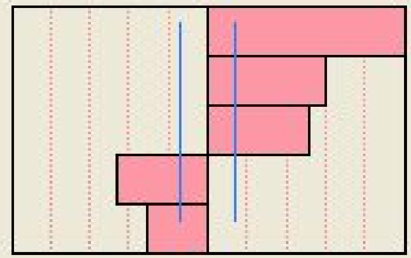
JMP DOE Design *(Cont.)*

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Cat(1,2)	10.25	0.662618	15.47	<.0001*
Temp(140,180)	6.125	0.662618	9.24	<.0001*
Cat*Temp	5.375	0.662618	8.11	<.0001*
Temp*Conc	-4.75	0.662618	-7.17	<.0001*
Conc(3,6)	-3.125	0.662618	-4.72	0.0008*



- **Sorted Estimates** summarizes the model and its effect on the response.
- You can go directly to this output and see the relative effect of the model terms with the model coefficients listed and the corresponding p-values.
- Question: For Conc (3,6), what does -3.125 mean practically? (See the Prediction Profile Graph).

JMP DOE Design *(Cont.)*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	65.25	0.662618	98.47	<.0001*
Cat(1,2)	10.25	0.662618	15.47	<.0001*
Temp(140,180)	6.125	0.662618	9.24	<.0001*
Conc(3,6)	-3.125	0.662618	-4.72	0.0008*
Cat*Temp	5.375	0.662618	8.11	<.0001*
Temp*Conc	-4.75	0.662618	-7.17	<.0001*

Prediction Formula:

Reacted (%) = 65.25 + 10.25(Cat) + 6.125(Temp) – 3.125(Conc) + 5.375(Cat)(Temp) – 4.75(Temp)(Conc)

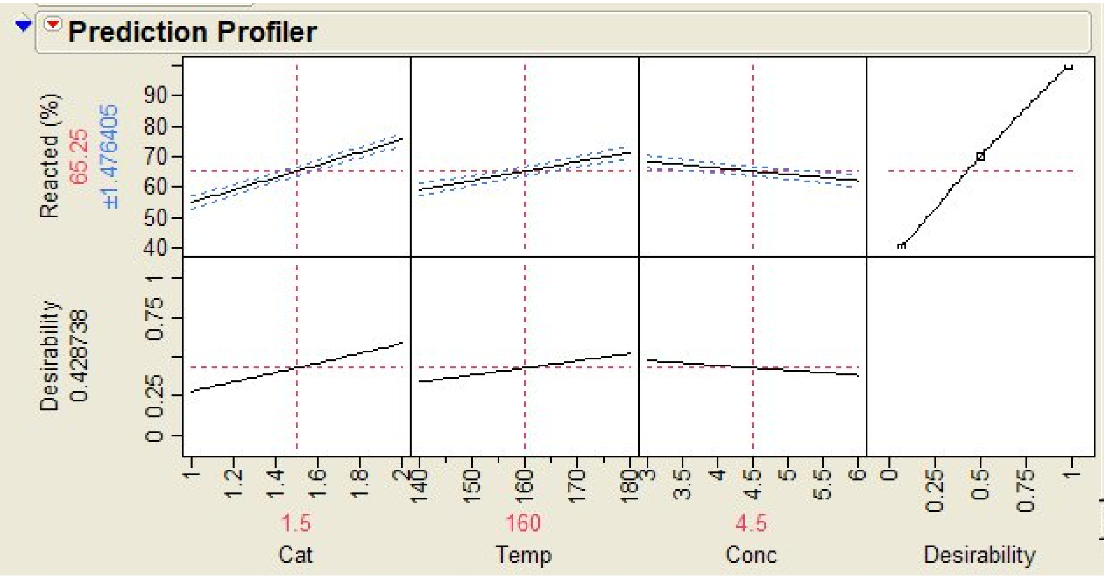
Note: Use "coded" values: Cat(-1,1), Temp(-1,1), Conc(-1,1)

Select the levels of Temp, Conc, & Cat to maximize the Reacted (%)?

Calculate the maximum predicted Reacted (%). [94.875 %]

Note: You cannot have two different levels of the same factor!!!

JMP DOE Design *(Cont.)*

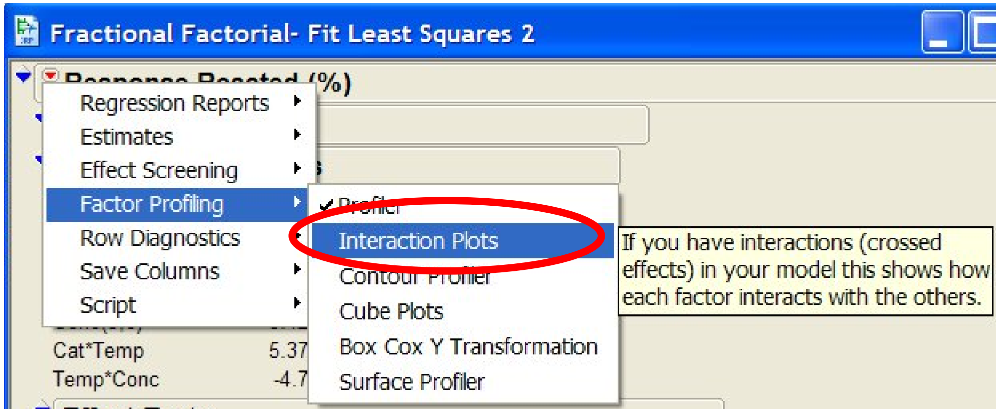


- Notice that the reduced model does not have Feed and Ag rate, in the model. We have to recall from our first analysis what levels to set these factors when we conduct additional trials.
- Concentration level 6 has an average 3.125 Reacted (%) reduction compared to Conc. Level 3 ("-3.125" means that the response goes down from Level 1 to Level 2).

JMP DOE Design *(Cont.)*

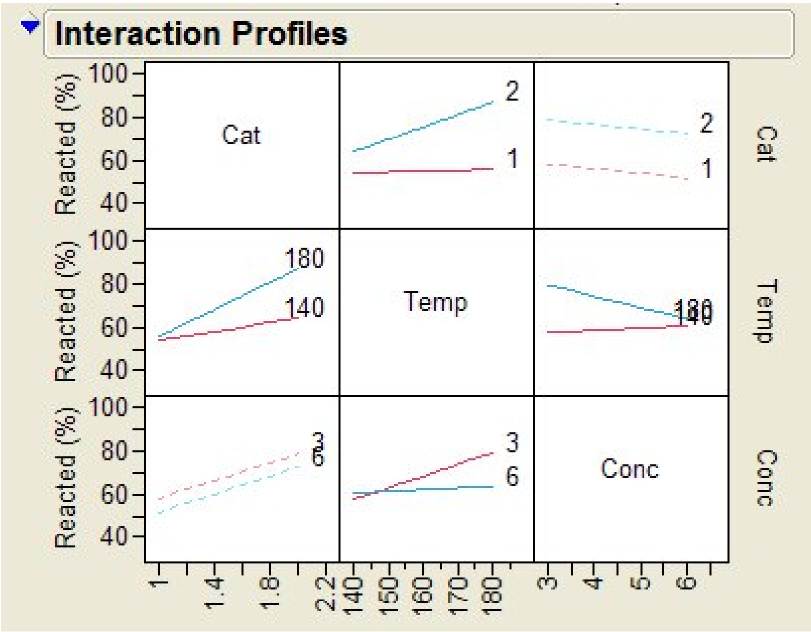
- Next, let's examine the **Interaction Plots**

- **Response Reacted (%)>Factor Profiling>Interaction Plots**



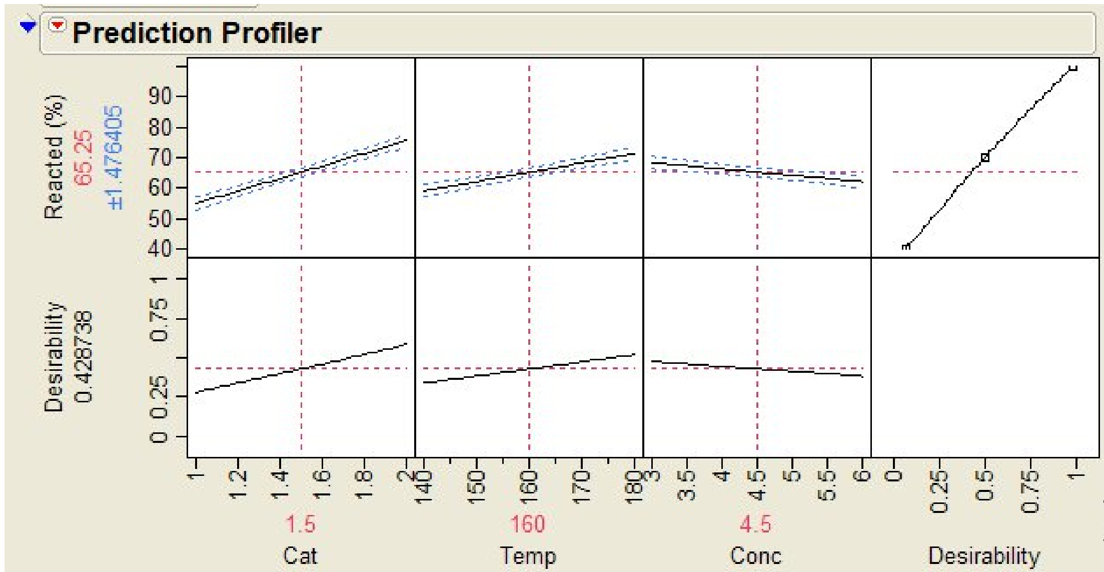
JMP DOE Design *(Cont.)*

- What does the interaction plots tell us?
- We determined from our analysis that Cat*Temp and Temp*Conc were statistically significant.
- We can see that these interactions are not parallel, indicating an interactive effect on the model



- Key Question: What levels of the Temperature, Concentration, and Catalyst would you select to **maximize** the response, Reacted (%)? [Look at the interaction plot and select the levels that maximize the Reacted (%).]

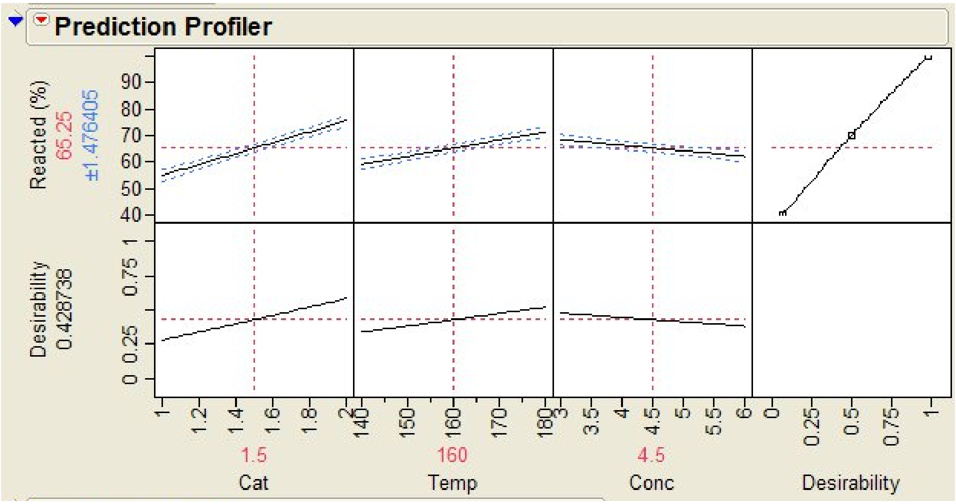
JMP DOE Design *(Cont.)*

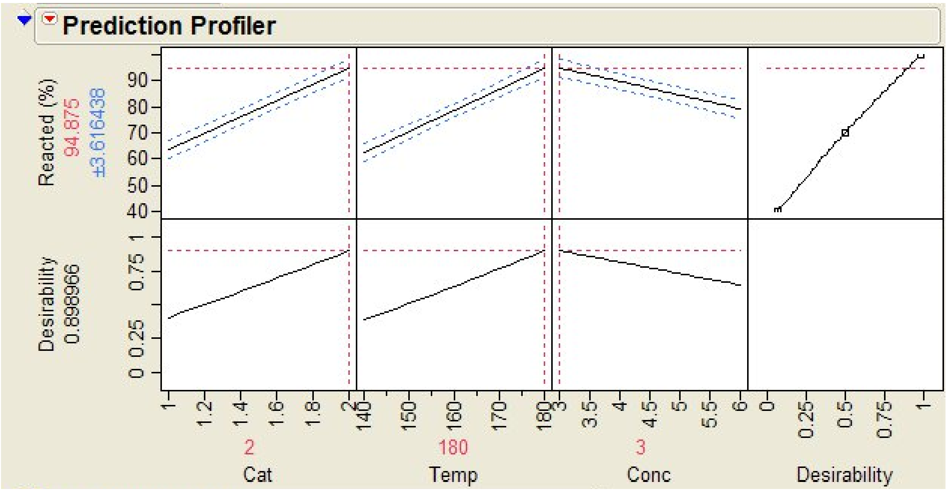


- Now drag Conc over to 3
- Drag Temp over to 180
- Drag Cat over to 2
- You should now be at 94.88% reacted and desirability around 0.89

JMP DOE Design *(Cont.)*

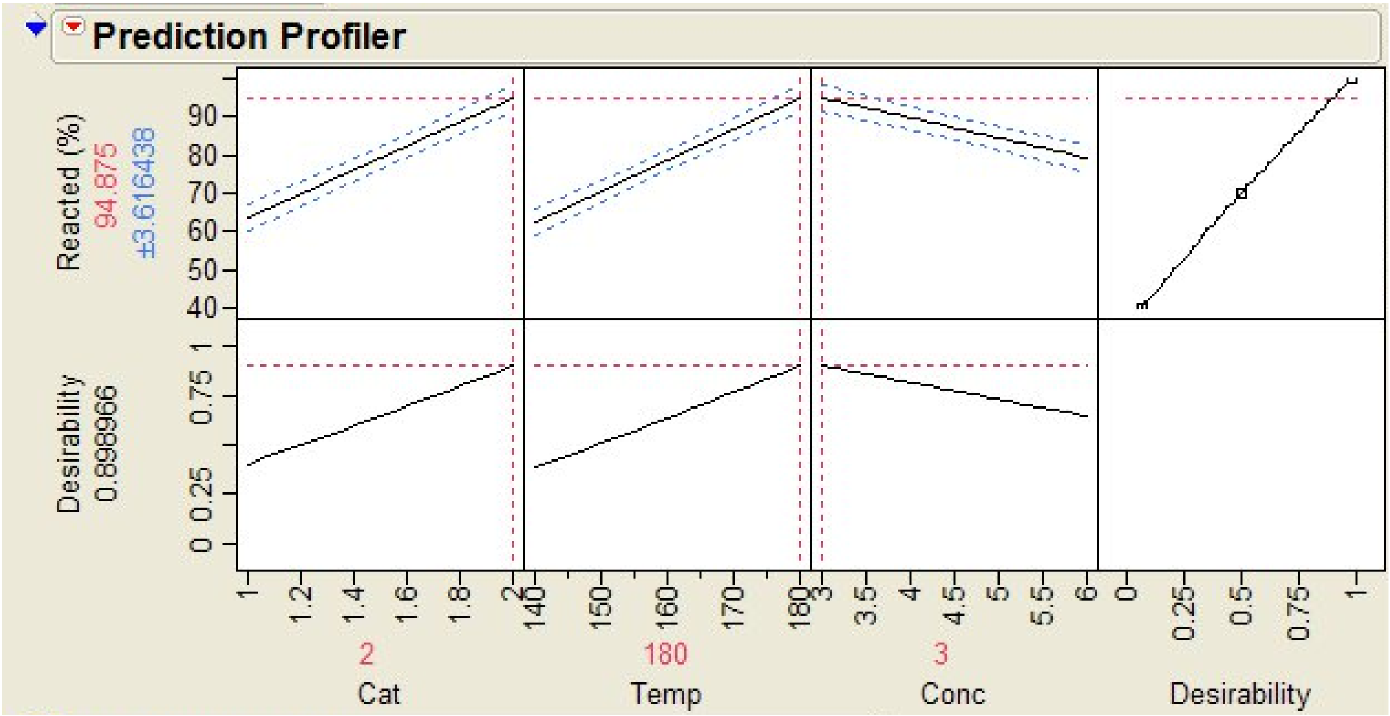
- Return to the **Prediction Profiler** and drag the vertical dashed lines to the levels that will maximize the reacted (%). (Or double click on the red x-axis value and enter the level value.)
- The Vertical Axis shows the predicted response value by the horizontal red dashed line and the predicted value in red(94.875).



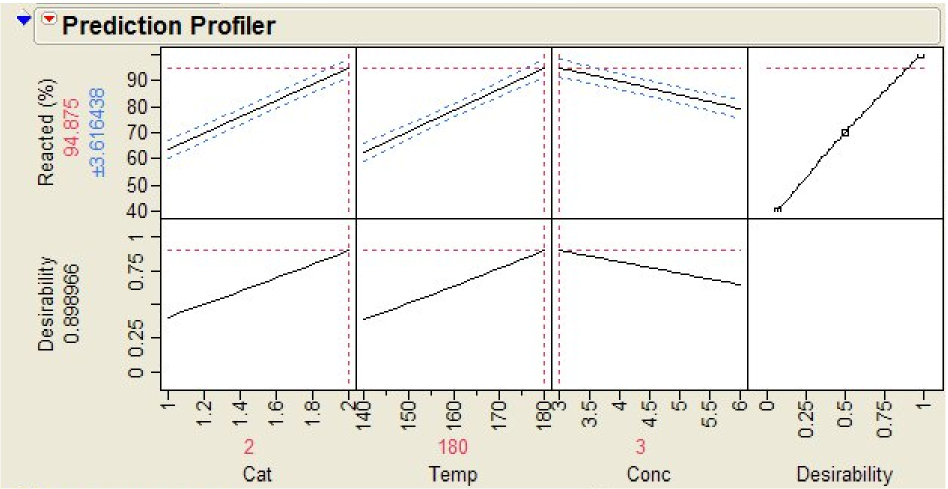


JMP DOE Design *(Cont.)*

- The **Desirability Function** automatically provides the best combinations.



JMP DOE Design *(Cont.)*



- The Prediction Profiler is using the prediction formula derived from the estimates for each factor in the reduced model.

Prediction Formula:

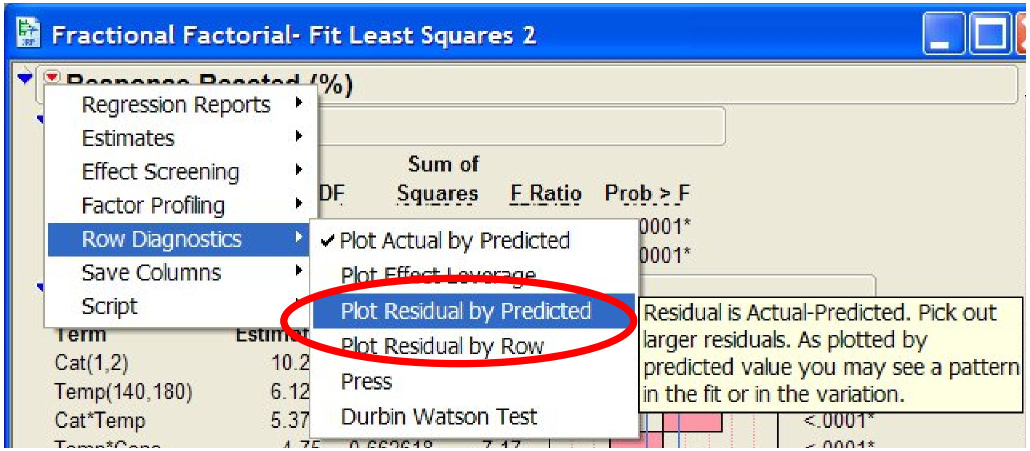
Reacted (%) = 65.25 + 10.25(Cat) + 6.125(Temp) – 3.125(Conc) + 5.375(Cat)(Temp) – 4.75(Temp)(Conc)

Factor Settings: Cat = 1(2%), Temp = 1(180C), Conc = -1(3%)

Reacted (%) = 65.25 + 10.25(1) + 6.125(1) – 3.125(-1) + 5.375(1)(1) – 4.75(1)(-1) = 94.875 %

JMP DOE Design *(Cont.)*

- We are almost finished with the analysis. We always want to check the residuals to see if we have missed something that may not be considered random noise!
- **Response Reacted (%)>Row Diagnostics>Plot Residual by Row**, and **Plot Residual by Predicted** (JMP output default)



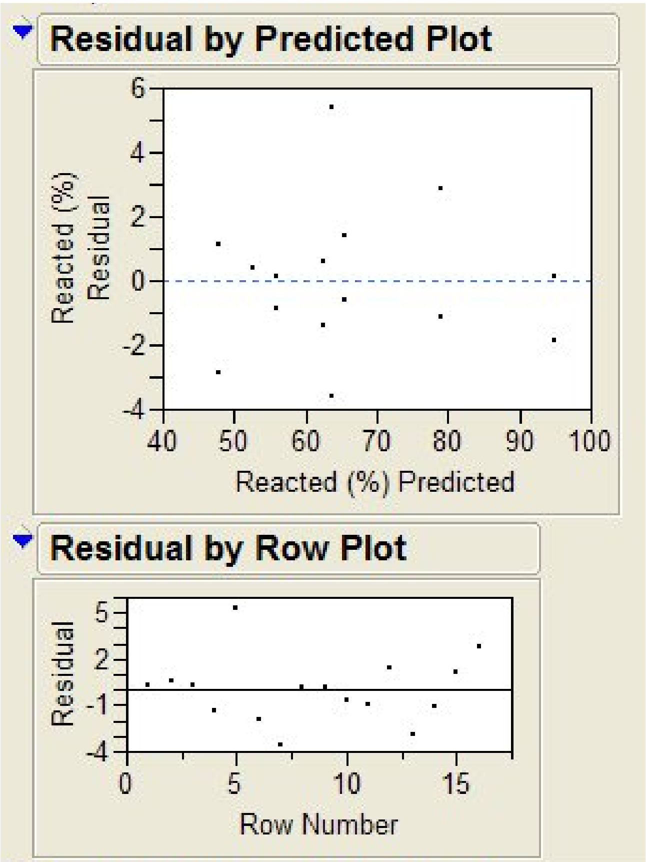
JMP DOE Design *(Cont.)*

Residual by Predicted Values

- We are expecting to see the residuals randomly distributed (STD = constant) around a mean = 0. (i.e., no patterns)

Residual by Row

- If the order of the rows represent the sequential (time) order when the data was collected, then any patterns in the plot would indicate possible variation that occurred over the duration of the experiment.



JMP DOE Design *(Cont.)*

Summary

1) We started with 5 factors at 2 levels, $2^5 = 32$ runs. We decided to design a ½ **fractional factorial, 2^{5-1} = 16 runs, Resolution V Design**. We did not replicate the design to minimize costs.
2) We analyzed the results graphically to select the factors/interactions that had the most influence on the response. Then we **reduced the model** and kept the significant interactions and main factors. *We selected the optimum levels of the main factors not considered significant (Feed Rate, Ag rate).*
3) We ran the reduced model (3 factors: Cat, Temp, Conc, Cat*temp, Temp*Conc) - a 2^3 design. Therefore, with 16 runs, we now have replication and can estimate the error!

JMP DOE Design *(Cont.)*

Summary (Continued)

4) We analyzed the reduced model by:

- Looking at the **Scaled Estimates** to check to see if the factors were statistically significant. We could also see the magnitude of the effect of each factor.
- Plotting the **Prediction Profiles** and the **Interaction Plots** to graphically see the effect of the factors on the response.
- Optimize the factor levels using the **Prediction Profiler**. In this example, we selected factor levels to maximize the response. (Cat(2%), Temp(180°C), and Conc(3%)

5) Next, we analyzed the residuals using **Residual by Predicted Values** and **Residual by Row** to look for any trends that may suggest other factors influenced the experiment that were not in the model.

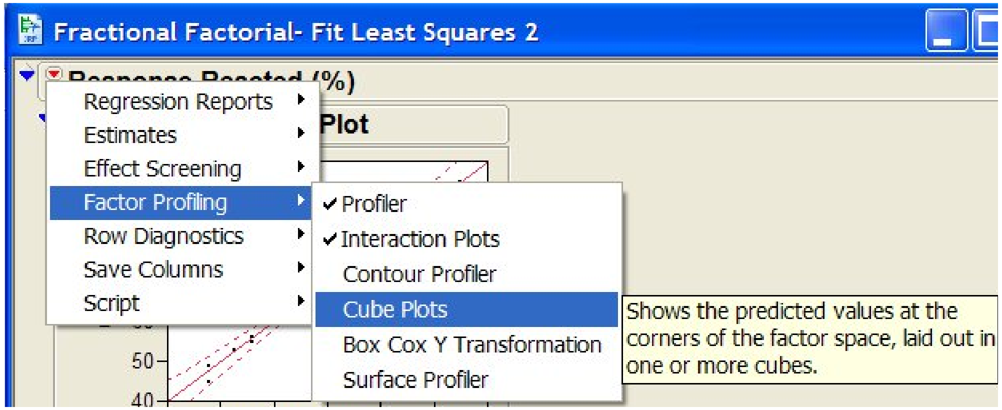
JMP DOE Design *(Cont.)*

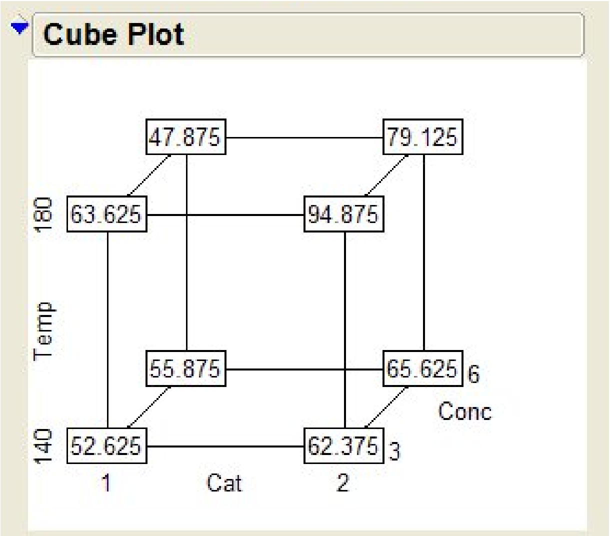
Additional Graphical Output

JMP also provides additional graphical output that helps to optimize the response using the predictive model.

- Cube Plots
- Contour Plots
- Surface Plots

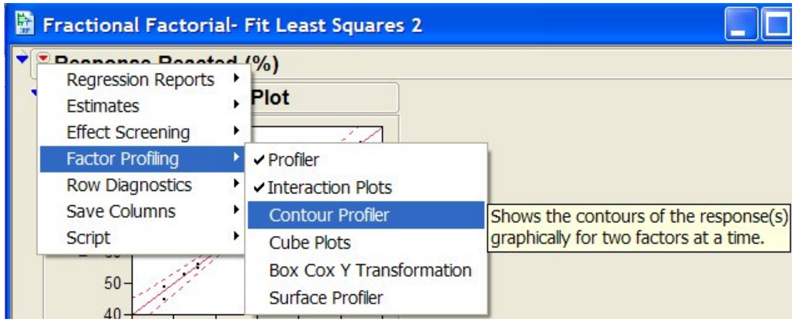
JMP DOE Design *(Cont.)*

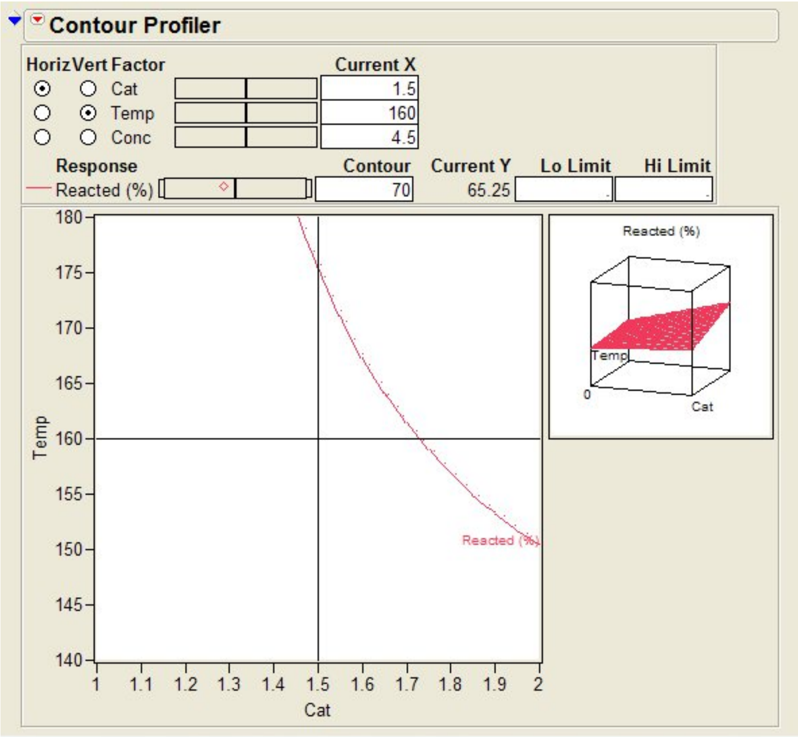




- **Cube Plots** enable us to look at the "response space" as a function of three factors. If we want to maximize the response, we look for the corner with the maximum value.

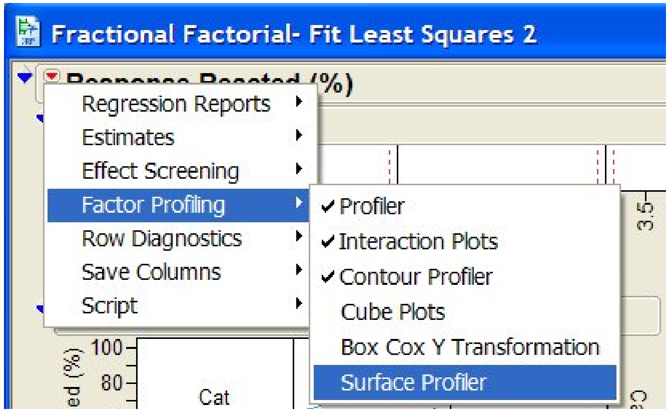
JMP DOE Design *(Cont.)*

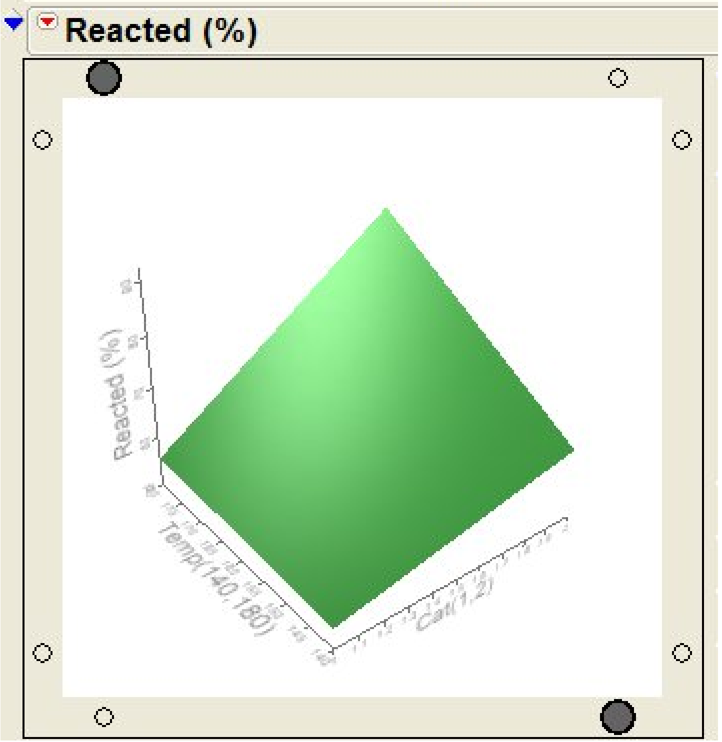




- **Contour Plots** enable us to look at a response contour as a function of two factors. Additional factors must be held at a selected constant level. (Ex. Given a conc=4.5, we can follow the contour line to select any combination of Temp and Cat to give us 70%).

JMP DOE Design *(Cont.)*



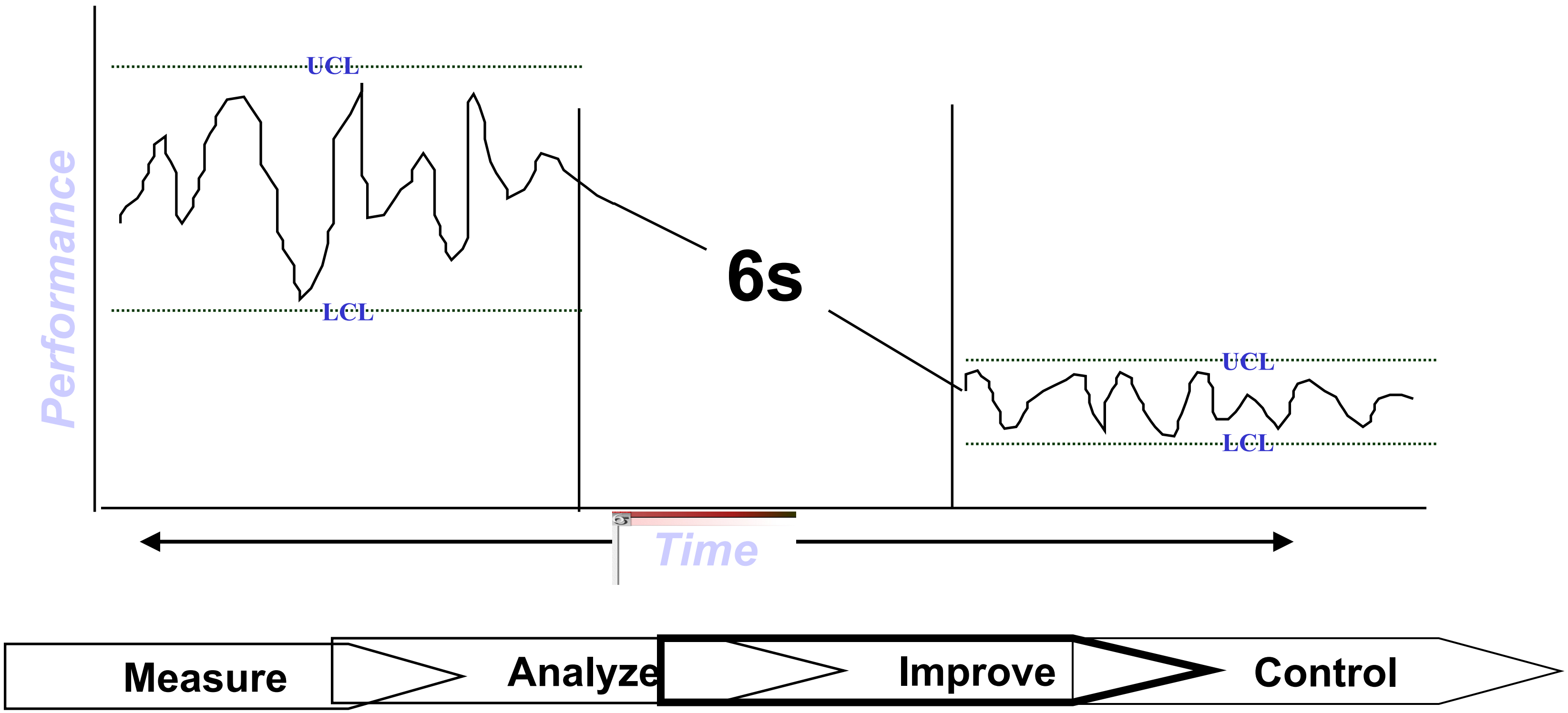


- **Surface Plots** enable us to look at a response surface as a function of three factors. You can dynamically rotate and move the plot to see the response space generated by the prediction model.

JMP Analysis *(Cont.)*

- Translate the statistical conclusion into process terms. Formulate conclusions and recommendations.
  - To maximize % reacted we should use 2% catalyst at 180 °C. We should also set the concentration to 3%. Select Feed Rate and Agitation Rate to minimize overall cost.
- **Replicate optimum conditions. Plan the next experiment and/or institutionalize the change.**

Goal of DOE


UCL
LCL
Performance
6s
UCL
LCL
Time
Measure
Analyze
Improve
Control

Error Proofing and Innovative Problem Solving

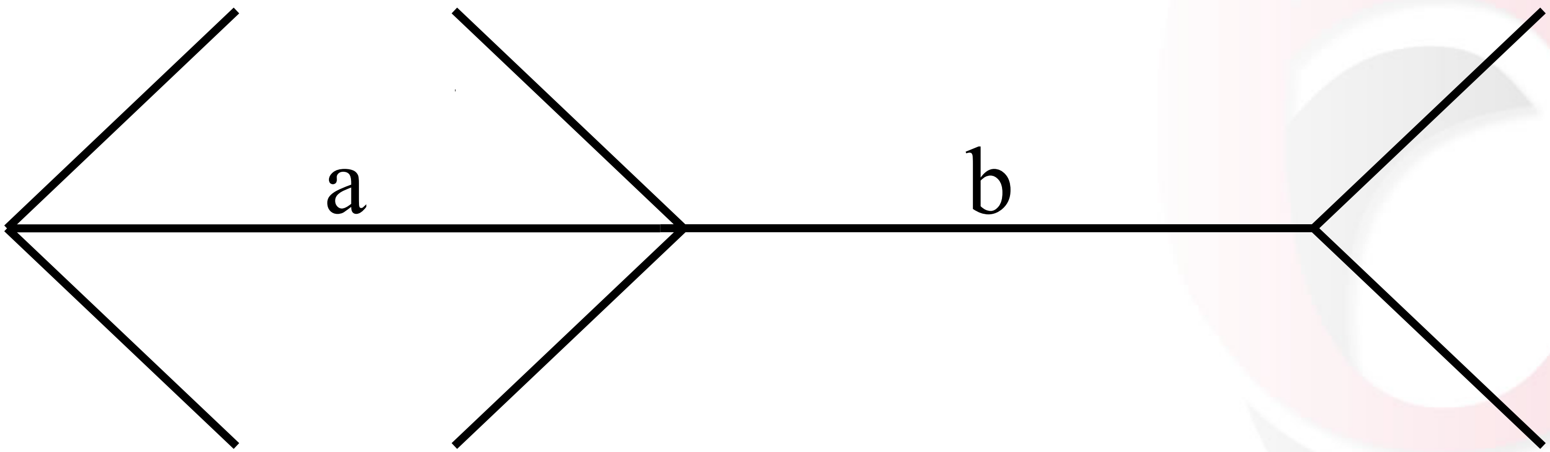
Objectives

- Understand the importance of error proofing
- Discuss the basic steps in error proofing
- Identify general failure modes in a process
- Learn the five principles of error proofing
- Use innovative problem-solving tools to determine error proofing solutions

Errors

- Everyone makes errors in every operation.
- Occurrence rate of individual errors is very low.
- Human carefulness can be effective only for a short time.
- How many times a year does a police officer pull out his or her gun when he or she means to pull out the taser?

Which Line is longer? a or b



Example Errors

- A store associate fails to acknowledge a customer has entered the store/area
- An event planner forgets to arrange catering
- The receptionist enters a client's name and/or address in the computer incorrectly
- A customer receives an incorrect order
- The professor fails to grade one question on the midterm

Error Proofing

Error Proofing is known by many names:

- Poka-Yoke
- Mistake proofing
- Foolproofization
- Murphyizing

Error Proofing

Error Proofing is the improvement of work operations, including materials, machines and methods, with the goal of preventing problems due to human error.

Improve **People** to Fit **Work Operations**	→	Improve **Work Operations** to Fit **People**

Error Proofing Examples

- A store associate fails to acknowledge a customer has entered the store/area
  - Attach a bell or buzzer to the door
- An event planner forgets to arrange catering
  - Create a checklist that must be completed for each event
- The receptionist enters a client's name and/or address in the computer incorrectly
  - Allow customers to enter their own information at a kiosk
- A customer receives an incorrect order
  - Color code shelves or packaging – or weigh box

Four Phases of Error Proofing

- **Phase 1:** Identify Potential Errors
- **Phase 2:** Generate error proofing solutions
- **Phase 3:** Evaluate solutions and select the best solution(s)
- **Phase 4:** Deploy solutions

IDENTIFY POTENTIAL ERRORS

Identifying Errors

Key to the error proofing process is an understanding of where errors might occur in the process as well as the types of errors that may occur. To gain this understanding, teams should:

- Conduct a process FMEA
- Use the list of general sub-processes developed by NCSU to ensure that the full complexity of each process step is described
- Use the list of general failure modes to generate a list of potential errors for each step in the process.

FMEA

- Define the scope of the FMEA.
- Assemble the team.
- Graphically describe the process.
- Brainstorm potential errors and determine the RPN for each error.
- Recommend actions to prevent errors and determine who is responsible for implementation.

Describing the Process

To fully understand and describe a process, teams should:

- Develop a process map
- Verify the process map
- Use the NCSU general sub-processes to ensure the complexity of each process step is clearly defined

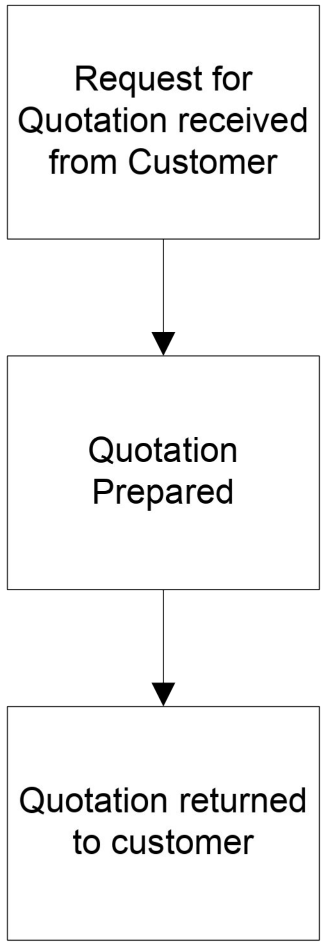
NCSU General Sub-processes

The general Sub-processes identified by NCSU, help the team describe in detail, the complexities of each process step

NCSU General Sub-processes

- Visit / see
- Assess / evaluate
- Review / screen
- Consult / discuss
- Calculate / score
- Enter into computer
- Identify / clarify
- Monitor / observe
- Receive
- Transport
- Place
- Pick up / return

Example



- Sales person visits customer
- Requirements are reviewed
- Sales person enters specifications into request database

- Clerk verifies requirements
- Clerk obtains BOM from engineering
- Clerk prepares quotation
- Clerk sends quote to sales for review

- Sales person checks quotation
- Sales person notifies customer the quote is ready
- Sales person delivers quote

NCSU General Failure Modes

Traditionally, when conducting an FMEA, teams:

- Brainstorm potential failures
- Rate the severity of the failure if it occurs
- Rate the likelihood of the failure occurring
- Rate the ability to detect the failure if it occurs
- Calculate a Risk Priority Number (RPN)

The list of General Failure Modes developed by NCSU assists the team in generating a comprehensive list of potential errors.

NCSU General Failure Modes

Progress Failure	Omission Excessive repetition Wrong sequence Early / Late Execution
Selection Failure	Incorrect identification / selection Incorrect counting / calculating
Perception Failure	Overlooking Misreading / misunderstanding Incorrect decision Miscommunication
Motion Failures	Incorrect transcription / entering Incorrect route / orientation / positioning Unintentional touching / sticking / splashing Hazardous movement
Other Failures	Not available Hardware failure / incorrect information Unexpected reaction

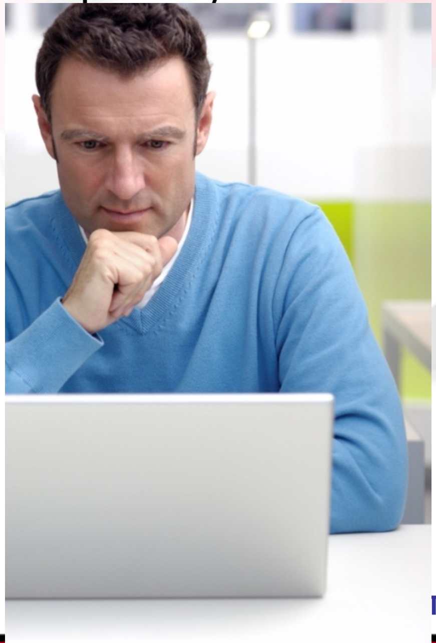
Example

Request for Quotation Received from Customer

- Sales person visits customer
- Requirements are reviewed
- Sales person enters specifications into request database

→

- Sales person misunderstands customer's expectation of product's use
- The sales person enters the wrong quantity



Exercise

- Sketch a process flow map.
- Select one step in your process and use the list of General Sub-processes to list the details of that step.
- Use the list of General Failure Modes to identify the potential errors that could occur in that step.

GENERATE ERROR PROOFING SOLUTIONS

Error Proofing

When error proofing a process, the focus may be on:

- Preventing the error from occurring, or
- Minimizing the effect of the error once it occurs.

The cost to the organization is minimized if the error can be prevented.

5 Principles of Error Proofing

Preventing the Error

- **Elimination** – Remove operations prone to human error
- **Replacement** – Replace human operations with more reliable machines/methods
- **Facilitation** – Make the operations easier for the employees

Minimizing the effect of the Error

- **Detection** – Insure that defects created by human errors are detected
- **Mitigation** – Reduce the effects of the error

Elimination

- Eliminate an error prone task
- Eliminate risks inherent in objects or in the tasks themselves

Examples

Error	Error Proofing Solution
Entering customer shipping information incorrectly in automated ordering system	Modify ordering system to allow customers to enter their shipping and order information
Customers are not notified when shipping dates change	Create an automatic notification system that sends an email when an order change occurs
Products are damaged when dropped during transport	Redesign moving pr

Replacement

- Use automation to replace a human operation
- Provide employees a support system or tools that help them perform an operation

Examples

Error	Error Proofing Solution
Reporting an incorrect weight on goods sold in bulk, resulting in a loss of revenue	Install scales which interface with software to automatically weigh and report shipment weight
Patients forgetting they have an appointment	Implement an automated appointment reminder phone system
Tools are not in the proper location for the second shift	Create a tool storage area with outlines indicating where each tool should be located

Facilitation

- Simplify a process by reducing the number of changes or differences
- Distinguish changes or differences in objects
- Adjust the environment or the characteristics of an operation to suit a person's capabilities

Examples

Error	Error Proofing Solution
Omitting cables when packaging a TV for delivery	Bundle cables in plastic bags stored next to the packaging center
Selecting the wrong item from a warehouse shelf	Color-code boxes and shelving
Clerks selecting the wrong item from a shelf because the shelf is above their head	Purchase mobile stairs for clerks to use to retrieve items from higher shelves

5 Principles of Error Proofing

Preventing the Error

- **Elimination**
  Remove operations prone to human error
- **Replacement**
  Replace human operations with more reliable machines/methods
- **Facilitation**
  Make the operations easier for the employees

Minimizing the effect of the Error

- **Detection**
  Insure that defects created by human errors are detected
- **Mitigation**
  Reduce the effects of the error

Detection

- Record steps taken or required and verify these steps at a later point in the process
- Restrict the process and signal (visually or with an alarm) that a defect/error has occurred.
- Verify the shape / quality / state of objects at a point in the process

Examples

Error	Error Proofing Solution
All the tasks necessary to ensure classes are successful are not completed	Develop and use a checklist to ensure all tasks are completed in a timely manner in the correct order
Omitting a contact phone number on a web registration page	An asterisk appears next to the field that is not properly completed and do not continue registration until information is provided
Errors in final report to customer	Use a word processing program that marks misspellings in red

Mitigation

- Implement redundant systems
- Use a failsafe to limit the number of unsafe conditions that may occur
- Create processes/methods that protect against losses when a failure occurs

Examples

Error	Error Proofing Solution
Technical errors in printed course materials	Use multiple reviewers to check accuracy
Incorrectly entering a password on a banking site	Lock-out account after three attempts
Users have the ability to delete entire database	Automatically backup database nightly to enable recovery of lost information

5 Principles of Error Proofing

Preventing the Error

- **Elimination**
  Remove operations prone to human error
- **Replacement**
  Replace human operations with more reliable machines/methods
- **Facilitation**
  Make the operations easier for the employees

Minimizing the effect of the Error

- **Detection**
  Insure that defects created by human errors are detected
- **Mitigation**
  Reduce the effects of the error

Class Discussion

Request for Quotation Received from Customer

- Sales person visits customer
- Requirements are reviewed
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- Sales person misunderstands customer's expectation of product's use
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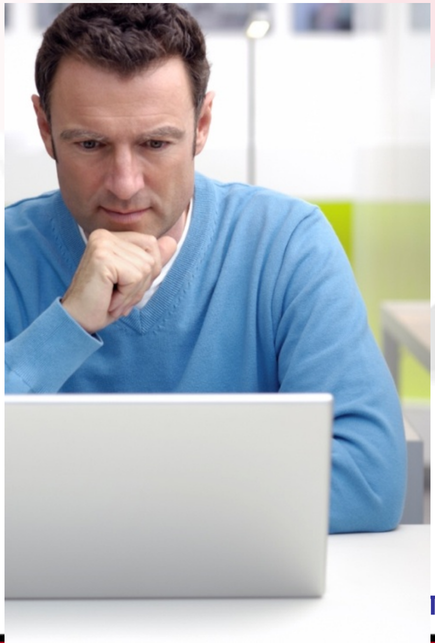
Error Proofing Principle to apply?

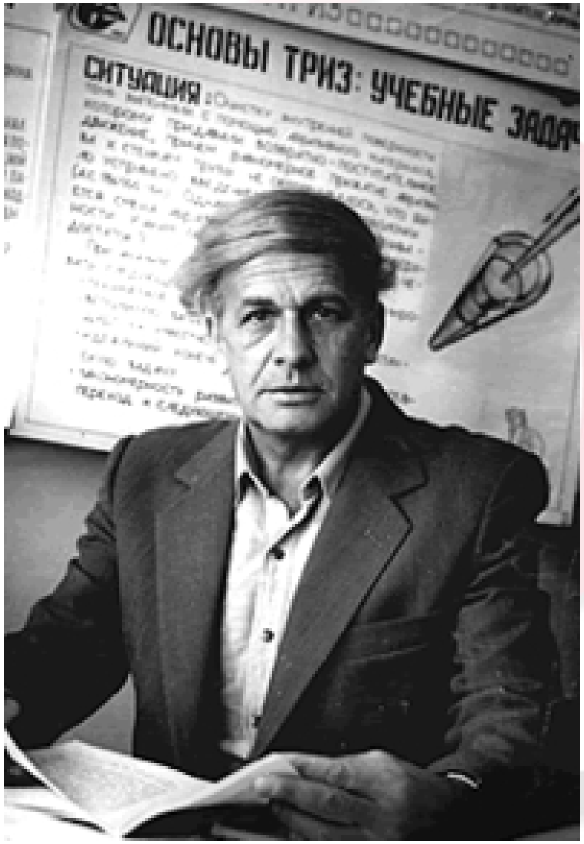


Generating Solutions

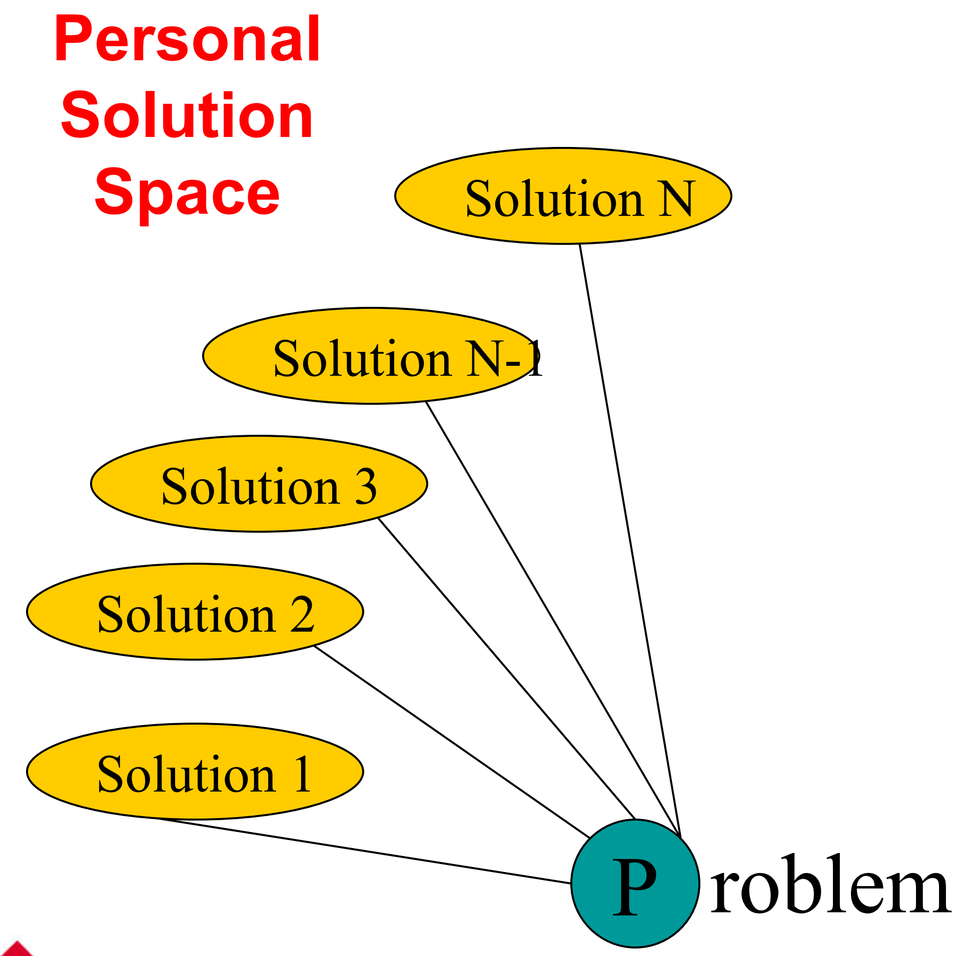
- The five error proofing solutions provide Lean Six Sigma teams with a basic understanding of the types of solution strategies they may want to implement.
- Teams are often limited by their personal experience and may miss potential solutions.
- The use of a directed problem-solving methodology can help teams develop a richer set of potential solutions.

Theory of Inventive Problem Solving

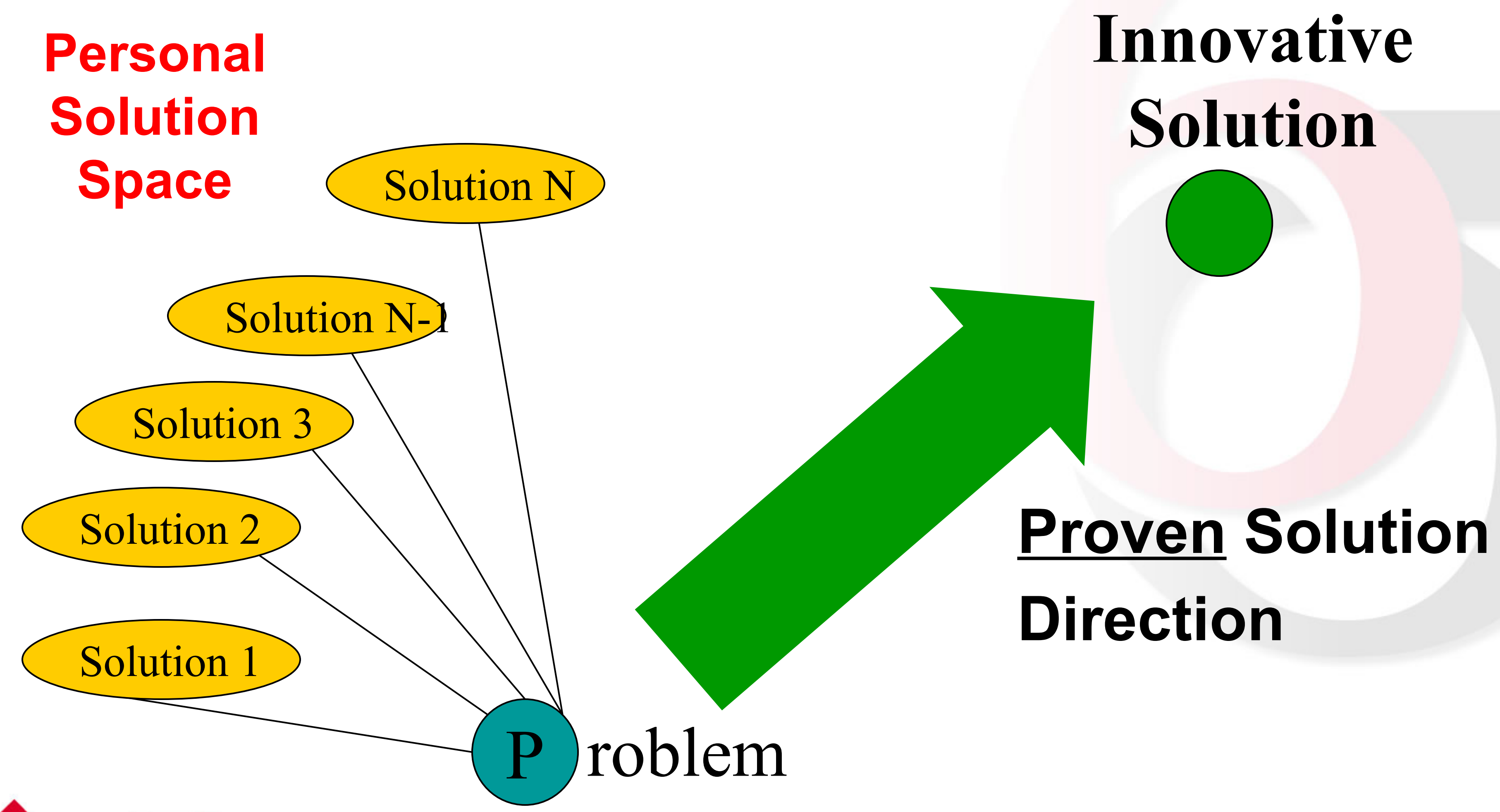
- The Theory of Inventive Problem Solving (TIPS or TRIZ) is the result of a study of patent literature by Genrich Altshuller.



Traditional Trial & Error Problem Solving



Using Proven Solution Directions



Solution Directions

- Each error proofing solution may be matched with proven solution directions to develop a richer set of error proofing solutions

Solution Directions

- Trimming
- Self Elimination
- Prior Action
- Automation
- Combining
- Standardization
- Copying
- Flexible films / Thin membranes
- Color
- Counting
- Unique shape / Geometry

Solution Directions

Solution Direction	Questions to Ask	Error Proofing Principle
Trimming	Can we eliminate the error-prone process or harmful objects?	Elimination Facilitation Mitigation
Self Elimination	Can the harmful action or object eliminate itself?	Elimination Detection
Prior Action	Can we do something beforehand to eliminate the error-prone process or harmful objects?	Elimination Replacement Facilitation Mitigation
Automation	Can we automate the process to solve our problem?	Replacement Detection
Combining	Can we combine (bring together / closer) two or more things to automate or support human operations?	Replacement Facilitation

Solution Directions

Solution Direction	Questions to Ask	Error Proofing Category
Standardization	Can we standardize the process to facilitate human operations?	Facilitation Detection Mitigation
Copying	Can we use redundancy to facilitate human operations?	Facilitation Mitigation
Flexible Films / Thin Membranes	Can we flexible films or thin membranes to facilitate human operations?	Facilitation
Color	Can we use color to facilitate human operations?	Faciliatation
Counting	Can we count something to detect errors?	Detection
Unique Shape / Geometry	Can we use shapes (1D, 2D, or 3D) to detect errors?	Detection

Class Discussion

Request for Quotation Received from Customer

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→

- Sales person misunderstands customer's expectation of product's use
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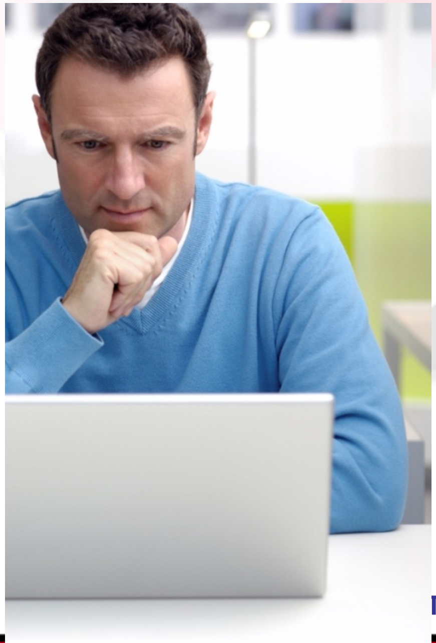
Solution Directions?



Exercise

- Using the process flow map and the list of potential errors developed earlier list the error proofing principle that may be used to error proof your process.
- Which solution directions can your team use to address these potential errors?
- What are your potential solutions?

EVALUATING SOLUTIONS

Evaluating Solutions

- Typically, multiple solutions are proposed when error proofing a process.
- Teams must determine the best solution.
- A Solution Priority Number (SPN) may be calculated.

Solution Priority Number

SPN = Effectiveness * Cost * Implementation

- How effective is the solution?
- How much will the solution cost?
- How difficult is it to implement the solution?

Effectiveness

Score	Definition
3	**Very Effective**: The error can be eliminated.
2	**Effective**: The chance an error may occur can be reduced; however, it may still occur.
1	**Ineffective**: The error *can* not be reduced.

Higher is Better

Cost

Score	Definition
3	**Low**: Within daily operating budget. No specific budget is needed.
2	**Moderate**: Department level budget approval is needed.
1	**High**: Corporate level budget approval is needed..

Higher is Better

Implementation

Score	Definition
3	**Easy**: No training is needed. No resistance is expected.
2	**Moderate**: Training course is needed. Some resistance is expected.
1	**Difficult**: Culture change is needed. Strong resistance is expected.

Higher is Better

Comparing Solutions

After completing the Solution Priority Matrix, keep in mind:

- Combined solutions are often more effective than individual solutions
- Look for solutions that impact more than one potential failure
- Cost concerns can be overcome with management buy-in

Example

Request for Quotation Received from Customer

- Sales person visits customer
- Requirements are reviewed
- Sales person enters specifications into request database

→

- Sales person misunderstands customer's expectation of product's use
- The sales person enters the wrong quantity

Potential Solutions

- Create a checklist for the sales person to use when specifying the product
- Create a web-based ordering application and equip the sales person with mobile internet card. Orders will be entered with the customer so that accuracy can be checked immediately

Solution Priority Matrix

Solution	Effectiveness 1 - 3	Cost 1 - 3	Implementation 1 - 3	SPN E*C*I
Create Check list for sales	2	3	3	18
Web ordering	3	2	2	12
				0
				0
				0
				0
				0
				0

Error Proofing Action Plan

Develop an Error Proofing Action Plan:

- Assign responsibility for each task
- Assign additional resources as needed
- Develop a timeline for completion
- Document the new process

IMPLEMENTING SOLUTIONS

Objectives

- Discuss the importance of prioritizing solutions during the Improve phase of a project
- Understand how to use the Criteria/Solutions matrix
- Review the Improve tollgate

Implementing Solutions

At the end of the Improve stage of a Lean Six Sigma project teams must decide which solution(s) they will recommend to resolve the problem. Teams will:

- Evaluate and select the best solution(s)
- Get buy in from the process owner
- Create a Solution Implementation Plan
- Implement the solution

Selection Criteria and Importance

- Teams must determine a list of criteria that solutions will be evaluated against.
- Some criteria will be more important than others when evaluating a solution. A weighting system may be used to distinguish more important criteria.
- Use team consensus to finalize the list of evaluation criteria and weightings.

Prioritizing Solutions

NC STATE UNIVERSITY Six Sigma

Criteria/Solution Matrix

Date:	
Project Title:	
Project Leader:	
Objective:	

Criteria						Final Weighted Score	Overall Ranking
Weighting							
Solution							

Process Owners

- The key to successfully completing a Six Sigma project and making sure it can be turned over to the process owner is having buy-in to the final solution.
- Teams may find they need to include the process owner and key members of his team during the Improve phase of the project. Their input is often invaluable, and they are more likely to accept a solution they have participated in creating the solution.

Solution Implementation Plan

Document! Document! Document!

- New process flow map
- Training requirements
- Job requirements
- Standard operating procedures
- Implementation time frame
- Implementation responsibilities

Improve Tollgate

- Brainstorm potential solutions for each root cause
- Prioritize potential solutions
- Create a pilot/DOE to test solution effectiveness
- Use data to verify the effectiveness of solutions
- Document new process
- Create a solution implementation plan

DMAIC Process

DEFINE	MEASURE	ANALYZE	IMPROVE	CONTROL
What problem are we addressing?	What data is needed and what is the current	What are the root causes of the problem?	What is the best solution to remove each root cause?	How can we insure the gains are maintained?

DEFINE
- Potential projects evaluated and selected
- Project charter completed
- VOC collected and analyzed
- Process mapped

MEASURE
- Data collection plan created
- Data collection completed
- Process baseline established

ANALYZE
- Potential root causes identified
- Analysis of data completed

IMPROVE
- Brainstorm potential solutions
- Pilot solutions
- Optimize process outputs
- Document solution implementation plan

CONTROL
- ❑Select appropriate controls
- ❑Document control plan
- ❑Deliver project documentation
- ❑Celebrate completed project

INTRODUCTION TO CONTROL

Objectives

- Review the activities involved in the Control phase of a project
- Understand the objective of the Control phase of a Six Sigma project
- Discuss the elements included in a closed loop control plan
- Introduce types of process controls

Overview of Control Phase

Document improvements

Brainstorm appropriate controls to sustain the gains

Select measurement based controls where appropriate

Create process management plan and review with management

Implement and validate controls

Realize project savings and determine final benefits

Hand over to process owner, determine translation opportunities and clear tollgate

Close project and Celebrate

Control

Unfortunately, some teams move successfully through the Define, Measure, Analyze and Improve phases, but fail to fully understand or implement Controls on the new process. Without Control, too often, the gains made by the Lean Six Sigma team are lost.

To be successful during the Control phase, organizational management and the Lean Six Sigma teams must:

- Be disciplined about the maintenance of improved processes,
- Document the improvements,
- Create process metrics or measurements, and
- Create a closed loop, process management/control plan.

Brainstorming Potential Controls

- Control Plan
  - Strategy for maintaining the improved process performance over time
  - Tools and actions
- Types of Controls
  - Measurement based controls
  - Documentation
  - Design
  - Test and Inspection
  - Audits

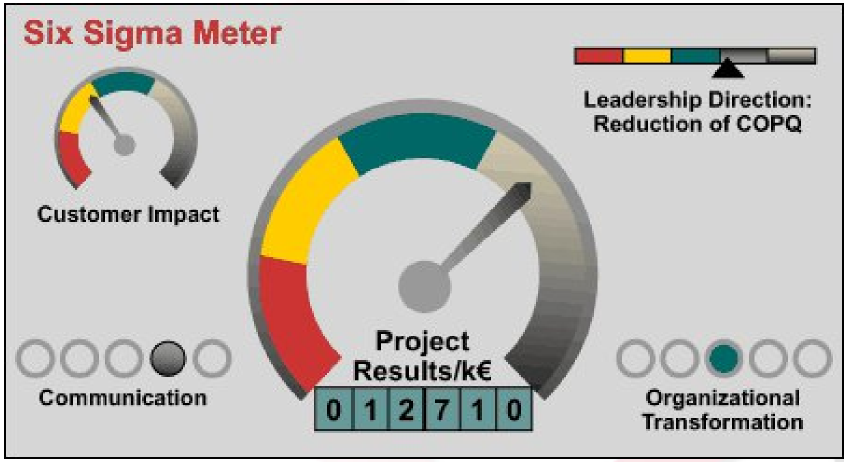
Documentation

Towards the end of the Improve phase, as the final changes to the process are being implemented, the team should begin to document the process. The documentation should:

- Include updated process flow maps
- Photographs
- Be clear and concise
- Be reviewed by the people who work with the process
- Be easily accessible

Measurement Based Controls

- Dashboards
- Scorecards
- Statistical Process Control



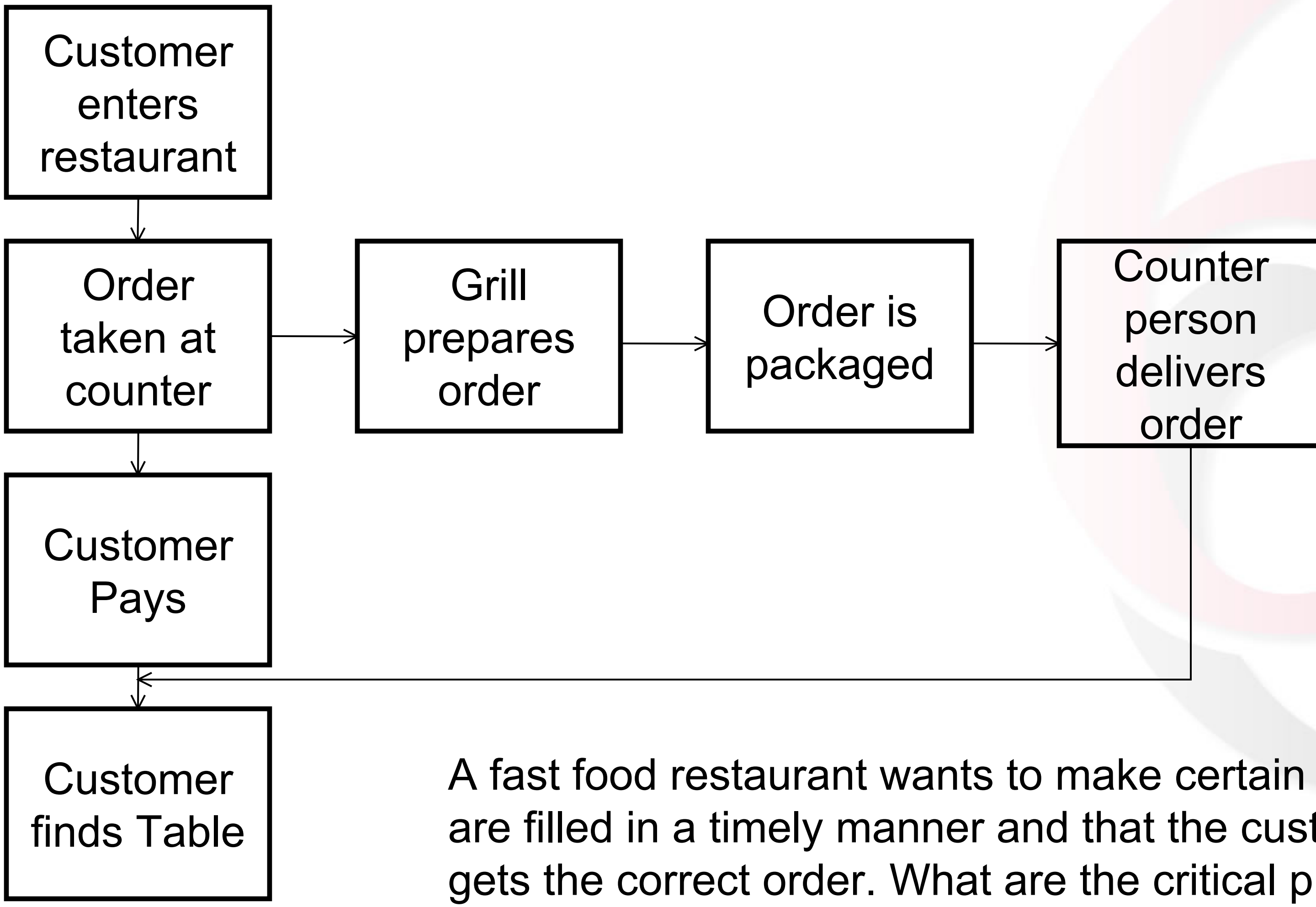
Process Measures

A critical success factor in Control is identifying the key measures that will allow the organization to maintain and manage the process over time.

Process Measures

- To select the key measures, the team should:
  - Examine the new process map
  - Determine which upstream measures are linked to the improvement
  - Review critical process inputs that drive the quality of the process or product
  - Chart the measures

Process Measures



A fast food restaurant wants to make certain orders are filled in a timely manner and that the customer gets the correct order. What are the critical process measures that should be monitored?

Other Types of Controls

Design

- Error Proofing

Test and Inspection

- Inspections
- Automated checks

Audits

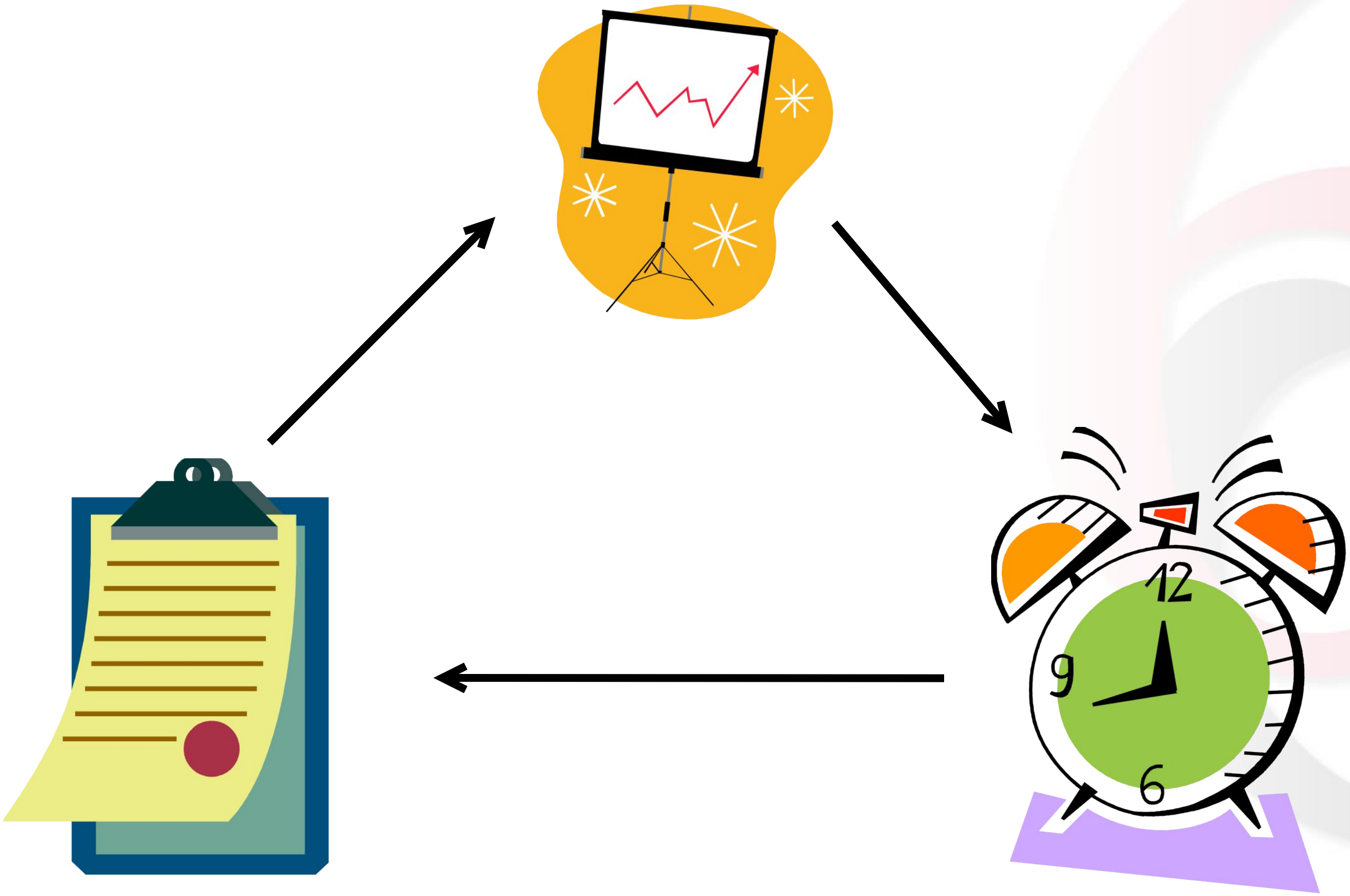
- Training Certification
- Periodic Reviews

Process Management Plan

A Process Management Plan is essentially an “owner’s manual” for the newly improved process. It includes:

- Current process map
- Types of Controls
- Action alarms
- Emergency fixes
- Plans for future improvements

Process Management Plan



Lean Six Sigma

Introduction to Control Charts

Objectives

- Review basics of control charts and process control
- Introduce Control Chart Roadmap

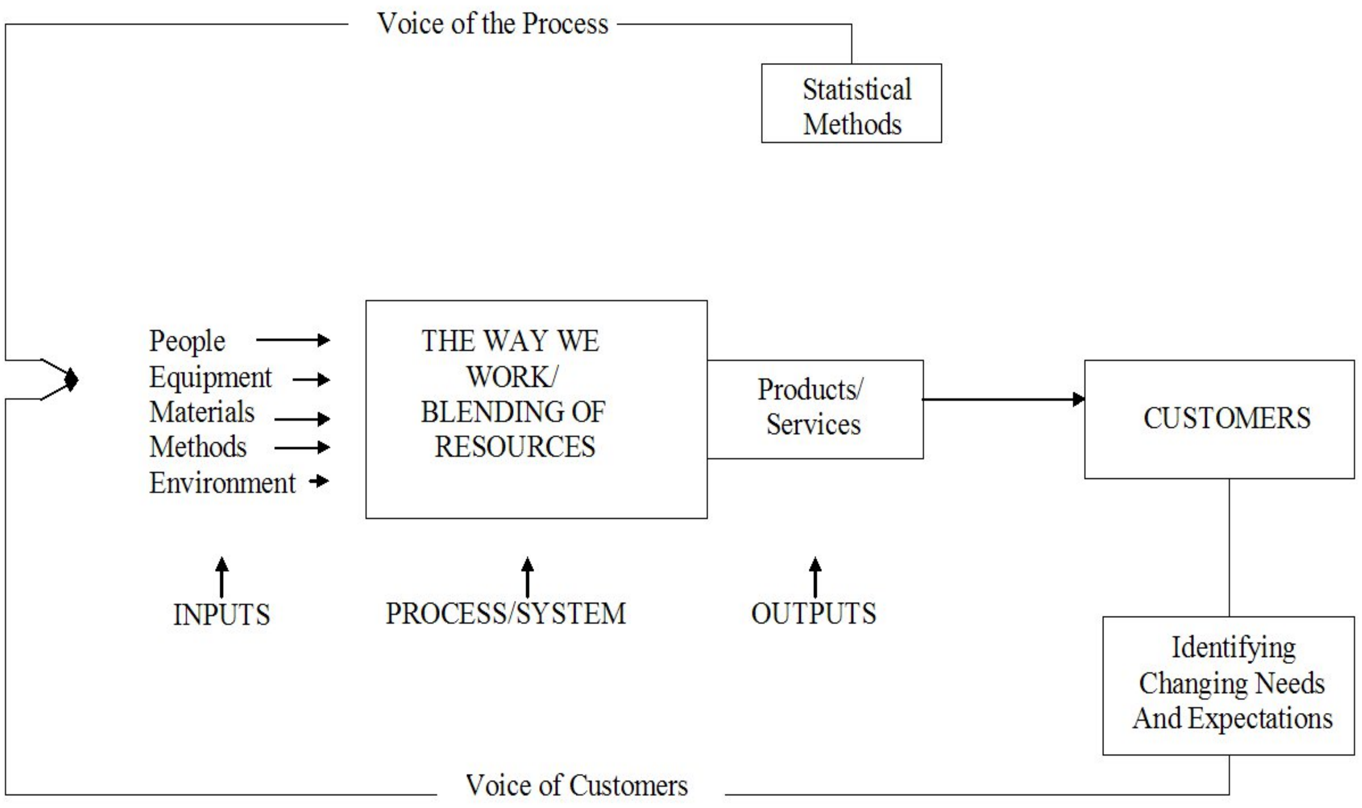
Control Charts

- Used to monitor, control, and improve process performance over time
- Key Elements in Control Charts:
  - Is the process on target?
  - Helps in defining the total system variation
  - Identifies different sources of variation (common cause and special cause variation)

AIAG - SPC Chapter Outlines

- Chapter 1: Continual Improvement and Statistical Process Control
- Chapter 2: Control Charts
- Chapter 3: Other Types of Control Charts
- Chapter 4: Understanding Process Capability and Process Performance for Variables Data

Process Control System Model with Feedback

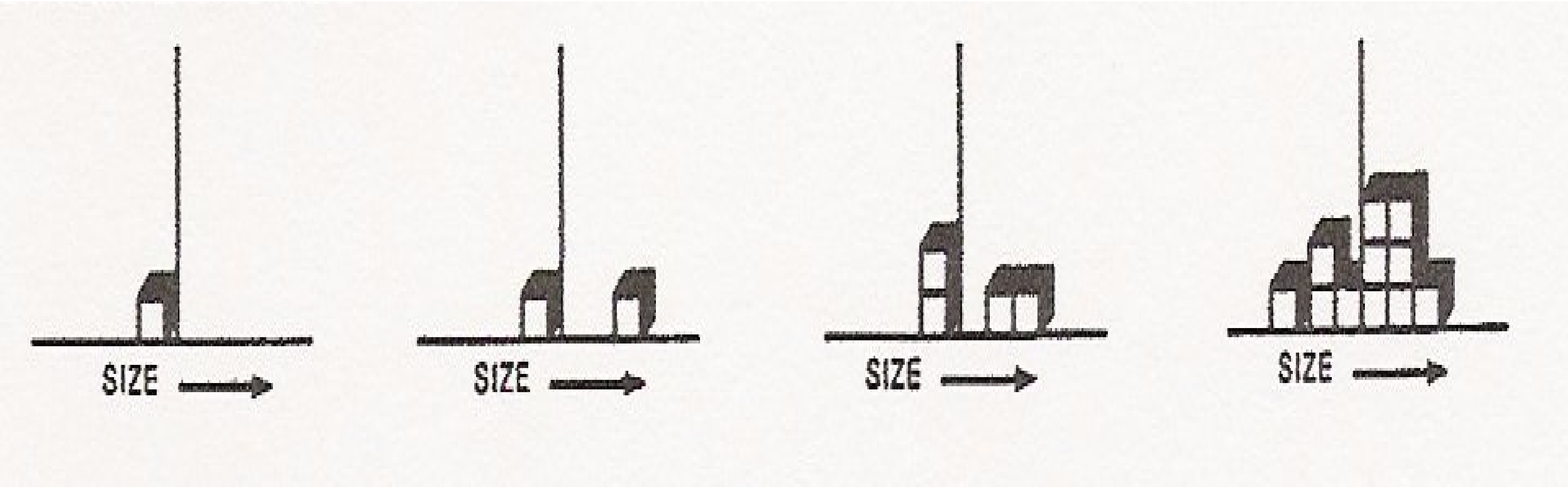


AIAG – SPC, p. 8

Variation: Common and Special Causes – Chapter 1 Section C

Pieces vary from each other…

Variations always exist…

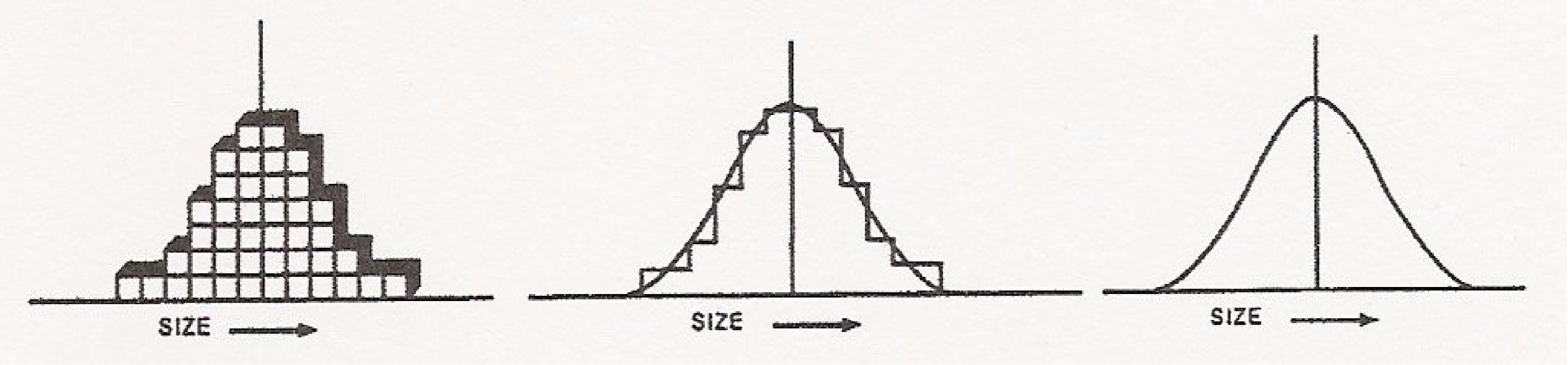


AIAG – SPC, p. 12

Variation: Common and Special Causes – Chapter 1 Section C *(cont.)*

But they form a pattern that, if stable, can be described as a distribution…

Some sources of variation cause short term, piece to piece differences some are long term, such as machine wear, or step wise as with procedural changes. Therefore, the time period over which measurements are made will affect the amount of total variation that will be present.



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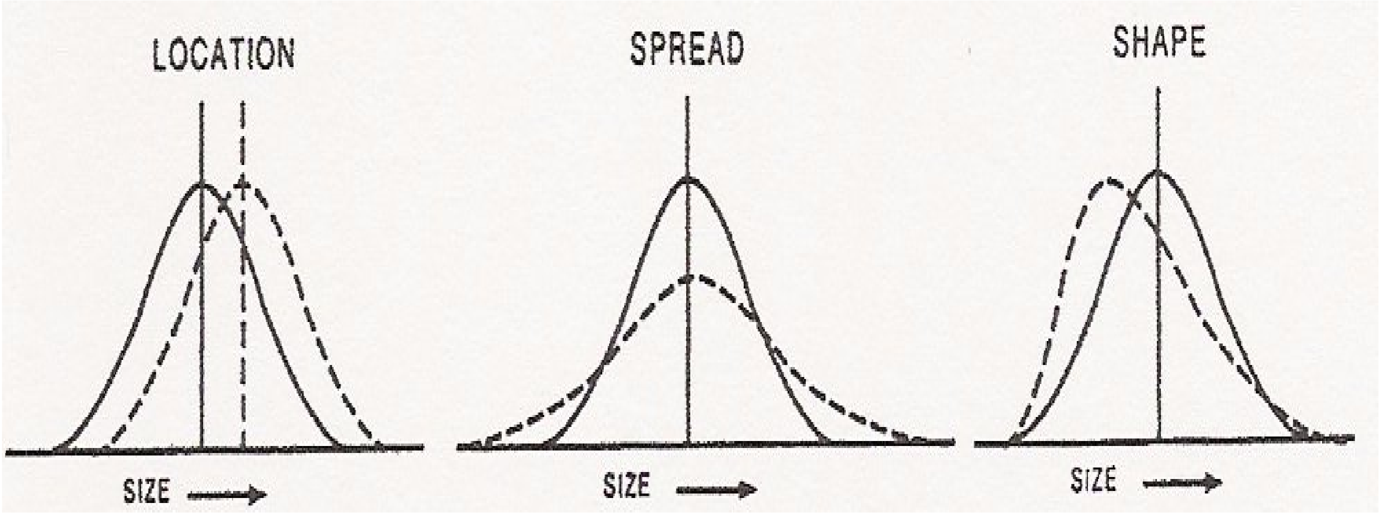
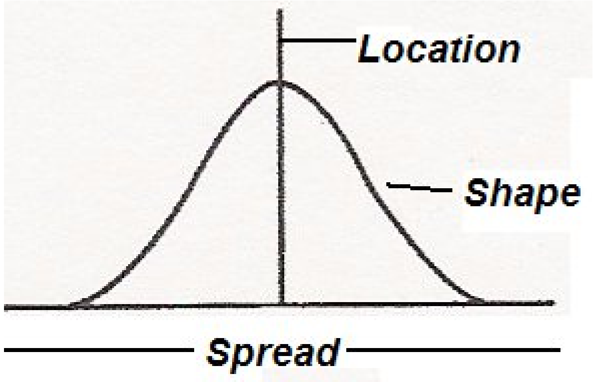
Variation: Common and Special Causes – Chapter 1 Section C *(cont.)*

Distributions can differ in location, spread, and shape…





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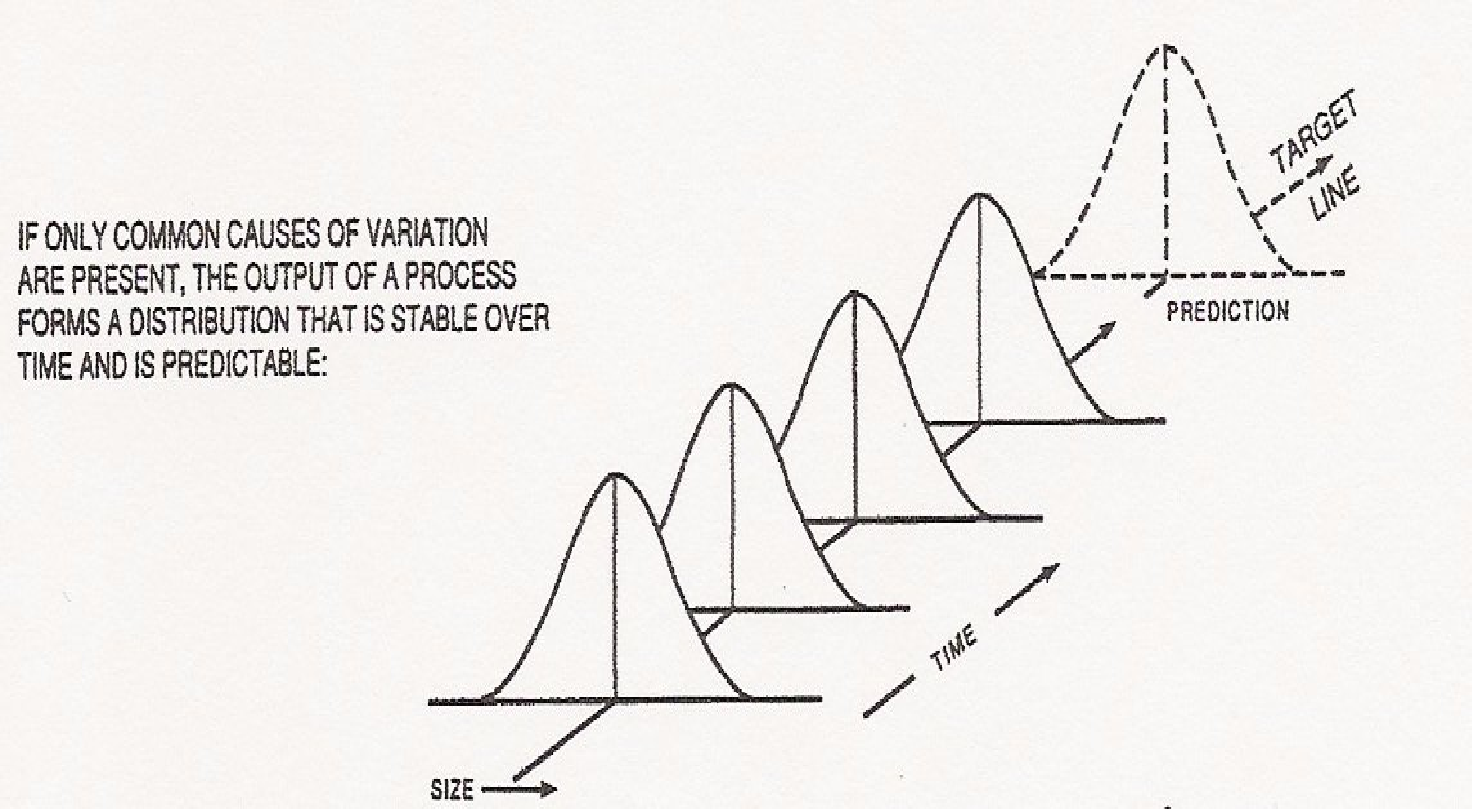
Variation: Common and Special Causes – Chapter 1 Section C *(cont.)*

Common causes of variation in a state of statistical control…



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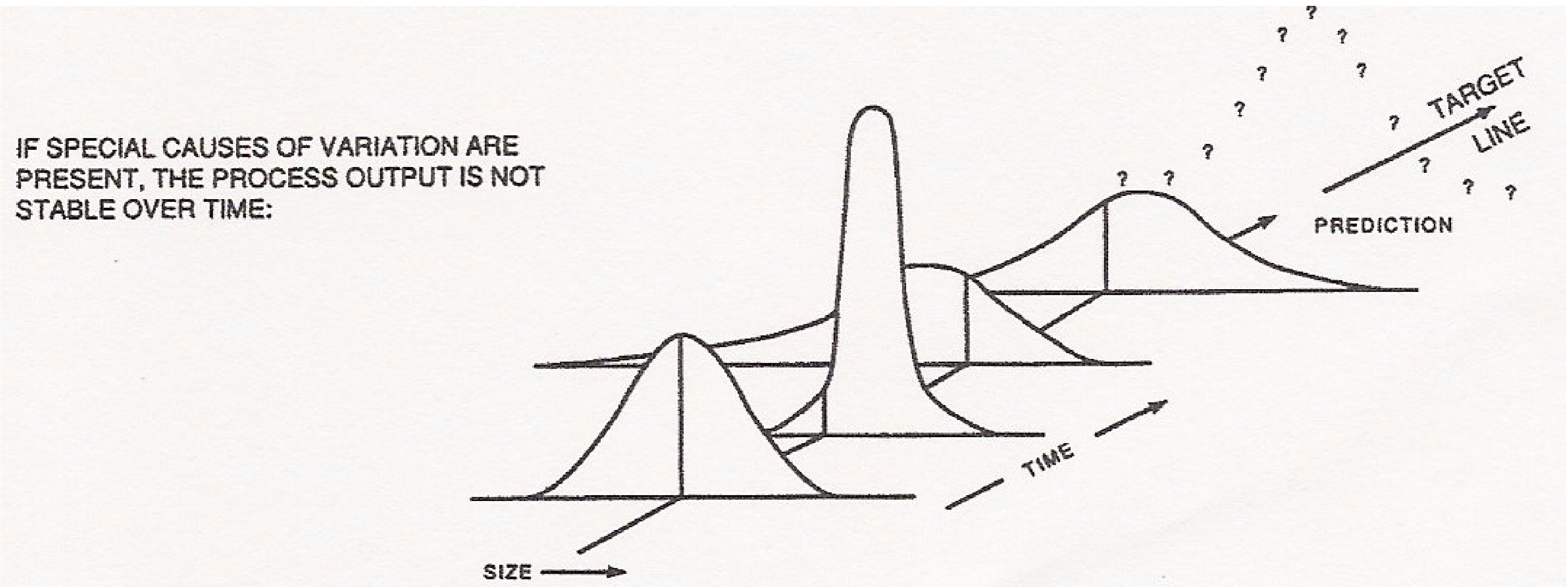
Variation: Common and Special Causes – Chapter 1 Section C *(cont.)*

When special causes (assignable causes) occur, they make the overall process distribution change. Unless all are identified, they will continue to affect the output in unpredictable ways.



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Local Actions and Actions on the System

- Local Actions on Sporadic Disturbances:
  - Usually required to eliminate *special causes* of variation
  - Taken by people close to the process
  - Corrects about 15% of process problems
- Actions on the System for Chronic Variation:
  - Usually required to reduce the variation due to *common cause*
  - Almost always require management action for correction
  - Corrects about 85% of process problems

AIAG – SPC p. 16

Control Charts: Tools for Process Control – Chapter 1 Section G

- Dr. Walter Shewhart first made the distinction between controlled and uncontrolled variation in the 1920's.
- Process Improvement using control charts is an iterative procedure.

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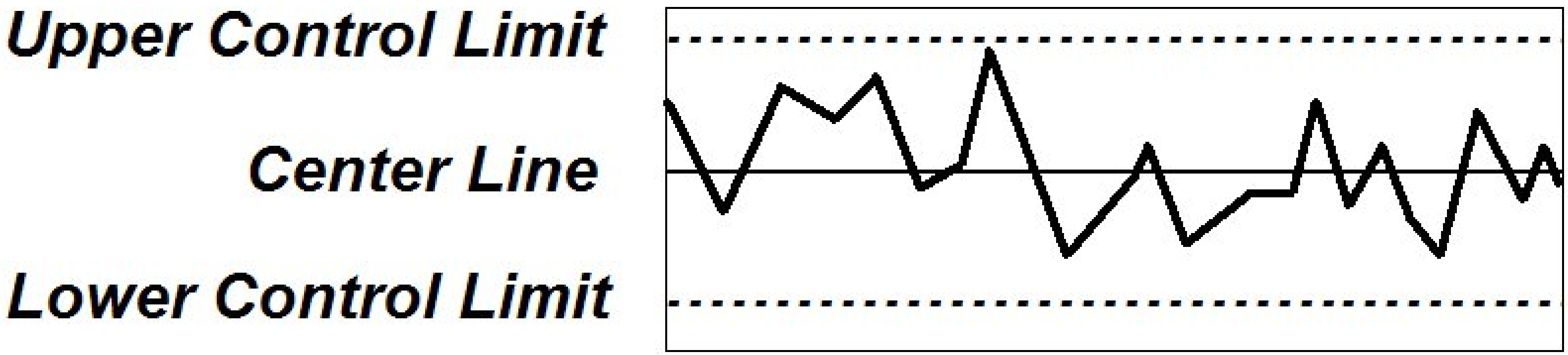
Control Limits



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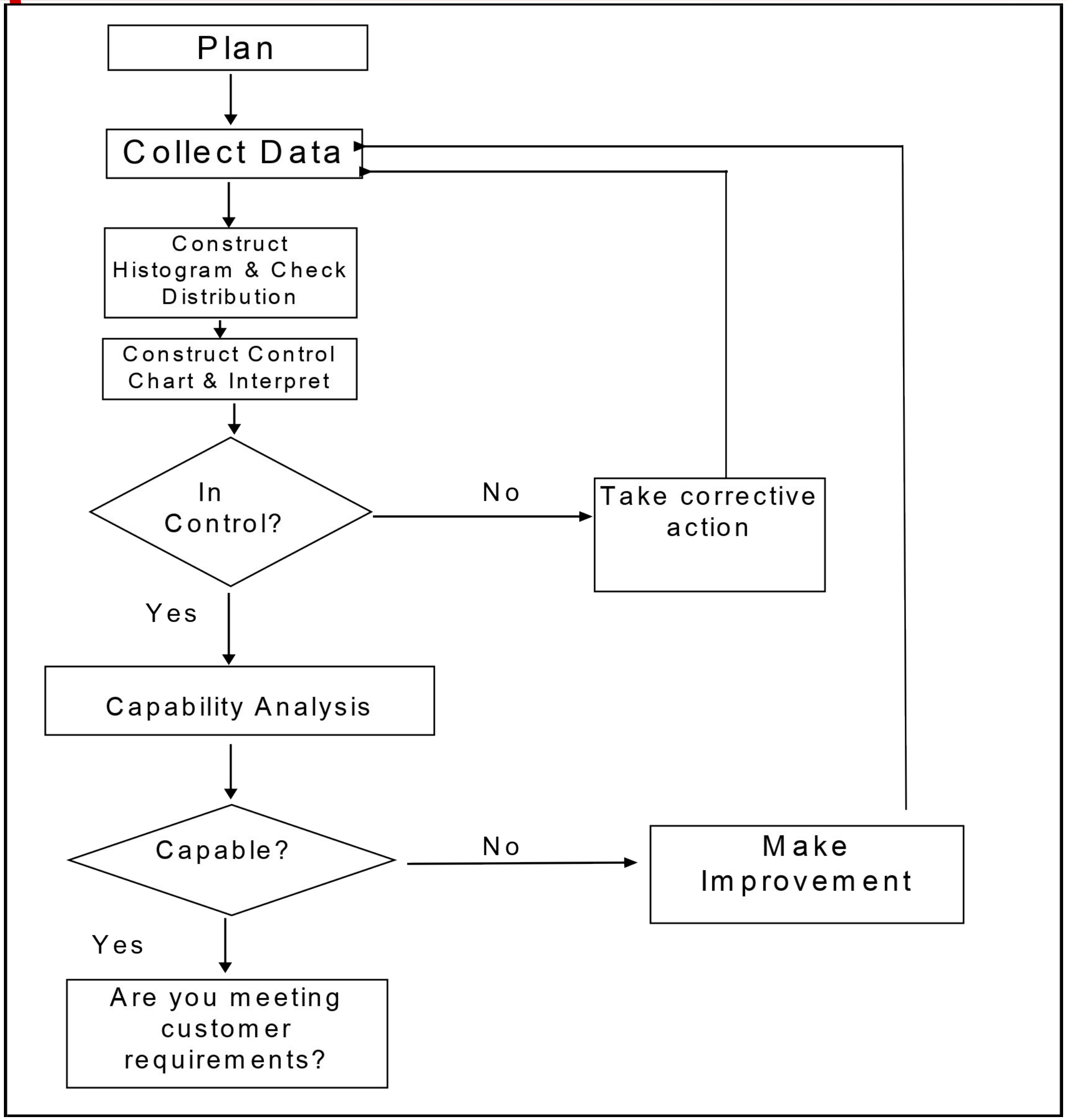
Control Charts: Tools for Process Control

- Collection
  - Gather and plot data
- Control
  - Calculate trial control limits from process data
  - Identify special causes of variation and act upon them
- Analysis and Improvement
  - Quantify common cause variation; take action to reduce it

- These three phases are repeated for continual process improvement.

Decision Making Flow Chart for SPC



Benefits of Control Charts – Chapter 1 Section H

Properly used control charts can:

- Be used by operators for ongoing process control
- Help the process perform consistently and predictably for quality and cost
- Allow the process to achieve:
  - Higher quality
  - Lower unit cost
  - Higher effective capacity
- Provide a common language for discussing the performance of the process
- Distinguish special from common causes of variation, as a guide to local action on the system

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Process Control

- Goal is to make economically sound decisions about actions affecting the process.
- Find balance between taking action when action is not necessary (over control or tampering) versus failing to take action when action is necessary (out of control).
- A process is said to be operating in statistical control when the only sources of variation are from common causes.
- Function of a process control system is to provide a statistical signal when special causes of variation are present.

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Process Control

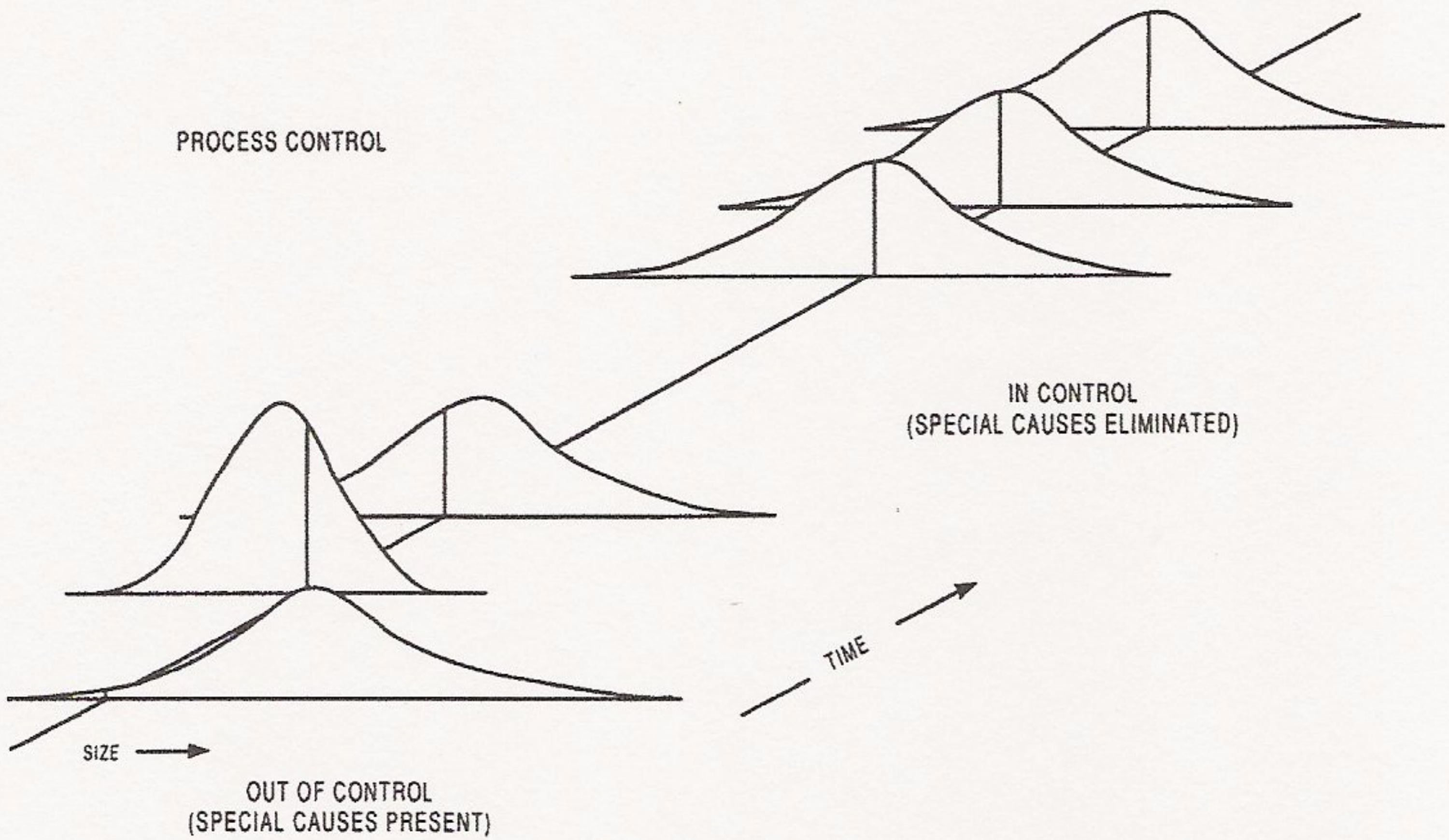

Figure I.3- Process Control

AIAG – SPC p. 18

Process Control Conditions

Consider the following conditions:

Meeting Requirements	In Statistical Control	Not in Statistical Control
Acceptable	Case 1	Case 3
Not Acceptable	Case 2	Case 4

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Process Control Conditions

- The *ideal situation* is to have a Case 1 process where the process is in statistical control and the ability to meet requirements is acceptable.
- A Case 2 process is in control, but has excessive common cause variation which must be reduced.
- A Case 3 process meets requirements and is acceptable, but is not in control. Special causes of variation must be identified and acted upon.
- In Case 4, the process is not in control nor is it acceptable. Both common and special cause variation must be reduced.

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Process Capability

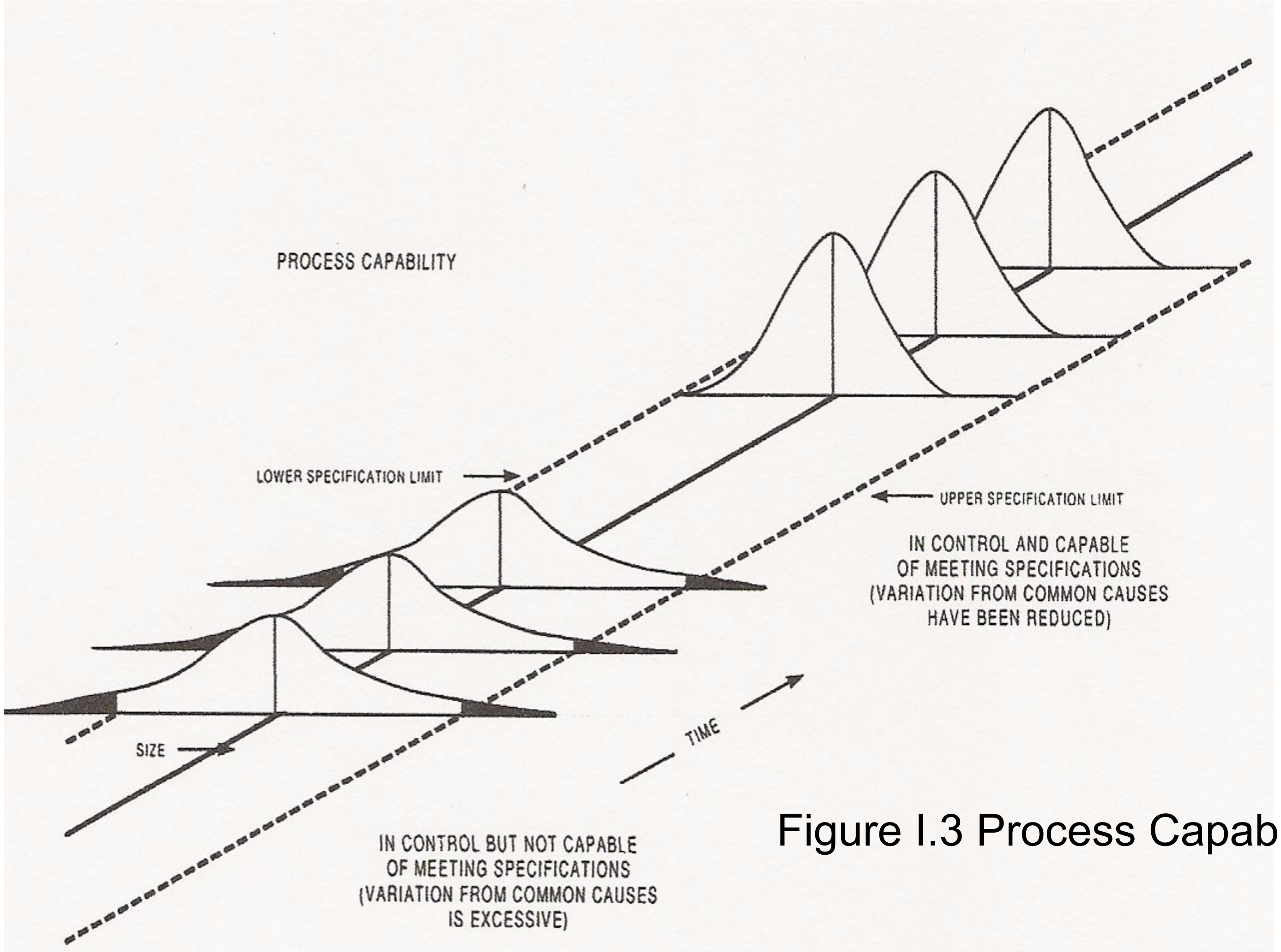

Figure I.3 Process Capability

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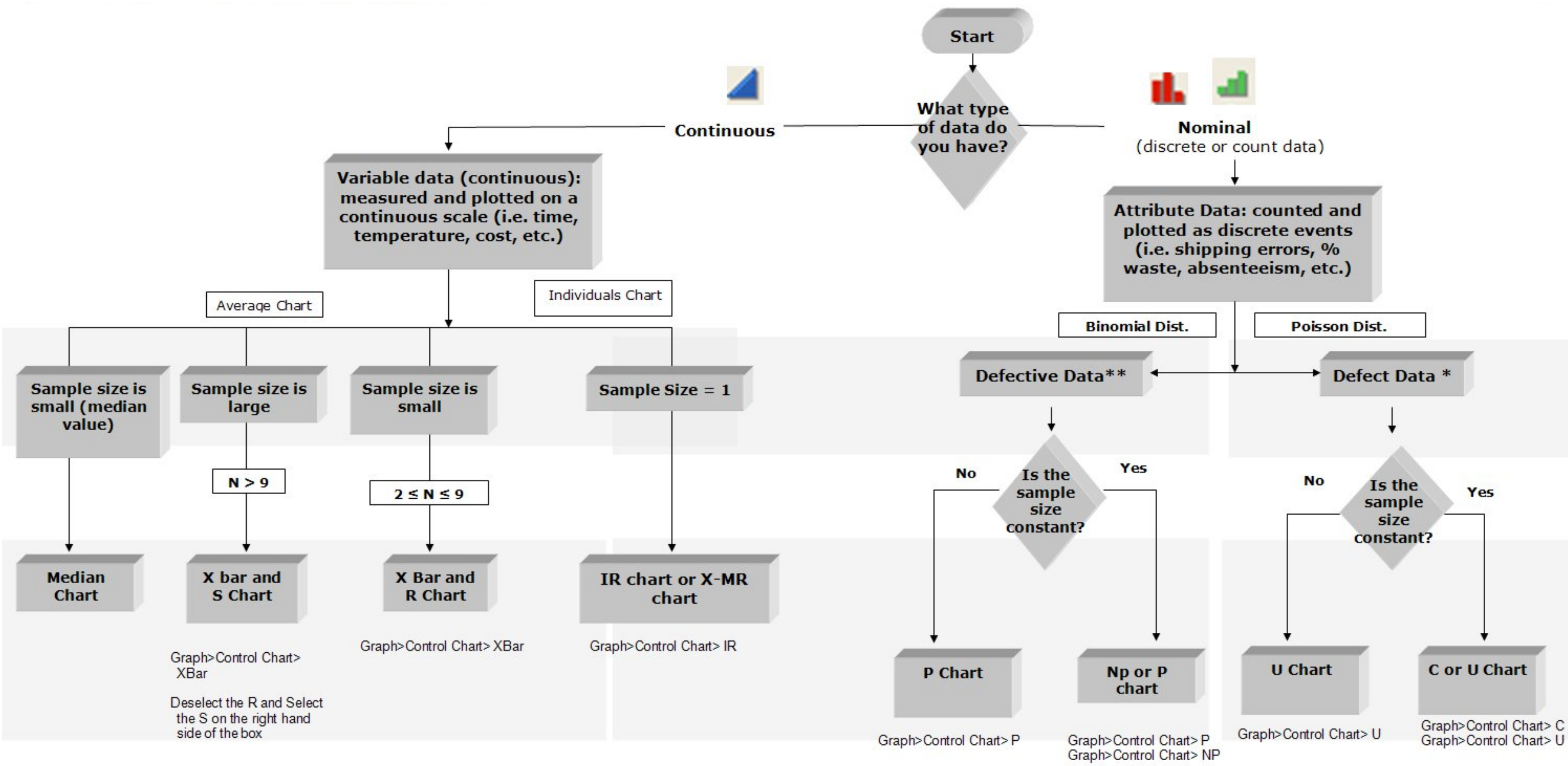
Steps to Create a Control Chart

1. Identify the type of data (variables or attribute).
2. Depending on the type of data, ask the following questions:
   a. Variables – What is the sample size?
   b. Attributes – Is the sample size constant?
3. Use the following Roadmap to select the appropriate SPC Control Chart

Control Chart Roadmap



*A defect is a failure to meet one of the acceptance criteria. A defective unit might have multiple defects.
**Defective is when an entire unit fails to meet acceptance criteria (good vs. not good), regardless of the number of defects in the unit.

CONTROL CHARTS

Introduction to Statistical Process Control

- Discuss control chart fundamentals
- Construct variables control charts
- Construct attribute control charts

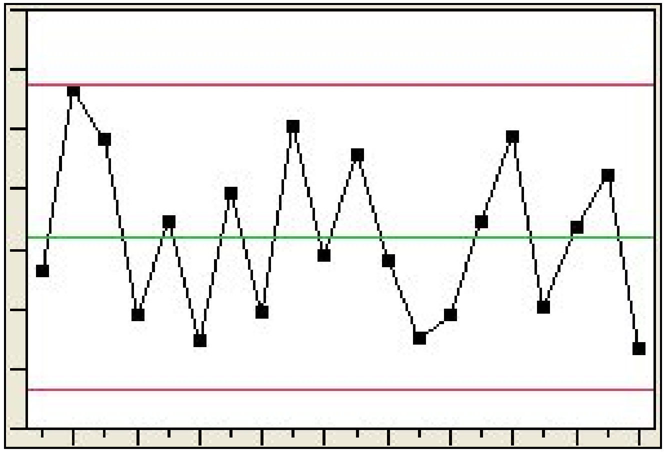
Terminology

- **Specification Limits**
  - Boundaries, usually set by management, engineering or customers, within which a process must operate
  - Voice of the customer
  - Is the service or product meeting the customer's expectations?
- **Control Limits**
  - Calculated from process data for a specific control chart
  - Voice of the process
  - Is the process behaving as expected?

Terminology - Continued

- **Common cause variation**
  - Variation that is inherent in the system
- **Special cause variation**
  - Variation resulting from an assignable cause
- **Process Capability**
  - Answers the question of how well a process meets a customer's expectations
- **Statistical Process Control**
  - Answers the question of whether or not a process is performing normally. If a process is not behaving normally, it is not predictable.

Control Charts



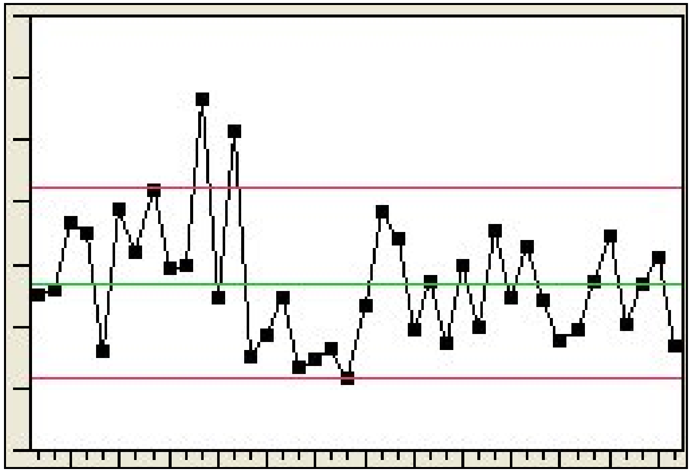
Upper Control Limit

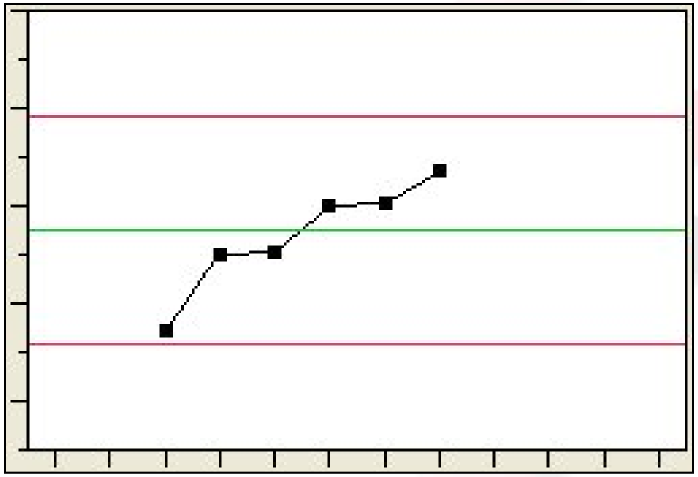
Process Average

Lower Control Limit

Control limits are typically +/- 3 standard deviations from the process average. A process that is in control, will have points distributed randomly within the control limits.

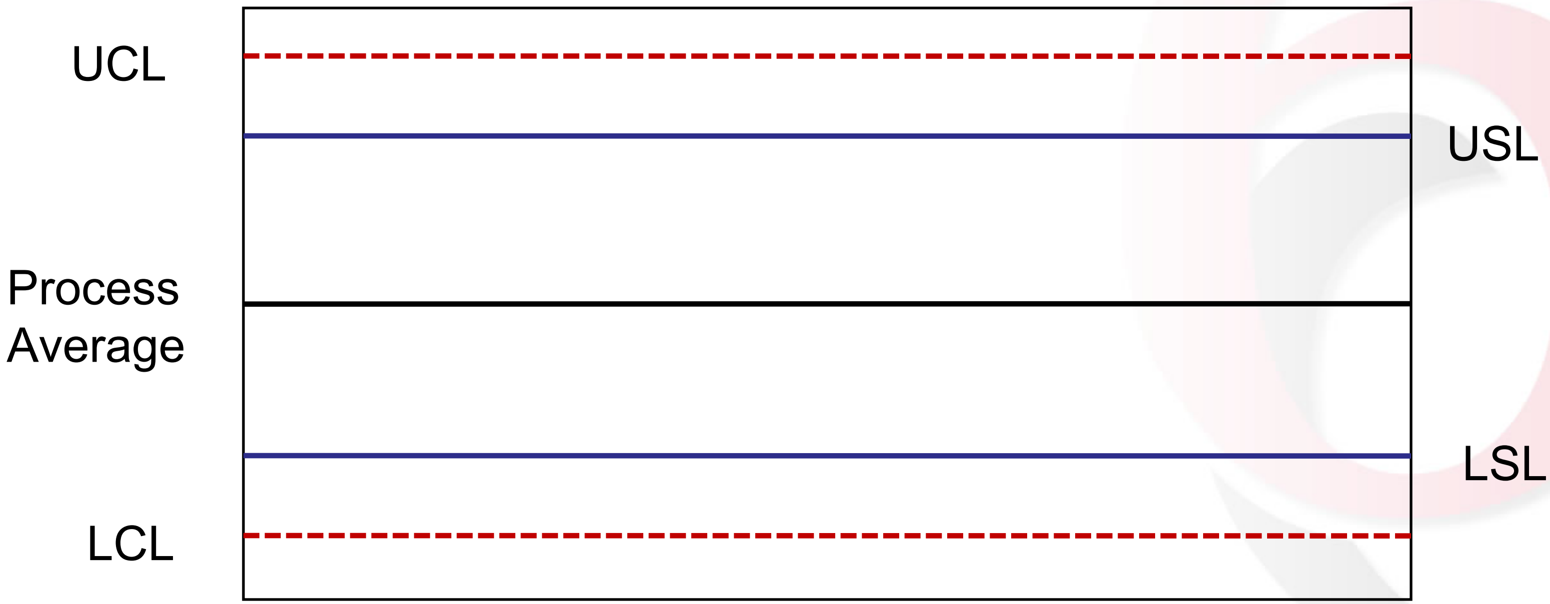
Control Charts





Processes that are not in statistical control are not predictable. Control Charts are often an element in process management plans because they allow users to determine when special cause variation is occurring.

Capability versus Control



Is this a favorable condition?

Selecting the Correct Control Chart

What type of control chart should I select?

The answer depends on the type of data being measured.

Variables Data

Attribute Data