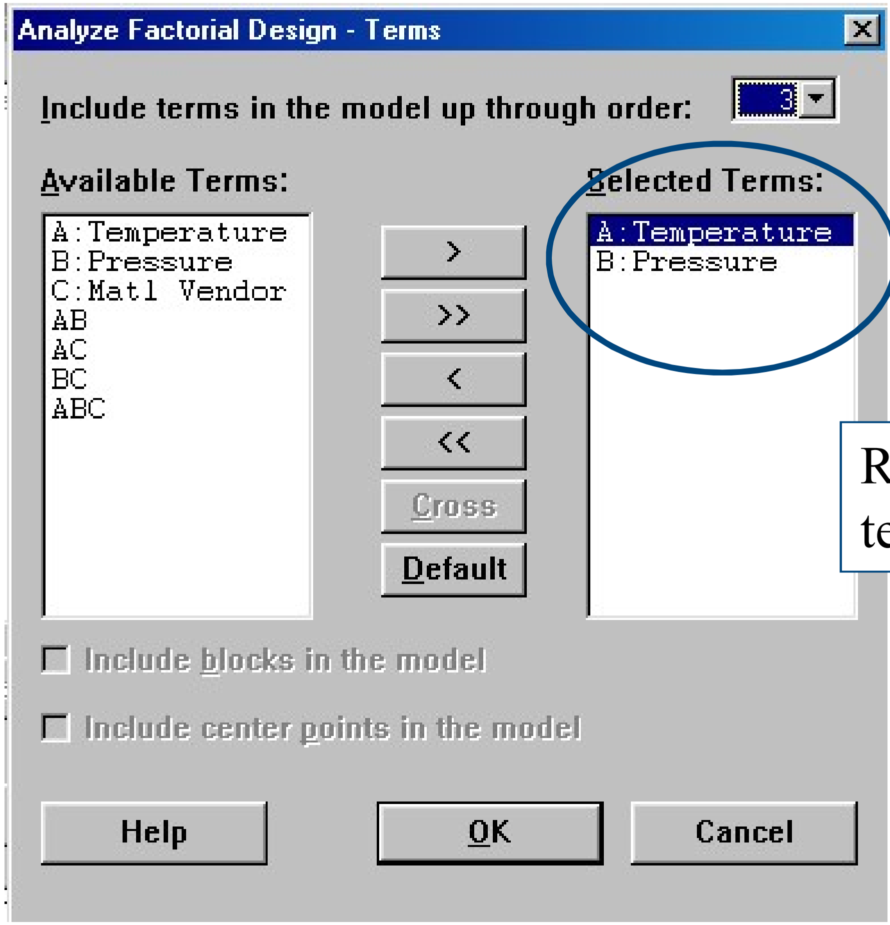
- The ANOVA table coefficients column feeds the prediction equation

$$Y = b0 + b1\ A + b2\ B + b3\ C + b4\ AB + b5\ AC + b6\ BC + b7\ ABC$$

- The ANOVA table p-value column identifies the significant effects, or terms of the regression; to simplify the prediction equation the number of terms must be reduced

Removing Model Terms in Minitab™

Tool Bar Menu > Stat > DOE > Factorial > Analyze Factorial Design > Terms



Remove insignificant terms

Removing Terms Stepwise

- When reducing the regression model do not remove all insignificant terms at once
- Removed terms variance go into error, along with their degrees of freedom
- Significance levels can change as terms are removed.
- Start with higher order terms and remove no more than two at a time.
- Run analysis and check for changes in significance

Re-run Reduced Model in Minitab™

Fractional Factorial Fit: Yield versus Temperature, Pressure

Estimated Effects and Coefficients for Yield (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		0.66432	0.01328	50.02	0.000
Temperat	-0.12226	-0.06113	0.01328	-4.60	0.000
Pressure	-0.05303	-0.02651	0.01328	-2.00	0.053

Analysis of Variance for Yield (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	2	0.17759	0.17759	0.088796	12.59	0.000
Residual Error	37	0.26104	0.26104	0.007055		
Lack of Fit	1	0.01356	0.01356	0.013561	1.97	0.169
Pure Error	36	0.24748	0.24748	0.006874		
Total	39	0.43863				

$$Y = 0.664 - 0.061A - 0.026\ B$$

Where do you set the factors to optimize this process?

Class 2^3 DOE Exercise Part 1

- Your company has a global operation. Times are tough and a restructuring of your world wide product centers is needed. Your team is required to develop the restructuring model based upon three core global business metrics: exchange rate, customs hold time and cross border banking fees. The goal is to find the combination of these criteria that minimizes the variance to the operating plan for the business.
- Exchange rate is felt to be unimportant due to currency stability in the countries you deal in. Cross border fees are a matter of local control and can be greatly reduced by moving cost centers into the countries, thus keeping money transfers to a minimum. The team agrees that the real problem is custom hold time – which can be expedited by additional cost, but will reduce the supply side pressure.
- What do you recommend to the CEO about the importance of exchange rates, cross border fees and custom hold times as she makes her decision - in the next 20 minutes?

Class 2^3 DOE Exercise
Part 2

- Using the file ***TWO CUBED CLASS.XLS***
- Create the design in Minitab
- Import the data from Excel™
- Analyze the factorial plots
- Analyze the ANOVA
- Select significant terms
- Reduce the model
- Determine the final prediction equation
- Optimize the process by selecting factor levels
- Be prepared to present your results

Anexas Consultancy Services

The General Linear Model

Why GLM?

- The General Linear Model
- Allows more flexible design
- Allows multiple levels
- Does not require factors to have same number of levels
- Is well suited for business process problems

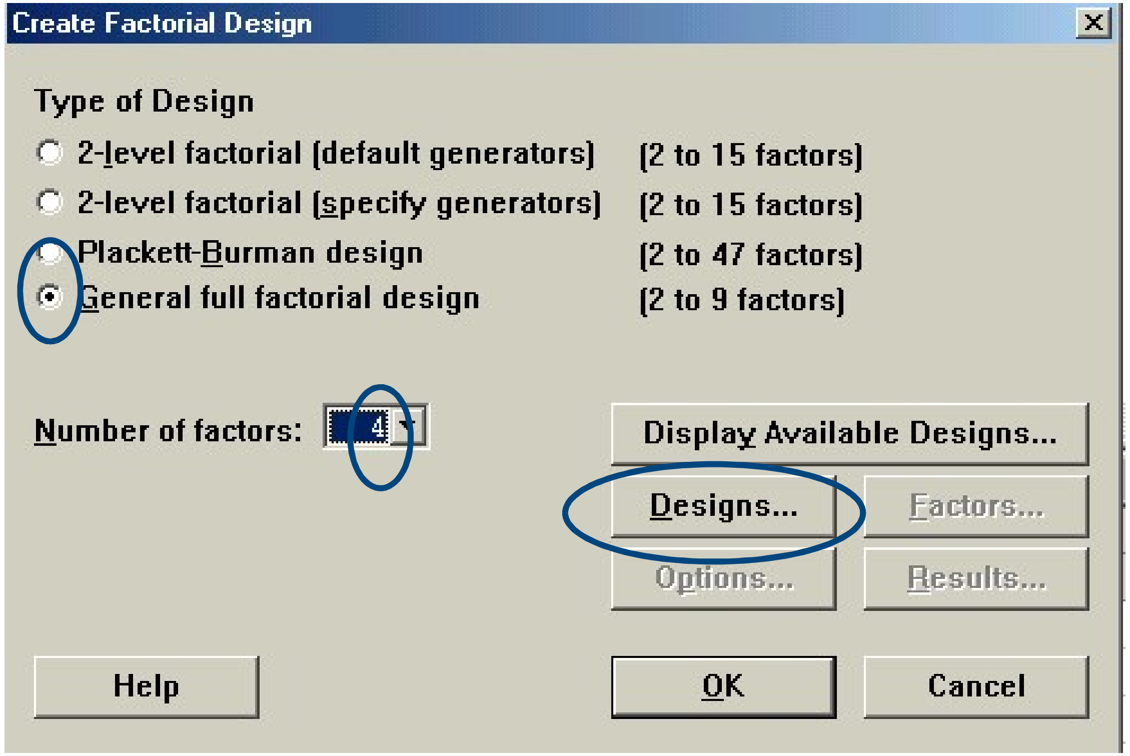
Setting up a GLM Design

- Account receivables lockup, where payments are withheld, is thought to be caused by four factors
- SPAs (Special Pricing Agreements) -4 categories
- Market sector – 3 demographics
- Sales region – 6 regional centers
- Performance to contract – 3 levels

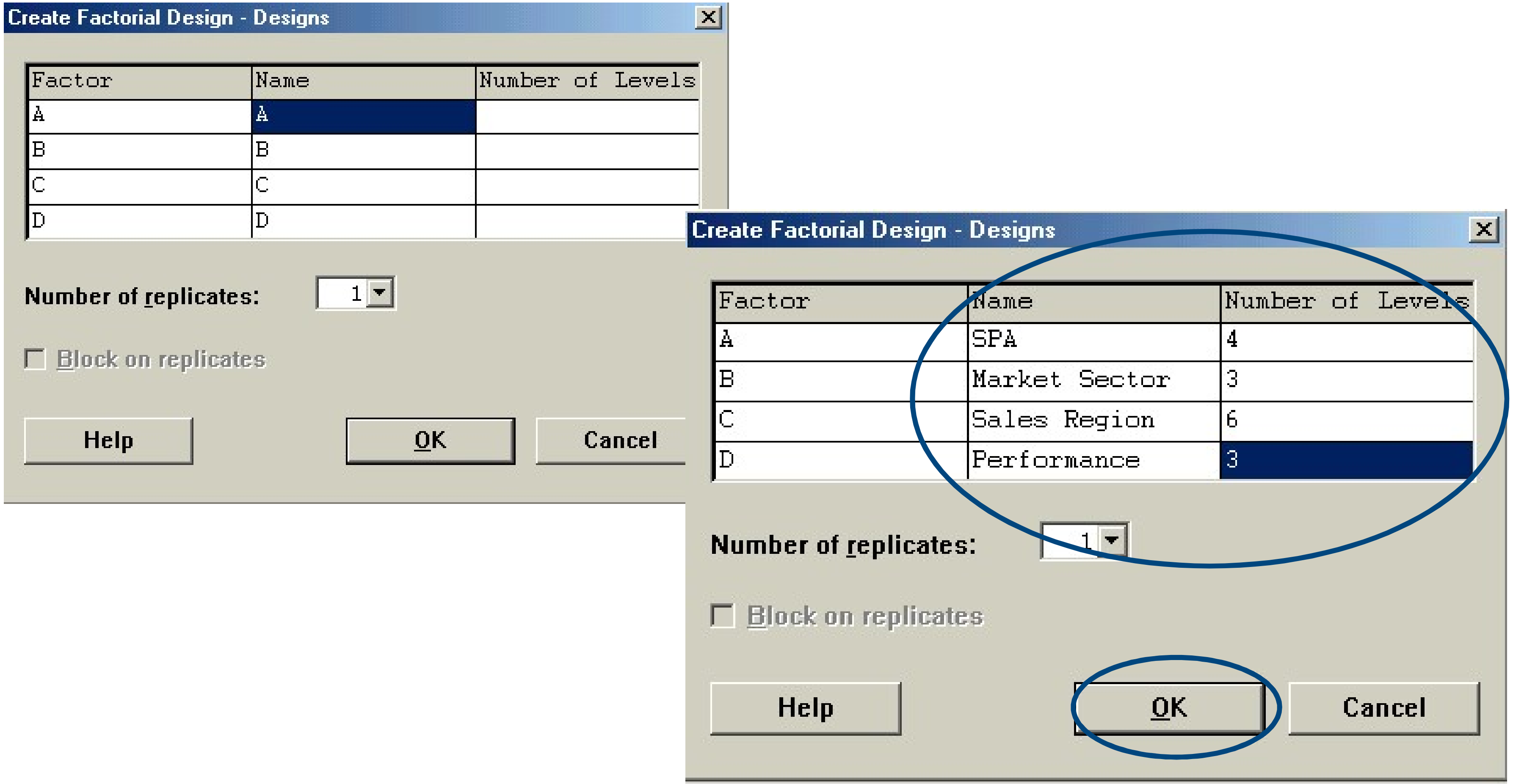
- Design a DOE to study the problem

Setting up GLM

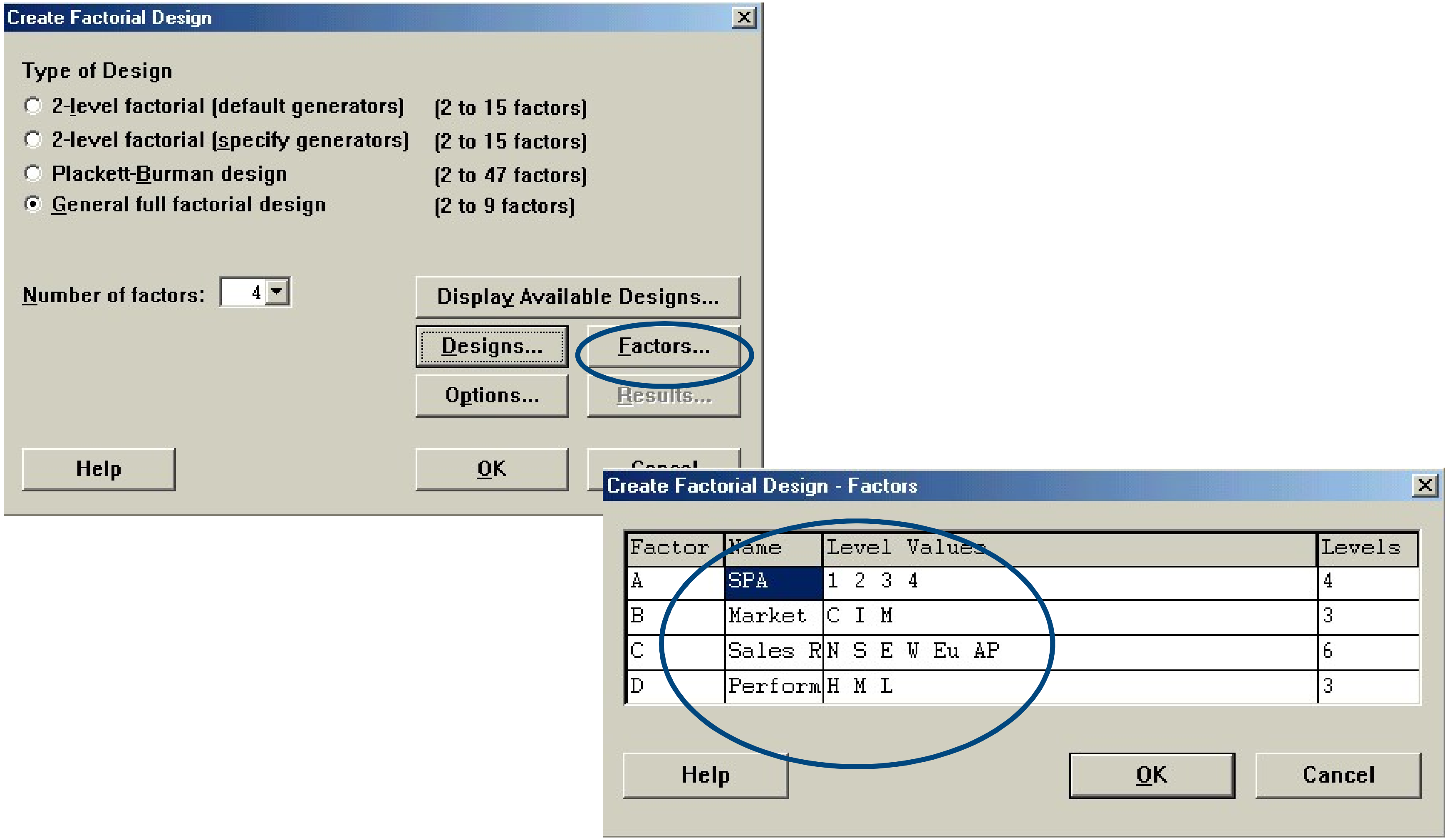
Tool Bar Menu > Stat > DOE > Factorial > Create Factorial Design



Factor Name and Number of Level Assignments



Factor Level Assignments



Options


Create Factorial Designs - Options
Randomize runs
Base for random data generator
Store design in worksheet
Help
OK
Cancel

GLM Generated Worksheet

C1	C2	C3	C4	C5-T	C6-T	C7-T	C8
StdOrder	RunOrder	Blocks	SPA	Market Sector	Sales Region	Performance	AR Held
1	1	1	1	C	N	H	
2	2	1	1	C	N	M	
3	3	1	1	C	N	L	
4	4	1	1	C	S	H	
5	5	1	1	C	S	M	
6	6	1	1	C	S	L	
7	7	1	1	C	E	H	
8	8	1	1	C	E	M	
9	9	1	1	C	E	L	
10	10	1	1	C	W	H	
11	11	1	1	C	W	M	
12	12	1	1	C	W	L	
13	13	1	1	C	Eu	H	
14	14	1	1	C	Eu	M	
15	15	1	1	C	Eu	L	
16	16	1	1	C	AP	H	
17	17	1	1	C	AP	M	
18	18	1	1	C	AP	L	
19	19	1	1	I	N	H	
20	20	1	1	I	N	M	
21	21	1	1	I	N	L	
22	22	1	1	I	S	H	

C1	C2	C3	C4	C5-T	C6-T	C7-T	C8
StdOrder	RunOrder	Blocks	SPA	Market Sector	Sales Region	Performance	AR Held
196	196	1	4	I	AP	H	
197	197	1	4	I	AP	M	
198	198	1	4	I	AP	L	
199	199	1	4	M	N	H	
200	200	1	4	M	N	M	
201	201	1	4	M	N	L	
202	202	1	4	M	S	H	
203	203	1	4	M	S	M	
204	204	1	4	M	S	L	
205	205	1	4	M	E	H	
206	206	1	4	M	E	M	
207	207	1	4	M	E	L	
208	208	1	4	M	W	H	
209	209	1	4	M	W	M	
210	210	1	4	M	W	L	
211	211	1	4	M	Eu	H	
212	212	1	4	M	Eu	M	
213	213	1	4	M	Eu	L	
214	214	1	4	M	AP	H	
215	215	1	4	M	AP	M	
216	216	1	4	M	AP	L	

This is a BIG test – but Minitab easily handles it.

Objectives Review

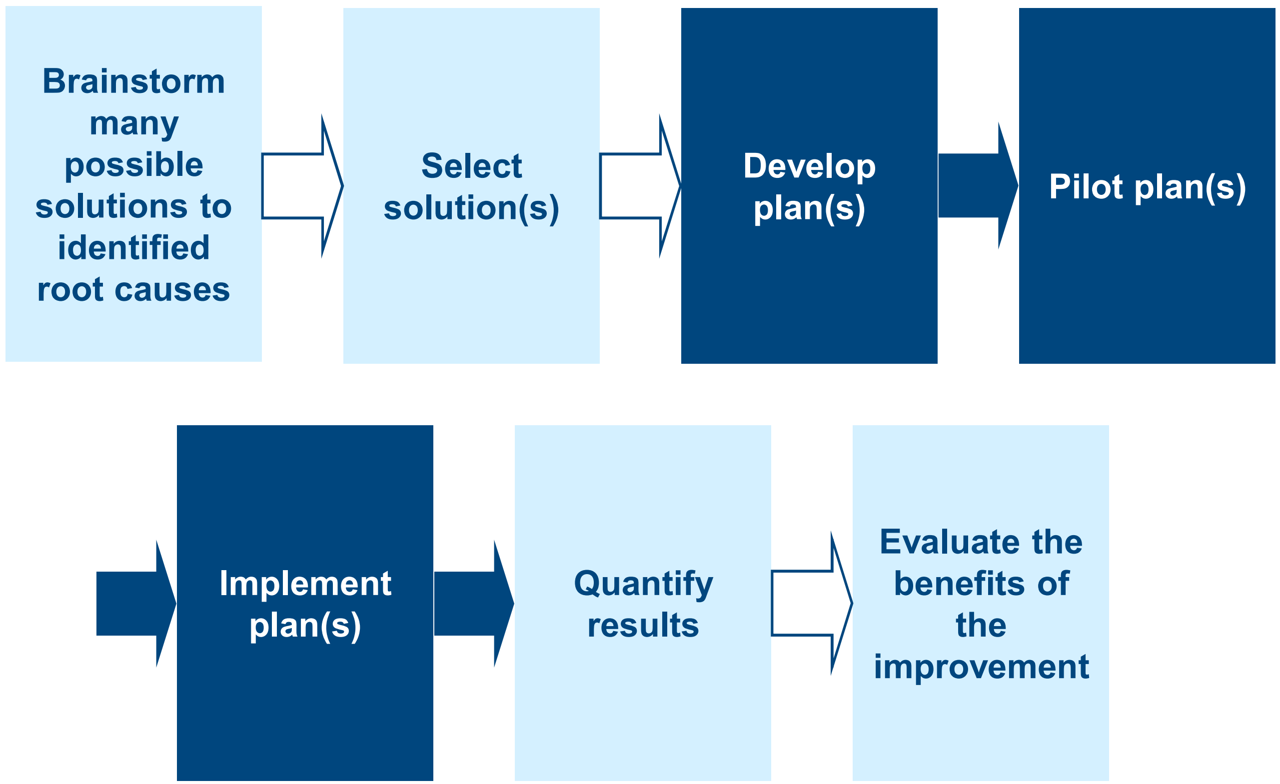
By the end of this module, the participant should:

- Generate a full factorial design
- Look for factor interactions
- Develop coded orthogonal designs
- Write process prediction equations (models)
- Set factors for process optimization
- Create and analyze designs in Minitab™
- Evaluate residuals
- Develop process models from Minitab™ analysis
- Determine sample size

Anexas Consultancy Services

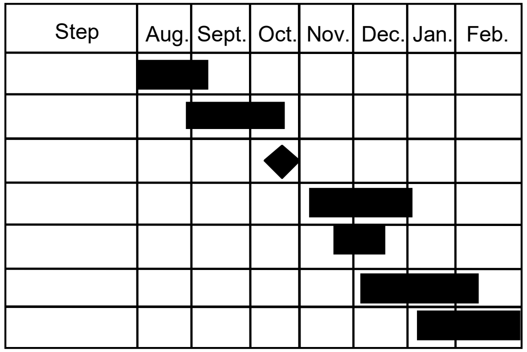
Implementing Solutions

You Are Here


Brainstorm many possible solutions to identified root causes
Select solution(s)
Develop plan(s)
Pilot plan(s)
Implement plan(s)
Quantify results
Evaluate the benefits of the improvement

Elements of a Plan

Tasks and Timeline



Budget and Resources

Expenses

xxxxx	00.00
xxxxx	00.00
xxxxx	00.00

Staff time

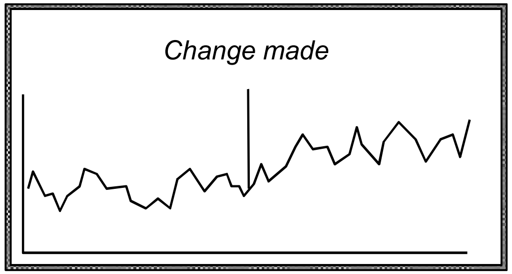
Ted	5 hrs

Stakeholders

PERSON or GROUP	***Communication and Participation***
Finance	
Sales	
IS	

How to Check

PLAN	***ACTUALS***



Potential Problems

Step	***Pot. Failure***	***Pot. Cause***	***Counter-measures***

Anexas Consultancy Services

FMEA

Capturing FMEA Information

FMEA Analysis

Project: ______________________ Team : ______________________

Date ____________ (original)
____________ (revised)

Item or Process Step	Potential Failure Mode	Potential Effect (s) of Failure	Severity	Potential Cause(s)	Occurrence	Current Controls	Detection	RPN	Recommended Action	Responsibility and Target Date	"After" → Action Taken	Severity	Occurrence	Detection	RPN
Total Risk Priority Number =									**"After" Risk Priority Number =**						

Anexas Consultancy Services

Piloting

Benefits of Piloting

- Improved solution
- Improved implementation plan
- Increased buy-in
- Get some of the benefits of the improvement quickly
- Reduced risk of failure or unknown complications
- Ability to confirm assumed cause-and-effect relationships
- Increased ability to quantify costs and benefits
- Overall benefit is a better solution with fewer surprises

Implementing the Plans

Implementation Steps

- Flowchart new procedures if you have not already
- Revise job instructions
- Prepare data collection forms
- Provide training
- Test on a small scale first, if at all possible:
  - Revise procedures based on the test
- Do full-scale implementation
- Monitor the implementation

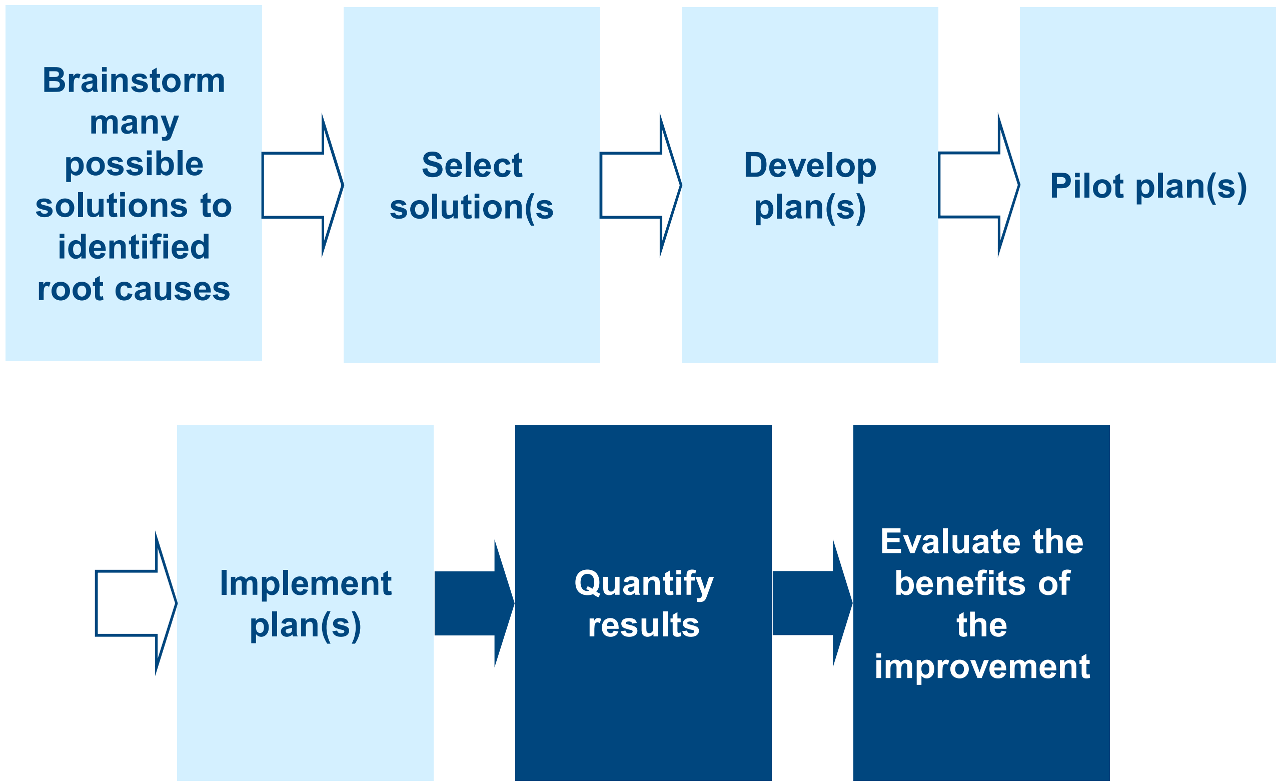
Implementing Solutions: Review

- Prepare detailed plans that include:
  - Tasks and timelines
  - Budgets and resources
  - Stakeholder involvement
  - Plans for checking
  - Failure prevention
  - Implement on small scale first, then move to full scale

Anexas Consultancy Services

Evaluating Results

You Are Here



Brainstorm many possible solutions to identified root causes
Select solution(s
Develop plan(s)
Pilot plan(s)
Implement plan(s)
Quantify results
Evaluate the benefits of the improvement

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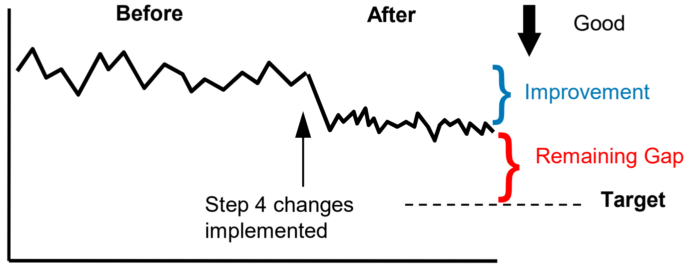
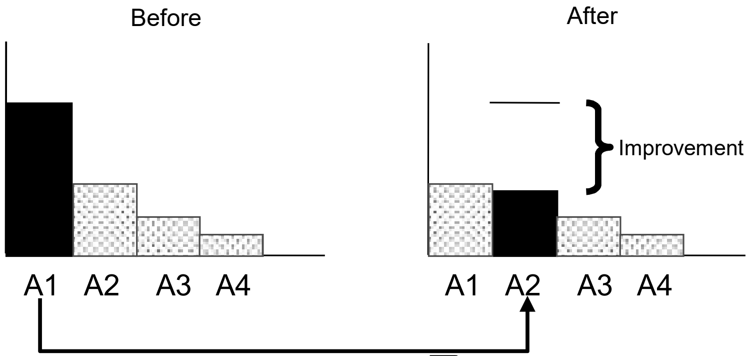
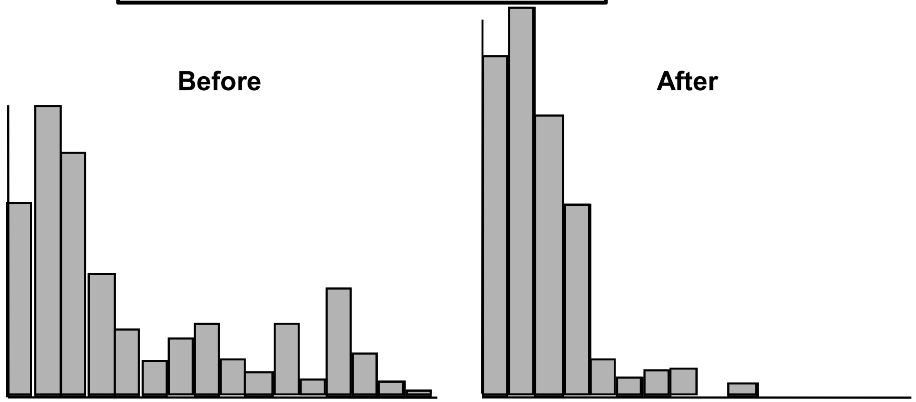
Quantifying Results

Displaying Before and After Data

- Add more data to an existing run chart or control chart
- Prepare new Pareto charts for those you created in MEASURE:
  - Make scale and dimensions the same so you can more accurately judge degree of improvement
- Draw new frequency plots on the same scale as the original plots







Recalculate Process Sigma

Step	Units	Opportunities	BEFORE	AFTER
1	40	2 x 40 = 80	61	17
2	40	1 x 40 = 40	37	1
3	40	3 x 40 = 120	113	12
4	40	1 x 40 = 40	34	0
5	40	4 x 40 = 160	142	8
6	40	1 x 40 = 40	38	0
7	40	2 x 40 = 80	69	3
8	40	4 x 40 = 160	143	37
9	40	1 x 40 = 40	37	0
10	40	2 x 40 = 80	64	5
11	40	2 x 40 = 80	72	2
12	40	1 x 40 = 40	35	1
		960	**846**	**86**

BEFORE

Yield $= 1 - \frac{846}{960}$

$= 1 - .88$

= 12%

Sigma = 0.3

AFTER

Yield $= 1 - \frac{86}{960}$

$= 1 - .09$

= 91%

Sigma = 2.8

Financial Results

- Estimate the financial benefits of the project:
  - Cost/benefit ratio
  - Payback cycle time
- Order-of-magnitude estimates usually enough:
  - Benefits of scrap or rework reduction are straightforward
  - Benefits of cycle time reduction, etc. are more difficult to quantify
- Consult with the Financial Controller to validate the estimate

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IMPROVE: Implement Solutions and Evaluate Results

Review

You Were Here—IMPROVE

IMPROVE Phase Deliverables

- List of potential improvements
- Optimum solutions identified and selected
- Proof of impact of solutions
- Failure mode effects analysis (FMEA)
- Cost benefit analysis
- Before versus after analysis
- Revised process map
- Implementation plan

IMPROVE Phase Deliverables, cont.

- Revised stakeholder matrix and communication plan
- IMPROVE section of storyboard completed
- IMPROVE phase discussed and agreed with sponsor and coach
- IMPROVE deliverables completed and phase approved

IMPROVE Checklist

- By the end of the IMPROVE phase, you should be able to answer the following questions. Please check!:
  - What solutions have you identified? How do they affect the root causes?
  - What criteria have you used to select a solution?
    - This includes criteria such as how the solution was linked to the verified root cause(s) identified in the ANALYZE phase
  - How do the various alternatives score against those criteria?
  - What are the results of designed experiments (if applicable) to find optimal settings?
  - How have you tested the solutions, and what were the results of these tests?
  - How do timing and results compare to plans and expected results?

IMPROVE Checklist, cont.

- By the end of the IMPROVE phase, you should be able to answer the following questions. Please check!, cont.:
  - What is your plan for detailed implementation, including training?
  - What process/areas are to be improved? Who are the process owners? Who else is affected?
  - What is the data showing about the solution's effectiveness?
  - What is the actual benefit? Was it calculated and approved by finance?
  - Is additional work required to refine the solution, such as collecting additional data, revisiting an earlier step, etc.?
  - Why are you confident that the current solution should be standardized?

You Are Here—CONTROL

CONTROL: Standardize and Make Future Plans

- **Goal:**
  - Maintain the gains by standardizing work methods or processes
  - Anticipate future improvements and preserve the lessons from this effort

- **Output:**
  - Documentation of the new method
  - Training in the new method
  - A system for monitoring its consistent use and for checking the results
  - Completed documentation and communication of results, learnings, and recommendations

Approach to CONTROL

Develop and document standard practices → Train → Ongoing monitoring → Build process for updating procedures → Summarize and communi-cate learnings → Make recommen-dations for future plans

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Standardization: Methods and Training

You Are Here

Develop and document standard practices → **Train** → Ongoing monitoring → Build process for updating procedures → Summarize and communicate learnings → Make recommen-dations for future plans

What Is Standardized Work?

- Standardized work is the most efficient and effective combination of people, material, and equipment that is presently possible:
  - Sets the baseline, which allows:
    - Measurement of performance
    - Identification of improvements
    - Assessment of changes

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Training

Training

- When you have completed the documentation, you need to make sure that everyone using the process is trained in the new methods
- Even experienced employees need to be trained in the new methods

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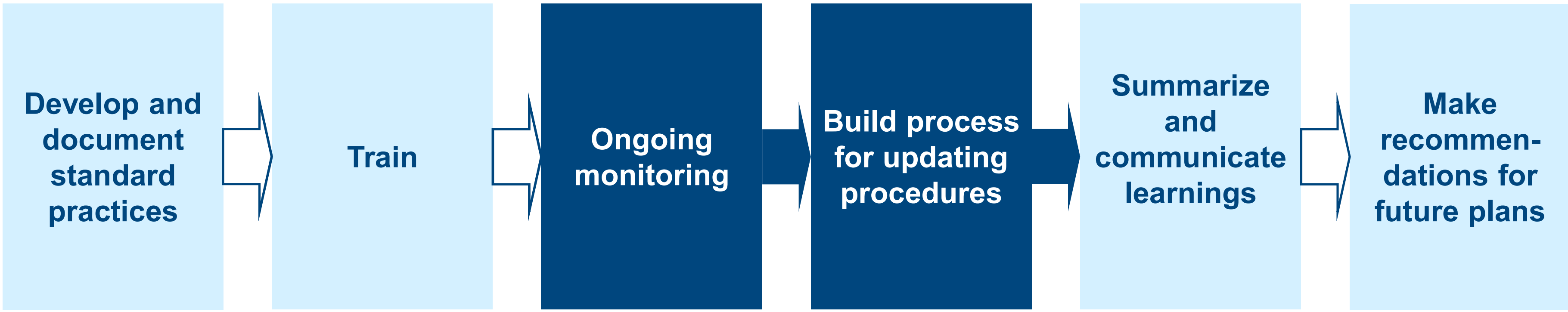
Process Monitoring and Control

You Are Here


Develop and document standard practices
Train
Ongoing monitoring
Build process for updating procedures
Summarize and communicate learnings
Make recommen-dations for future plans

Goals

- Understand what is meant by the term process management
- Create a process management chart using the process management chart format
- Understand what is meant by the term visual controls
- Match the following charts with situations in which each is most appropriate: Xbar, R-chart, pchart, npchart, cchart, and uchart
- Apply control charts to the monitoring plan for your project

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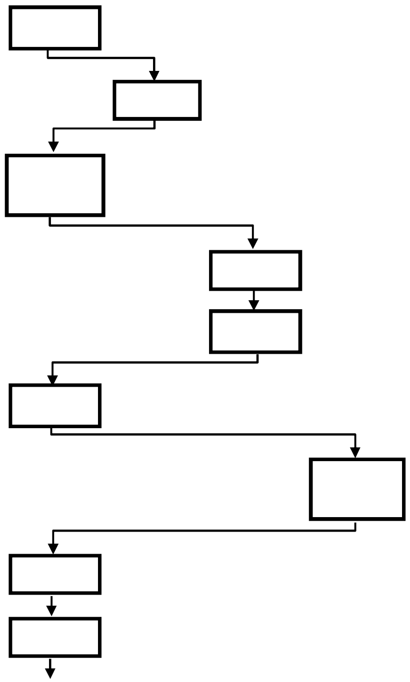
Methods for Monitoring and Control

Process Management Chart Definition

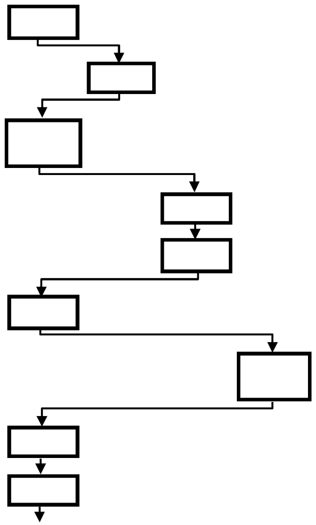
- Process management charts are tools that help you document PDCA for your process

PLAN/DO	CHECK	ACT
Process Map	**Indicators**	**Corrective Actions**
	Plot time on each order; should be ≤ 2 hours; check for special causes Count errors	If time exceeds 2 hours, alert Sam immediately; organize investigation If more than 1 per order, stop process, contact Sam

Process Management Chart Features

The plan is typically captured as a process map.

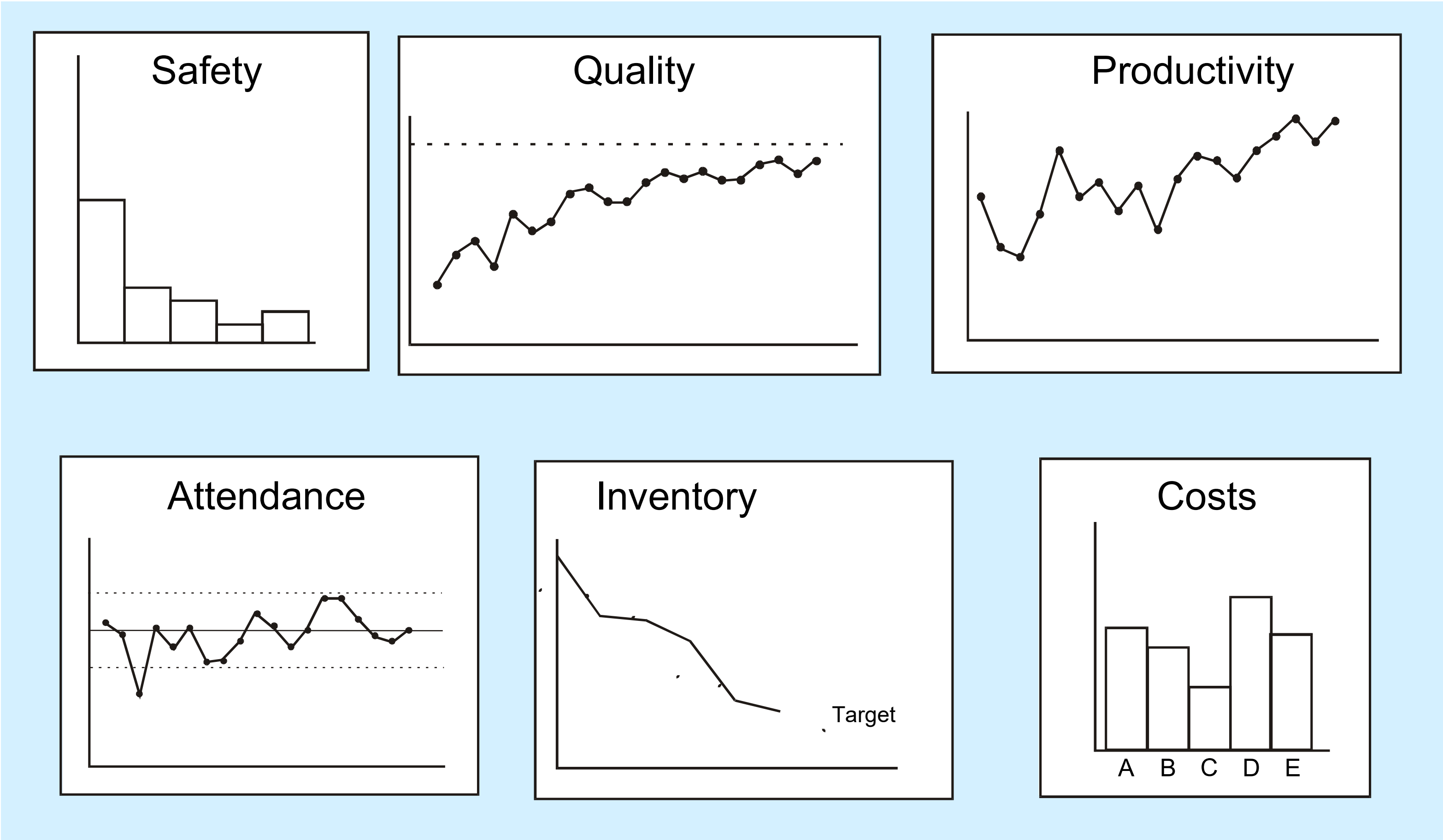
The middle column describes what you will check in the process to monitor its quality.

PLAN/DO	CHECK	ACT
Process Map	**Indicators**	**Corrective Actions**
	*Plot time on each order; should be ≤ 2 hours; check for special causes*	*Alert Sam immediately; organize investigation*
	Count errors	*If more than 1 per order, stop process, contact Sam*

The third column describes how the process operators should react depending on what they find in the measures.

Visual Controls: Communication Board

Visual Controls



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Ongoing Data Collection and Process Control

Ongoing Data Collection

- Monitor your process through ongoing data collection
- Use control charts to plot the data and identify signals of special causes
- Use special cause and common cause thinking to reduce variation

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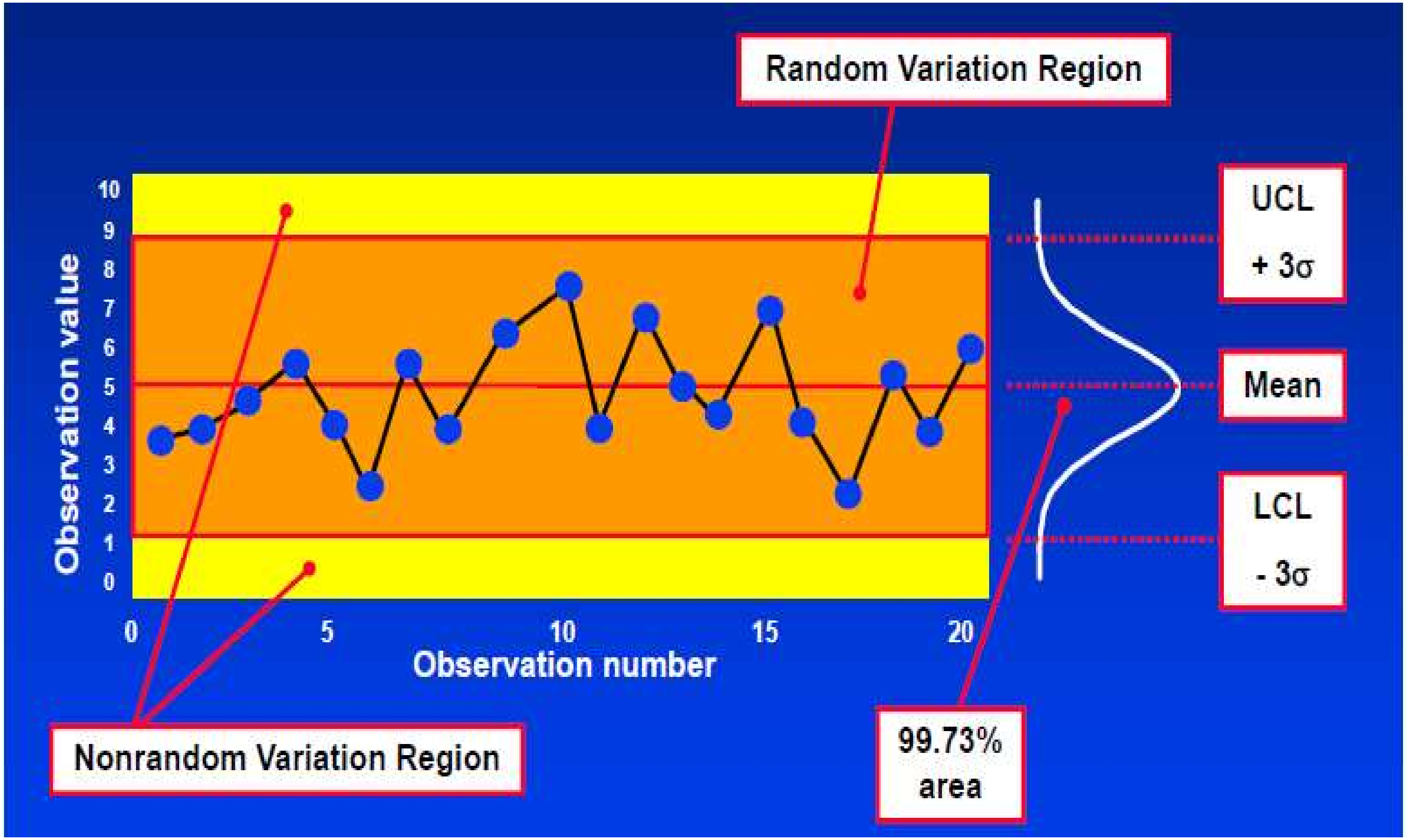
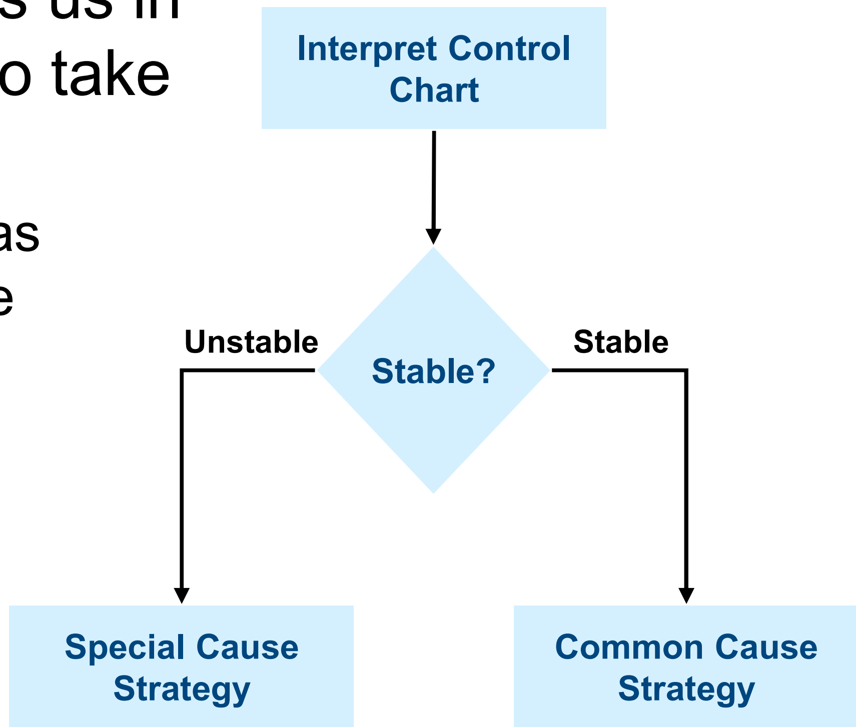
Control Charts

Statistics of a Control Chart



Responding to Control Charts

- Appropriate managerial actions are quite different for common causes than for special causes
- Control charts help us determine if we have special or common causes, which guides us in selecting what type of action to take and when:
  - The choice is an important one as inappropriate actions often make things worse; at the very least, they waste time, resources, and money

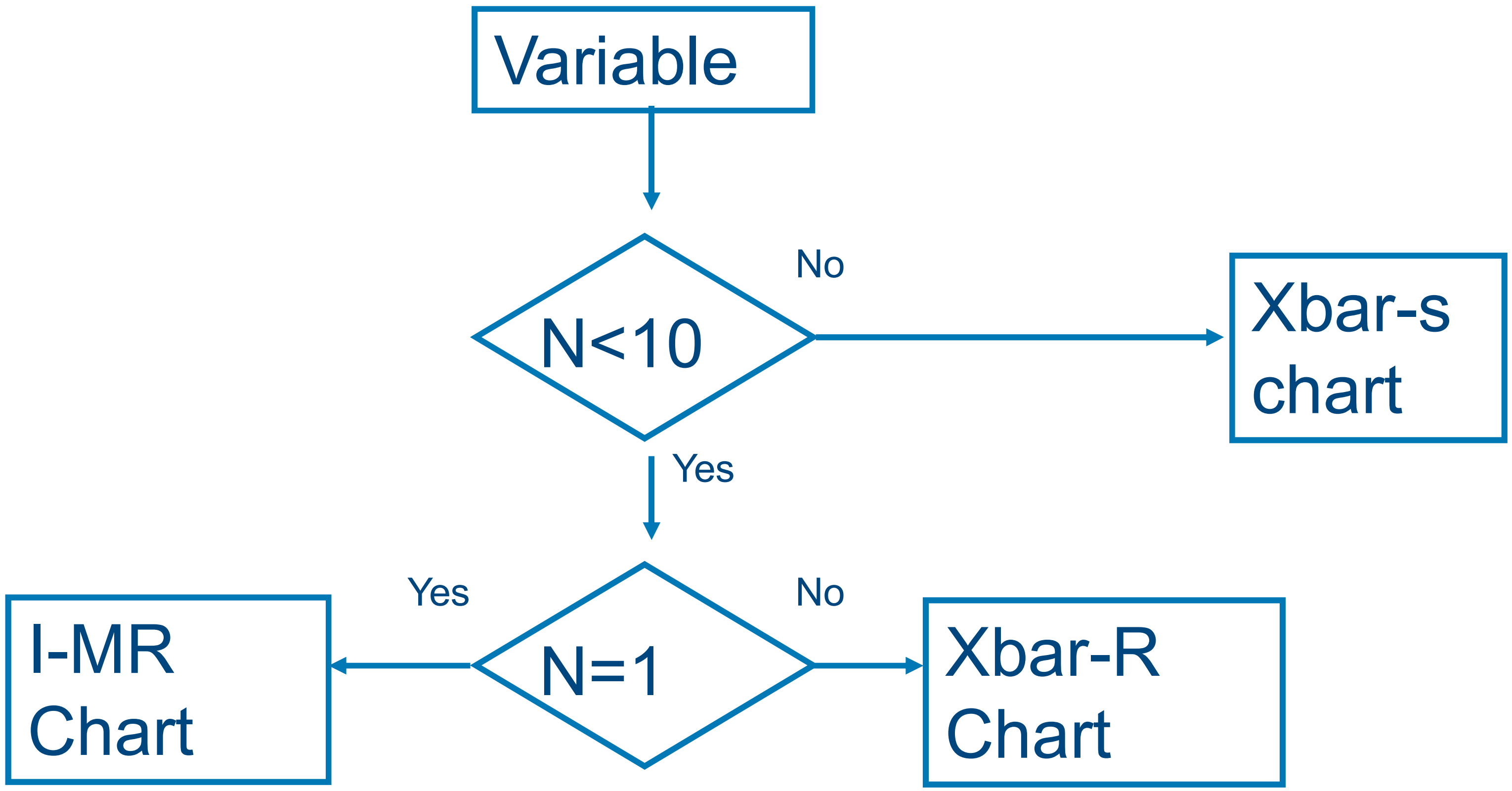


Consequences of Actions Taken in Response to Control Charts

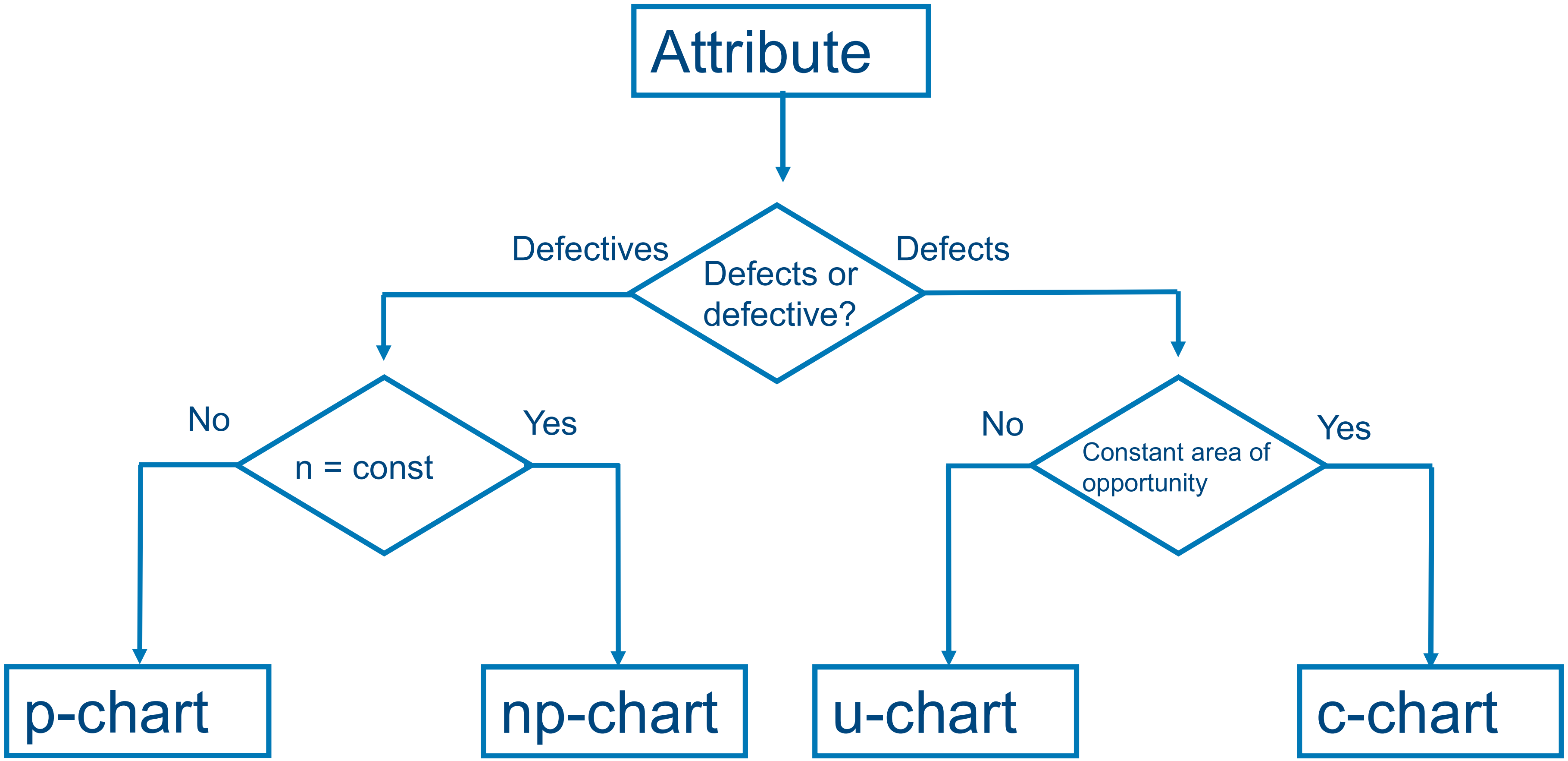
Type of Action

		Special Cause		**Common Cause**	
		Look for what was different between individual points	Take action based on the reported difference	Study all the data	Make basic changes to the process
Type of Variation	Common Cause	Waste time	Increase variation	Gain a better understanding of the system	Reduce variation
	Special Cause	Gain useful information	Reduce variation	Lose time in responding to the problem	Loss of productivity, may increase variation

Control Chart Roadmap



Control Chart Roadmap



Constructing Control Charts for Discrete Data

Chart	Control Limit Calculations
p -chart	$\bar{p} \pm 3\sqrt{\frac{\bar{p}(1\ \bar{p})}{n}}$
np-chart	$n\bar{p} \pm 3\sqrt{n\bar{p}(1\ \bar{p})}$
c-chart	$\bar{c} \pm 3\sqrt{\bar{c}}$
u-chart	$\bar{u} \pm 3\sqrt{\frac{\bar{u}}{a}}$

- More information on how to calculate the limits by hand is beyond the scope of Green Belt Training
- We will use Minitab to construct the charts and obtain the control limits

Summary of Assumptions for Control Charts, cont.

- **Binomial distribution:**
  - The term “binomial” derives from the fact that any given item either will or will not have the attribute being studied—so there are only two possible outcomes for each item (yes, it has the attribute, or no it does not): Yes/No an item is defective or Yes/No a sale was lost:
    - The binomial distribution describes the probability that a given number of items from the population will possess a given attribute (such as a defect) when the overall proportion of the population with the attribute is described by p:
      - A binomial distribution may or may not be symmetrical
      - To use a binomial distribution, you need to be able to count both occurrences (Yes) and non occurrences (No)
    - When the binomial assumption holds, the p chart is preferred
    - If the binomial assumption does not hold, use an individuals chart on percentages

Summary of Assumptions for Control Charts, cont.

- **Poisson distribution:**
  - When you can count occurrences but not non occurrences (such as counting the number of computer outages) and the probability of occurrence is relatively rare, your data are more likely to follow a Poisson distribution
  - A good rule of thumb is that an occurrence is rare if it is likely to occur less than 10% of the time
  - If the probability of occurrence is high, treat the data like individual data points and create an individuals chart based on the Normal distribution assumptions:
    - When the Poisson assumption holds, the c chart is preferred
    - If the Poisson assumption does not hold, use an individuals chart of counts

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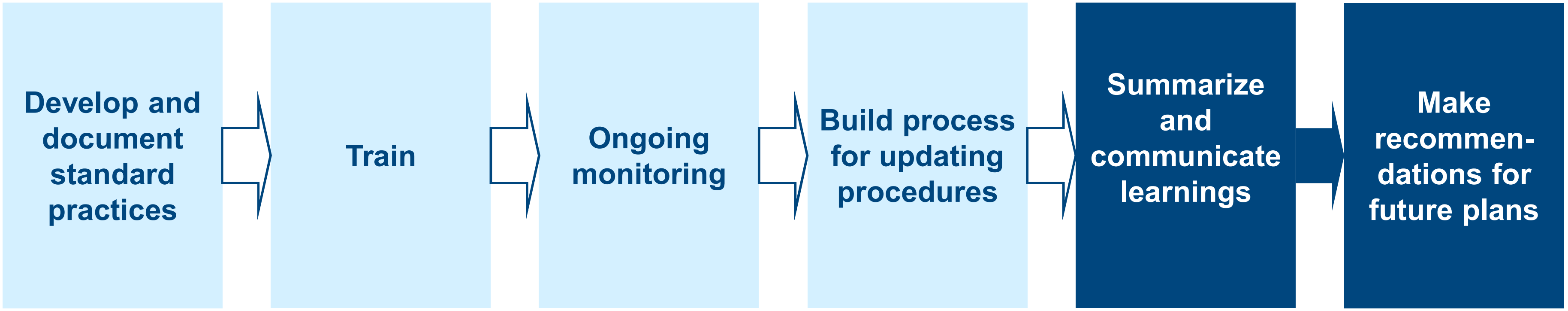
Communication and Future Plans

You Are Here


Develop and document standard practices
Train
Ongoing monitoring
Build process for updating procedures
Summarize and communicate learnings
Make recommen-dations for future plans

Goal

- Identify ways to bring a project to closure in your own organization

Importance of Closure

- Recognize the considerable time and effort that went into the initiative
- Capture the learnings from the initiative:
  - About the problem or process being studied
  - About the improvement process itself
- Hand over responsibilities for standardization and monitoring to the appropriate people

Project Closure

- Improvement must be continuous, but individual initiatives and project teams come to an end
- Learn when it is time to say good-bye
- Effective project closure weaves together the themes of:
  - Project purpose
  - Improvement methods
  - Team skills and structures
- Develop managerial systems to capture learnings and enable the organization to address system issues
- Documentation and recognition are two critical aspects of project team closure

Exercise: Closure

Objective: Build awareness of how to successfully bring a project to a close

Instructions:

- Work in pairs or small groups to answer the following questions:
  - What would indicate that a team had ended well? What would indicate that a team had not formally closed or had not done it well? Explain
  - Think of teams that have completed their work—what methods of closure were used by these teams? How effective were they? How do you know?
- Be prepared to share your answers with the whole group

Time: 10 minutes

Closure Checklist

1. Avoid needless continuation
2. Summarize learnings:
   - About the work process
   - About the team's process
   - About your results
3. Finalize documentation on improvements
4. Summarize future plans and recommendations
5. Communicate the ending
6. Celebrate

1. Avoiding Needless Continuation

2. Summarizing Learnings

- About your results
- About the work process
- About the team's process

3. Finalize Documentation on Improvements

- Finish your storyboard:
  - It should contain your final results and conclusions
- Present the completed document to:
  - The sponsors
  - The people whose jobs are changing as a result of the work
  - Customers of the change
  - Other interested people
  - Collect, catalog, and make the documentation available to others

4. Summarize Future Plans and Recommendations

- Have your team discuss the following issues and compile recommendations that you submit to your sponsor or guidance team:
  - What are your recommendations for maintaining the gains already put in place? What role would you like your team to play?
  - How much improvement is still needed to achieve the business goals?
  - What portions of the problem are still left to address? Which of these are the most urgent to address?
  - What would you and your team like to work on next, if approved by management? Where do you think management should devote resources next?

5. Communicate the Ending

- Communicating the team's results is a joint task for the project team and its sponsor or guidance team:
  - If not done already, identify the people who will be involved in implementing the improved methods
  - Which employees could benefit from your lessons learned?
  - How can you communicate to management? To the rest of the organization?
  - How can the end of this project sow the seeds for future projects?

6. Celebration and Recognition

- What is the appropriate way to celebrate this closure (lunch/dinner/dessert)?
- How will you say good-bye?

6. Celebration and Recognition, cont.

- Recognition is an important aspect of celebration and should reinforce intrinsic sources of satisfaction and motivation:
  - Examples:
    - A small souvenir related to the project work
    - A pizza lunch for everyone who was involved in the initiative, including those whose jobs have changed as a result of the initiative

Exercise: Closure in Your Organization

Objective: Understand what parts of closure may be most challenging in your organization

Instructions:

- Work alone or in small groups
- Review at least one of the closure checklist items and discuss how it would work in your organization
- Be prepared to discuss your results with the whole group

Time: 10 minutes

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CONTROL: Standardize and Make Future Plans

Review

You Were Here—CONTROL

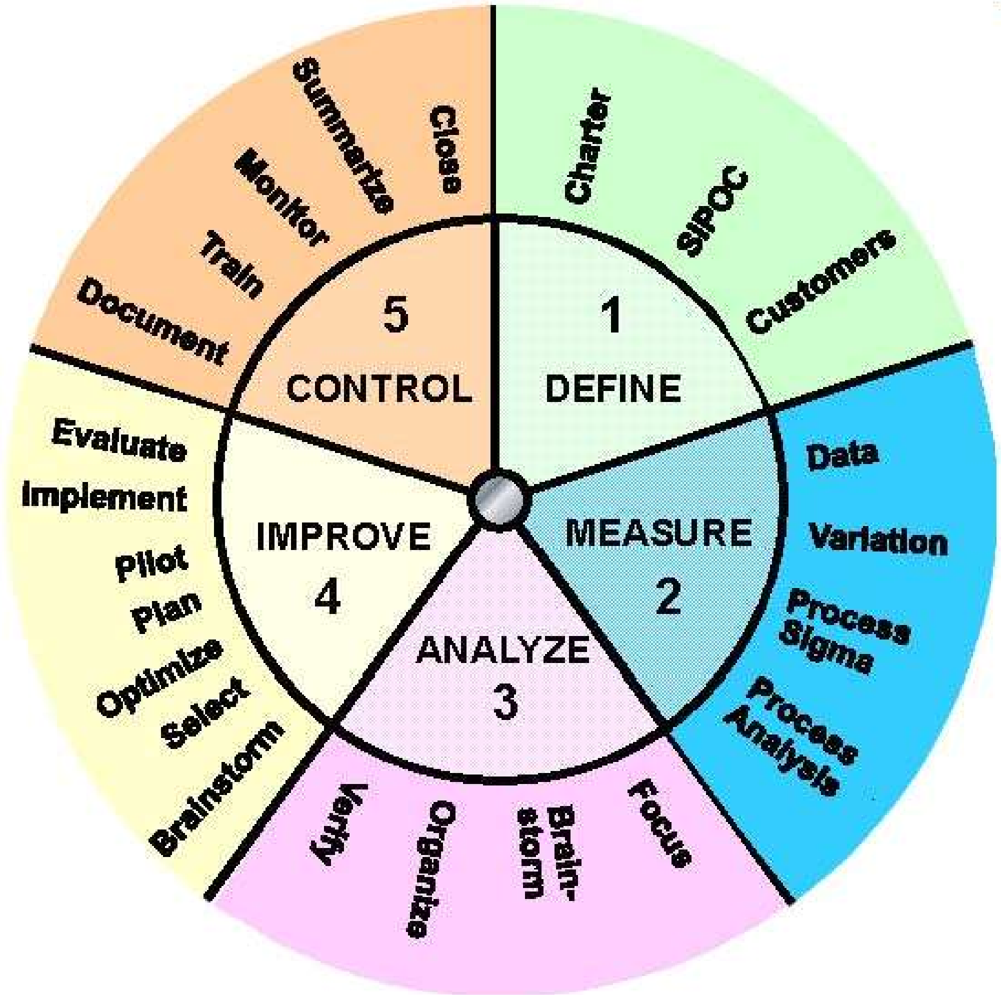
CONTROL Phase Deliverables

- All **standard documentation**, policies and procedures, role profiles, performance management, training, etc., updated to standardize and integrate improved process
- **Monitoring and controls** identified to sustain improved performance
- Controls documented in control and reaction plan
- **Final project report** completed
- **Post closure audit plan** (if required)
- Storyboard completed
- Project discussed and sign off agreed with sponsor, coach, and process owner
- CONTROL deliverables completed, phase and project closure approved
- Project handed over to process owner

CONTROL Checklist

- By the end of CONTROL, you should be able to demonstrate to your sponsor that everyone involved in the process is consistently using new methods designed to eliminate/minimize problems identified back in MEASURE:
  – Your sponsor may be interested in seeing:
    - Documentation of the new methods, and examples of how they are used (Standard Practice Worksheet, One-Point Lesson)
    - Examples of self-audits or other checks done to monitor implementation
    - Control charts regularly updated with new data and showing that process performance is within control limits (only common cause variation is present)
    - Method of ongoing control and acceptance of ownership by process owner
    - Recommendations (supported by data, if possible) for next actions involving this process or ideas for a spin-off from this project
    - Completed project documentation (include a final storyboard that shows the results of your data analysis)
    - Plans for (or results from) communicating achievements to the organization
    - Potential replication of solutions found to other similar lines/processes
    - Plans for celebrating your success

DMAIC REVIEW



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Thank You!

- Please write to Anexas Team at enquiry@anexas.net for any queries
- Anexas website: www.anexas.net

Thank You!

- Congratulations on completing a milestone in your life!
- Best wishes for your Lean and Six Sigma journey!

- Amitabh Saxena

CEO

Anexas Europe