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INTRODUCTION

Institutional Statistical Process Control (SPC) is a long term program and is much more involved than simply having charts on machines to monitor variation.

The key to the successful implementation of SPC is the combined effort of everyone working towards a reduction in and the eventual elimination of those factors causing inconsistency.

SPC provides a method to:

A. Identify and analyze problems
B. Determine process capabilities
C. Assist in setting design specification
D. Reduce rework and scrap
E. Reduce part-to-part and lot-to-lot variation
F. Increase productivity

Our goal is to reduce product variation resulting in the highest possible quality safety products and accomplish this to the least possible manufacturing cost.

To assure we meet this goal, management has made the commitment to implement SPC and to make all personnel knowledgeable with its uses. SPC provides all employees with a technique to ensure continued improvement of quality and productivity throughout our company. In today’s world market, we will use these techniques to compete. Everyone is responsible for quality.
MURRYSVILLE SPC MANAGEMENT STRUCTURE

SPC CORPORATE MANAGER

MURRYSVILLE PLANT SPC STEERING TEAM

FACTORY MANAGERS**
SPC TEAM

FACTORY MANAGERS**
SPC TEAM

FACTORY MANAGERS**
SPC TEAM

DEPT**
SPC TEAMS

DEPT**
SPC TEAMS

DEPT**
SPC TEAMS

DEVELOP AND GUIDE
SET SPECIFIC GOALS
WORK ON PROBLEMS

S. P. C. PROGRAM

* TO INCLUDE:
  MANAGER QA
  FACTORY MANAGERS
  SPC COORDINATOR

** TO INCLUDE:
  FACTORY MANAGERS
  SUPERVISORS
  INDUSTRIAL ENGINEERS
  MANUFACTURING ENGINEERS
  Q. C. ANALYST
  Q. C. ENGINEER
  S. P. C. COORDINATOR

*** TO INCLUDE:
  SUPERVISORS
  INDUSTRIAL ENGINEERS
  SET-UP MEN
  INSPECTORS
  FLOOR PERSONNEL
  Q. C. ANALYST
  S. P. C. FACILITATOR
S. P. C. TEAM FUNCTIONS

S. P. C. STEERING TEAM

TO DEFINE AND IMPLEMENT THE S.P.C, PROGRAM FOR THE MURRYSVILLE PLANT. THE CORPORATE S.P.C. MANAGER WILL ACT AS AN ADVISOR.

FACTORY MANAGERS S. P. C. TEAM

SET SPECIFIC GOALS FOR THEIR DEPARTMENTS, PROVIDE TOOLS, AND TRAINING FOR MEASURING AND EVALUATING PROCESSES. HAVE ROUTINGS CHANGED TO REQUIRE S.P.C. ON CRITICAL DIMENSIONS. WORK WITH DESIGN ENGINEERING TO ESTABLISH MEANIGFUL TOLERANCES AND WORK TO SOLVE PROBLEMS DISCOVERED BY, BUT NOT CORRECTABLE BY THE DEPARTMENTAL TEAMS.

DEPARTMENTAL S. P. C. TEAMS

TO SOLVE PROBLEMS AND ADVISE NEXT LEVEL OF MANAGEMENT OF PROGRESS AND NEEDS. TO PROVIDE AN OPEN AND FREE SPIRITED FORUM FOR DISCUSSION OF ALL QUALITY PROBLEMS WITH AN EMPHASIS ON STATISTICAL THINKING. TO WORK WITH OTHER DEPARTMENT TEAMS TO CORRECT COMMON PROBLEMS.
STATISTICAL PROCESS CONTROL
OVERVIEW

The goal of this manual is to explain your role in maintaining a successful Statistical Process Control System. This goal will be achieved by giving you a better understanding of the benefits of using process control charts, and how this information is used to improve quality and productivity. It contains the basic information we will use to start our program and will be amended as required by our experience.

Statistical Process Control (SPC) is a technique that is used to monitor, control, evaluate, and analyze a manufacturing process. It is a system of using charts and statistical methods to detect defects that need remedied in processes. Since operating characteristics of the process are what determines quality and productivity, improvement depends on the ability to improve the process. Once these defects are remedied, the process becomes stable and the true capabilities of process can be determined. This system can then be used to monitor and continually improve the process.

In no sense does a statistical procedure ever substitute for human knowledge and ingenuity. People still have to make decisions as to quality, production, or compatibility of specifications based upon information they obtain. The statistical method is simply a mathematical device or tool, which obtains better information than any other method known to date to assist people in making their decisions.

The points plotted and control limits derived are based on averages, not individuals. The process average and range are used to determine the stability of the process and are not to be used for acceptance or rejection of the individual parts. The individual parts will continue to be inspected to the drawing tolerances. The SPC information will be used to adjust and solve problems in the manufacturing process. It must be emphasized that the control limits have nothing to do with the drawing tolerances except in the calculation of process capability. When the process has been proven to be both capable and in statistical control, we may decide to reduce the level of end product inspection.

The role of the SPC facilitator in our SPC Program is to check the charts for statistical control and write reports to the supervisor when they find bad (out of specification) dimensions or out of control conditions. Also, their product knowledge should be used to correct problems found by the SPC charts. They will provide statistical knowledge to the department, as well as one-on-one training of individuals, while working with other facilitators in the plant on problem detection and solution. In areas where the operators have had simplified training, the facilitator will calculate limits and provide the first chart, as well as choose the characteristics to be charted.
The role of the operator or person in control of the actual manufacturing process shall be to make measurements or observations, make necessary calculations, and plot points on the appropriate type SPC chart. They will interpret the charts and make adjustments to the process when necessary or notify someone who can make the adjustments. They must note on the chart any changes that are made which may affect the process. As occasional members of the Department SPC Team, they will help to solve problems found both in their department and by another team or customer. They will file in-process and completed charts in the QA part number folder, and make new copies as required.

The Departmental **Supervisor** is responsible for the process and anything needed to perform the operator inspections as well as checking the charts periodically for statistical control. Also, they are to organize and promote group discussions for problem solving, and a continuous improvement policy.
Statistical Process Control
THE QUALITY / PRODUCTIVITY KEY:

INTERNAL
PROCESS CONTROL

NOT

EXTERNAL
QUALITY CONTROL
DETECTION METHOD

(Quality Through Inspection)

1. **Inefficient** – Physical and mental fatigue decreases the efficiency of inspection. Experts estimate 100% inspection is only 80% accurate at best.
2. **Costly** – Separating good from bad parts is not cost effective. Scrap, rework and repair all add to the cost of the final product.
3. **Customer Dissatisfaction** – The inspector of last resort is the customer. Reliance on inspection to assure quality will result in the customer being a vital ingredient in your quality control program.
4. **Confused Responsibility** – The Quality Control Department is not responsible for quality. Yet, most organizations believe that poor quality means the product has not been inspected enough.
5. **Symptom Oriented** – The detection method emphasizes production over quality. Therefore, adjustments to the process will be geared toward increasing production, not quality. Problems in the system are not removed but contained,
6. **Neglected Improvements** – Too busy “fighting fires” to work on process improvements.
1. **Change in Philosophy** – Away from emphasis on production to emphasis on quality. Away from short-term profits toward increased profitability through increased productivity.

2. **Change in Focus** – Solving problems at the point they occur rather than prior to shipment.

3. **Use of Statistics** – Reducing problems in the system through the use of statistical techniques that indicate how consistent, predictable and repeatable the process is.

4. **Change in Responsibility** – The prevention method brings a deeper sense of responsibility for quality to the production line.

5. **Change in Attitude** – Rather than acting as separate units, representatives of design, engineering, manufacturing, assembly, purchasing, accounting, etc. – act together to discover problem causes, not just the symptoms or the results of the problems.

6. **On-going Improvements** – Process orientation and the commensurate increases in process knowledge will lead to continuous improvement in process capability.
STATISTICAL PROCESS CONTROL

WHAT IS SPC?

- Controlling of a process through the use of a statistical or mathematical approach.

- Organized method for improving the quality and productivity of a process.
Statistical Process Control

A guideline for applying SPC tools and related problem solving concepts:

1. Select a candidate for study (try to find data having persuasive power).
   a) Pareto Analysis
   b) Cause & Effect
   c) General Listing

2. Define the process (scope of study).
   a) Cause & Effect
   b) Flow Chart of Process
   c) Brainstorming

3. Procure resources for the study.
   a) Develop forms to collect data
   b) Designate characteristics to be monitored
   c) Who is to collect data? Will process run undisturbed? How will project progress be reported?

4. Determine adequacy of measurement system
   a) Measurement System Analysis
   b) Calibration Program

5. Confirm Control Systems
   a) Be sure system provides means for identifying units in a manor allowing you to determine which variables have changed.
      (Flow chart, etc.)
   b) Assure adequate training is provided
   c) Identify as many assignable causes in advance.
      (Cause & Effect, Brainstorming)

6. Select methods of analysis
   a) Frequency Plot
   b) Run/Time Plots
   c) Multi-Vari Chart Study
   d) Control Charts (X, R, P, NP)
   e) Moving Range
   f) Scatter Plot
7. Gather & Analyze Data
   a) Frequency Plot
   b) Run/Time Plots
   c) Multi-Vari Chart Study
   d) Control Charts (X, R, P, NP)
   e) Moving Range
   f) Scatter Plot

8. Remove special causes of variation until process is stabilized (in statistical control)

9. Estimate process capability
   a) Compute S
   b) Compute X
   C) Compare 6S to Spec. Spread (capability ratio)

10. Establish quality control plan for process.
    a) Standardize what was learned in steps 1 – 9
    b) Audit established process
    c) Control charts in key process parameters on product characteristics
    d) Action to be taken when assignable cause is detected
CONTINUOUS IMPROVEMENT

KEY COMPONENTS

• TOP MANAGEMENT COMMITMENT AND LEADERSHIP

• QUALITY IMPROVEMENT BUILD INTO THE BUSINESS PLAN

• TRAINING AND PROJECTS

• PHILOSOPHY AND CONTINUOUS IMPROVEMENT – ALL DISCIPLINES – PROJECT BY PROJECT

• COST REDUCTION PROJECTS

• MEASURABLE PROGRESS

• COMMITMENT TO HUMAN RESOURCES DEVELOPMENT

• ORGANIZATION AND COMMUNICATION TO SUPPORT CONTINUOUS QUALITY IMPROVEMENT

• EMPHASIS ON CULTURE CHANGE

• STATISTICAL PROCESS CONTROL

• REWARD STRUCTURE TO ENCOURAGE QUALITY IMPROVEMENT

• INTERNALIZE QUALITY IMPROVEMENT PROCESS THAT BECOMES A WAY OF DOING BUSINESS
A PLAN FOR IMPLEMENTING CONTINUOUS IMPROVEMENT

1. To improve the control of processes / operations:

   • Determine key product / service variables for each customer / supplier relationship. (e.g. temperatures, chemistries, equipment availability, purchased material characteristics, timeliness)

   • Determine key process variables that are adjusted to obtain the key product / service variable (speeds, temperatures, purchasing criteria, frequency of maintenance)

   • Establish which process variables are in control. Hold regular review meetings to discuss status of this effort

   • Review or establish specifications for the key product / service and process variables

   • As the processes are brought under control, determine their capability.

   • Analyze the process to improve capability. Hold regular review meetings of operating people to discuss success stories, strategies and problems.

   • Develop standard operating practices.

   • Train staff to follow the standard practices.

   • Implement a program of process monitoring and review of capability with an aim toward organized adjustments in the standardized procedures for the improvement capability.

   • Establish quality improvement teams to attack selected processes and their related waste. These teams should contain operating people who understand and believe in continuous improvement.

   • Each team should have adequate technical resources, someone knowledgeable in statistical methods for problem-solving.

   • The team should be in an operation whose management is fully committed to the use of the tools of SPC and SPS.

   • Provide a communication system to disperse the results of the teams efforts to other areas. Avoid having to re-invent the wheel with each department.
2. **Address Organizational Needs:**
   - Designate a company coordinator with adequate staff for providing assistance.
   - The coordinator must be at a high enough level and report to senior management.
   - Identify staff members in each department who will be charged with applying SPC and SPS techniques to control and improve variability. Ensure that they have enough time to do this. Do not add this responsibility on top of everything else!
   - Every operating area should have at least one person skilled in statistical thinking.

3. **Plan for Training Needs:**
   - Training in statistical fundamentals
   - Training at all levels: management, operators and support staff
   - Techniques for sampling, determining maintenance programs and statistics for scheduling.
   - Additional resource people with more advanced skills.
   - Trainers for additional courses
   - Training hourly workers to, at least, plot points and look for out of control conditions.

4. **Work Toward Eliminating Waste:**
   - Long-term change to reward use of SPC and SPS techniques to correct problems when they occur.
   - A system to move away from “productivity” and towards productively following standard practices, and monitoring and improving the process.

5. **Develop a “Cost of Quality” System to Track and Report on the Hidden Cost of Poor Quality:**
   - Plan for a regular review of the costs of poor quality with emphasis on constant reduction.
   - This must be done carefully to avoid gamesmanship. The data must be used by the responsible manager to evaluate efforts and not people.
6. **Obtain the Involvement of Support Areas:**

   - The purchase department must ensure that suppliers are using statistical process control.
   
   - The maintenance department should be trained in statistical thinking to improve the quality of repair efforts.
   
   - The scheduling department can improve its capability through understanding of statistical principles.

7. **How to “Find Time”:**

   - Examine existing reports and eliminate those which do not help to manage effectively. We are drowning in enormous efforts to obtain disseminate useless numbers.

   - Eliminate the collection and reporting of statistics which do not reflect the natural variation caused by process changes.

   - Examine the decision-making process of management and decide when a phone call is likely to be ghost-chasing, wasting effort.
• Customize Training (Site Specific)

• Train Teams as Teams

• Train in Chunks (Use What You Learn)

• Train in the Real World (Real-Life Applications)

• Focus on Results, not Methods

• Install a Problem Solving Tool, not a system

• Use Statistical Problem Solving (SPS) Along with SPC
BENEFITS

1. **IMPROVED SALES** – People who understand how effective SPC is at controlling quality and improving productivity are much more likely to buy products produced under this system.

2. **IMPROVED PRODUCT QUALITY** – and therefore increase productivity

3. **REDUCE END ITEM INSPECTION** – Suppliers who successfully use these techniques during production are candidates for reduced inspection.

4. **HELP REDUCE** – scrap, rework, repair and unnecessary adjustments to the process.

5. Determine first of all whether a **PROCESS IS CAPABLE** of producing parts of specification.

6. Help Product Engineers to **ESTABLISH REALISTIC TOLERANCES** on future work or change existing tolerances to coincide with existing process capabilities.

7. **HELP DIAGNOSE AND CORRECT PRODUCTION PROBLEMS.** Decisions for corrective action are based on facts rather than intuition or memory.

8. Provide a **COMMON LANGUAGE** for effective communication between the machine, operators and management.
Seven Steps of Problem Solving

1. Define Problem / Set Priorities.

This can be done in several ways. Brainstorming will allow you to generate a list of problems. After the initial list of problems is generated, edit the list to similar categories and make a Pareto Chart. When collecting data for the Pareto Chart, be sure to spend enough time to actually represent the entire/complete process.

Examples:

- One job may run a high rate of “defect c.” If data is only collected during that job run, you may have misleading information.

- One day of order entry may have unusually high kick-outs. Collecting data for only that day may be misleading.

Accurate data collection may take weeks or months! Experienced team members may be tempted to make the problem selection based on gut feeling and bypass data collection but, factual information is important for several reasons:

- Data collected will show:

  How big a problem we have.

  How much it is costing us in production, waste, dollars, time, etc.

  These facts will be invaluable for the Steering Team later in this process. Cost may be analyzed in all of the 4M’s.

- You may find from the data collected, that the problem is not as great in magnitude as once suspected.

- When a team arrives at Step Seven and evaluates the action taken, there is historical data for comparison.
When a problem is selected it should be defined by a problem statement or short paragraph. DO NOT list any causes in this statement. By listing causes you limit yourself and exclude possibilities.

Often, several Paretos will be made in sequence. The information gained from one will be helpful for the next Pareto Chart.

Example:

The Team collected data in the injection molding and the types of defects. They found that contamination is the biggest type of waste.

At this point it may be appropriate to make a Pareto Chart on the types of contamination discovered. The same sequencing can be applied in the office area.

2. Analyze How The Process Behaves:

This step is often omitted by most teams. It is crucial to understand how this is affecting your process. Several tools will help:

**Histograms:** To show where your process is and the distribution.

**Control Charts:** Will help understand how this problem affects the process.

**Flow Chart:** Will help break down all steps in the process.

3. Identify All The Causes:

Many teams already know what is causing the problem because they have lived with the problem for years. Remember, the team is made up of persons from all parts of the process so each will see the problem from a different angle. If the previous two steps were followed properly, new light will likely be shed on the process.

A cause and Effect Diagram is an excellent tool here because it organizes all the potential causes to the problem and often opens doors that were not previously considered. Using the tool properly will take several hours. Upon completion, the team should go back through each area and if necessary collect data on several key causes.
Flow Charts may also be used at this point is the process. Look at the detailed, completed chart and find specifically which steps are the snags in the process.

When this step is complete, the team knows the problem (from step one), and the cause (from step three).

4. Identify All The Possible Solutions:

This is an excellent opportunity for brainstorming. Solutions may be generated by considering the 4M’s categories from the Cause and Effect Diagram; material, machines, method, manpower. Solutions may include a change in:

- **Material:** Deciding if one supplier of a material is capable of delivering consistently high quality at a reasonable price.
- **Machines:** Parts, rebuilding, or new machinery
- **Method:** The way you do things or a change in the process.
- **Manpower:** Training of the operator.

5. Select The Best Solution:

The team’s best approach to this is a Consensus decision. Ask clear questions:

- *How will this solution correct the problem?*
- *Why is this the best solution?*

The decision is one in which, after a structured discussion, everyone will support as if it were their own. It is always wise to choose an alternate solution.

Keep in mind the **value** of your solution. If the problem costs the company $350.00 a month, can your solution of a $1000,000 machine justify itself in a reasonable amount of time?
6. Implement Solution:

On a “common cause” type problem, the solution is presented to the Steering Team. Have your Key Facilitator (supervisor) look over the proposal. Invite the Coordinator to your meeting. The homework to be done to present to the Steering Team will be minimal.

The work has already been done in the previous five steps of Problem Solving. Bring all data, charts, etc. to the Steering Team meeting. When a decision has been reached, decide who will implement the solution.

7. Evaluate Action Taken:

This is a very important step to ensure that the solution implemented has worked. Many methods apply to this step. In essence you are repeating the first step. If a Pareto Chart was made on different types of contamination, collect data under the same conditions and categories at last time, and determine if the original biggest problem has changed to a different category.

Summary

Always think of problems as opportunities for improvement! Opportunities exist in waste reduction, problem solving, and most importantly process improvement. The emphasis is on improving productivity and when you improve productivity, production will automatically increase.
CONSENSUS DECISIONS

Consensus has been reached when:

- All group members agree to support the decision though it may not be everyone’s first choice.

- Everyone is committed to it as if it were the first choice of all group members.

- Everyone agrees that he or she has had sufficient opportunity to influence the decision.

Any member of the group can block a decision. This is precisely why consensus decisions are both more difficult and more effective than other group decision methods, such as voting. It forces the group to consider all aspects of the problem and objections to possible courses of action. Treat differences of opinion as a way of (1) gathering additional information; (2) clarifying issues and (3) forcing the group to seek better alternatives.

GUIDELINES

1. Try to get underlying assumptions regarding the situation out into the open where they can be discussed.

2. Listen and pay attention to what others have to say. This is the most distinguishing characteristic of successful work groups.

3. Be cautious of early, quick, easy arguments and compromises. They are often based on erroneous assumptions that need to be challenged.

4. Avoid competing and arguing. In this situation either the group wins or no one wins. What is “right” is the best collective judgment of the group as a whole.
5. **Do Not Vote.** It will split the group into “winners” and “losers”, it encourages “either……or” thinking when there may be other ways, and it fosters argument rather than rational discussion.

6. Encourage others, particularly the quieter ones, to offer their ideas so that everyone is included in what is decided.

7. Tension reducing behaviors can be useful so long as meaningful differences are not “smoothed over” prematurely.

8. The best results flow from a fusion of information, logic and emotion.
THE FIVE WAYS

The solution to some problems is readily apparent if the ROOT CAUSE can be determined. It is sometimes possible to determine the ROOT CAUSE by asking the question WHY about FIVE times.

EXAPMLE:

Q. 1. Why are we late in shipping complete units?
A. Final Assy. Is behind in completing gear boxes

Q. 2. Why is Final Assy. Behind in completing gear boxes?
A. Because of late delivery of finished shafts for the gear boxes from machining.

Q. 3. Why is machining behind in finishing shafts?
A. Because of an increased rate of breaking cutting tools.

Q. 4. Why are the cutting tools breaking more often?
A. The incoming shaft stock is harder.

Q. 5. Why is the incoming shaft stock harder?
A. The supplier sent the wrong grade of steel.

Some thought must be given to asking the right WHY’S. It is not uncommon to see solutions in less than an hour, when this technique is applicable and used correctly.

Extreme caution must be used in applying the WHY approach. It can be very intimidating if used to find blame. Particularly is the questions are used from the top down and/or with emotion.
FIVE WHYS EXAMPLE

Q. 1. Why did the crust breaker at the point line fail?  
A. Because of an air leak

Q. 2. Why was there an air leak?  
A. A hole developed in the hose (XYZ)

Q. 3. Why did this hose develop a hole?  
A. The hose rubbed thin around the pivot pin.

Q. 4. Why did the hose wear thin at that location?  
A. The hose was either too short or the radius of the pin was too small.

Q. 5. Why did either of these reasons occur?  
A. A design problem which could have resulted from lack of feedback to the design engineer.
BRAINSTORMING

Lesson Objectives….

To help you make the most effective use of this manual and your time in learning the concepts described, we have listed below your study objectives for this lesson. These objectives tell you where you are going in this lesson and what you can expect to learn.

Please read these objectives carefully and keep them in mind as you read and study this lesson. You should be able to accomplish each of these objectives upon completion of this lesson.

• Describe the Brainstorming process.

• Identify / List the steps in effective Brainstorming.

• Describe how / why Brainstorming is an effective tool.

• Identify possible uses for Brainstorming in your area.

• Participate effectively in Brainstorming in your team.
After Brainstorming:

Refine and screen the list of ideas. In this step, duplicate ideas are removed from the list, similar ideas are combined, ideas are put into categories, etc.

Present the “final” idea list (after refining and screening) to the group. Get agreement on the list.

Be sure to express appreciation to the group for their participation. Congratulate them for the idea list achieved.

Results and Benefits:

This process usually results in a good supply of ideas, many of them new and different.

“Creativity strikes again.”

Persons are more committed to implementing ideas they had a part in generating.
Specific Steps:

1. Introduce Brainstorming and get agreement to use the method.

2. Identify Topic

3. Select and instruct Recorder(s).

4. Set a time period.

5. Establish ground rules:
   - all ideas accepted
   - no criticism
   - no discussion
   - everyone participates
   - no evaluation

6. Begin idea generation:
   - as many ideas as possible
   - quantity not quality
   - popcorn effect

7. Allow for occasional “collection” times.

8. Stay with the process until all ideas are exhausted, or allotted time is used.
9. Review list of ideas

10. Refine and screen ideas

11. Allow any additional ideas

12. Present list as refined and screened

**Used To Generate / Identify:**

- New concepts / Ideas
- Existing problems
- Causes of problems
- New methods for doing things
- Goals and objectives
- Many, many ideas

(Why not brainstorm all the ways that brainstorming can be used?)
Summary:

Most group meetings involve both the generation and the immediate evaluation of members’ ideas. It is critical to keep the generation separate from the evaluation. The consequences of evaluating ideas as they are being generated is that group members will be less likely to continue generating ideas if past contributions are ridiculed or labeled impractical or unrealistic. The result of this, over time, will be that fewer and fewer ideas will be generated. Moreover, the ideas will tend to be primarily generated in order to gain group acceptance or respect.

Sooner or later, individuals internalize the idea evaluation process and “pre-edit” their ideas before expressing them to avoid ridicule by others. This slows down or eliminates the spontaneity needed for the creative process. Consequently, novel or outstanding ideas are rarely conceived. When this happens, groups tend to go over “old ideas” and then lose interest in and respect for the Brainstorming process.

The Brainstorming process attempt to avoid idea slow-down by separating the generating from the evaluating of ideas. The theory is that increased quantity of ideas (even though many may be “bad”) will result in increased quality. Additionally, ideas, which by themselves may not contribute to the problem solving, may in combination with other ideas, result in effective solutions or approaches to solutions.
Review:

Brainstorming is a method of idea generation used to ___________ a topic with Brain Power. This is usually done in _________________. This is more beneficial than discussion because _________________. Initially, always go for ________________ not _________________. A very desirable condition of the Brainstorming session is the ________________, which occurs when one idea sparks another from other team members. The recorder’s job is very important and he/she must be careful about ________ and be sure to ___________. After the initial Brainstorming is complete the next step is to _________________. Brainstorm three examples of how this problem solving method will help in your process.

1. ___________________________________________________________________

2. ___________________________________________________________________

3. ___________________________________________________________________
Pareto Chart

Lesson Objectives...

To help you make the most effective use of this manual and your time in learning the concepts described, we have listed below your study objectives for this lesson. These objectives tell you where you are going in this lesson and what you can expect to learn.

Please read these objectives carefully and keep them in mind as you read and study this lesson. You should be able to accomplish each of these objectives upon completion of this lesson.

• Construct a Pareto Chart using data.
• Construct a Pareto Chart in conjunction with Brainstorming.
• Define the purpose of the Pareto Chart.
• Describe how to collect data for the Pareto Chart.
• Identify how the Pareto Chart is used.
• Describe application of the Pareto Chart in your work area or team.

Definition:

The Pareto Chart is a bar graph which is used to prioritize items in their order of importance.

The Pareto Chart has a vertical axis which lists the number of times an event occurred and a horizontal axis which defines the various events which have occurred.

**Frequency**
(Number of times the event occurred)

<table>
<thead>
<tr>
<th>Events (Categories)</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Specific Steps:

1. Classify data by identifying categories (such as defects) to be considered.
2. Decide how long data will be collected.
4. Collect data by classification such as number of times it occurs, how much it weighs, how many items, or how much it costs.
5. Show totals from each category.
6. Draw a graph
7. Show each event in its order of importance. Draw the bars on the graph.
8. Tell what the graph is, and make a legend.

Used To:

The Pareto Chart is used to:

- Set Priorities
- Rank people’s perceptions when used with Brainstorming.

Application:

Apply the Pareto Chart to the process. Follow the steps for constructing a Pareto Chart. The priorities set by the Pareto Chart will show you were to begin your problem solving process in order to improve your process(es).

Example:

A completed Pareto Chart will look like the example below. Yours will have the classifications, numbers and information from your data collection and study.
Vilfredo Pareto (1848 – 1923) was an Italian economist who made contributions through his use of scientific methods and theory as an approach to the study and understanding of economics. Pareto also used sociology as a foundation for this theories. He was a professor of Political Economy at the University of Lausanne, Switzerland, from 1893 to 1907.

Vilfredo Pareto gave us the 20/80 rule, which says that 20% of the “problems are responsible for 80% of our “trouble”. Pareto’s “rule” holds true on your example graph. This rule applies in many other setting, too.

The graph has set priorities for you by separating the “trivial many” from the “vital few”. It tells you to begin to look for causes of your most important (top priority) problem or category, and to begin to analyze how the process behaves. This can be done by using several methods, possible the Cause and Effect Diagram, which will be discussed later.
### PARETO CHART
### DATA COLLECTION WORKSHEET

**Team:** ___________________  **Start Date:** ____________

**Department:** _______________________________________

**Operator(s):** _______________________________________

---

<table>
<thead>
<tr>
<th>Categories Of Data:</th>
<th>Frequency Tally Box:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>
Review:

In this lesson I have learned how to construct a Pareto Chart. The purpose of this is ______________________________. The person we developed this chart is _______________. Besides the Pareto Chart, he also popularized a rule of thumb called the ____ rule. This says that ____ of your problems will give you _____ percent of your trouble.

When a Pareto Chart is created, choosing a problem to work on is simple. Just select ____________.

To make a Pareto Chart, determine first your __________________ and decide upon ______________. Then collect data using a tally sheet which is usually designed in the team meeting.

Upon completion of data collection, add up each category. Next draw a ______________. Make a ______________ on the vertical axis which should go just a little higher than the biggest category. Show each bar starting with the ________ first and in __________ order. Show totals for each category.

The ____________ is important because it gives reference information such as ________________________.
PARETO DIAGRAMS

A pareto diagram (bar graph) indicates which area is responsible for the largest percentage of your problems. However, an area which shows only to be a small percentage of your problems may be costing you the most money. If possible, research the facts and classify your problems in dollar amounts.

PARETO PRINCIPLE:

“Vital Few” vs. “Trivial Many”

After acting upon the area you’re determined to be the most severe problems, construct another diagram to see if improvements have been accomplished. If so, the percentage or length of the bar for the problem for which you have been concentrating will have been reduced or replaced as the most severe. As changes are made to improve percentages or proportions of bars will vary depending upon how great the effect of the changes.
CONSTRUCTING A PARETO DIAGRAM

A. Decide upon classification for your diagram and be sure that these classes have itemized frequencies of occurrence or itemized costs.

B. Decide upon a time period for your diagram. All related diagrams should use the same period of time for ease of comparison.

C. Total each item, or use 100% as the total and list each item as a percentage of a 100.

D. Draw horizontal and vertical axis.

E. Segment the vertical axis in the terms you are using (ex. Dollars or percentages)

F. On the horizontal axis list in order of severity the classification you have researched. Severity can be thought of as the most dollars spent or costs per problem, or as percentages.

G. Extend the bars for each class to the appropriate frequency or percentage.

H. Log any pertinent information on your graph for future reference.
FLOW CHART

Lesson Objectives…. 

To help you make the most effective use of this manual and your time in learning the concepts described, we have listed below your study objectives for this lesson. These objectives tell you where you are going in this lesson and what you can expect to learn.

Please read these objectives carefully and keep them in mind as you read and study this lesson. You should be able to accomplish each of these objectives upon completion of this lesson.

• Describe the Flow Chart
• Identify/list the steps in constructing a flow chart
• Describe why the Flow Chart is an important tool.
• Identify ways you will use Flow Charts in your job.
Definition:

A Flow Chart is a graphic representation of the sequence of all events (actions) occurring during the performance or procedure. It is a “map of the system”.

How To Construct:

1. Identify the system/process to be charted.
2. Write a simple step-by-step description of the process.
3. Describe on a level of detail
4. Identify each function on the process.
5. Identify the appropriate symbol to use with each function.
6. Draw symbols/functions in sequence.
7. Review the Flow Chart
Reminders:

- Keep the wording simple

- Maintain a consistent level of detail. Recheck periodically

- Use a few easily understood symbols.

- Analyze to insure inclusion of each step.

- Check your flow chart for necessity of each step.
  
  - Look for complexities and redundancy.
  
  - Are there control points built in to prevent errors and rejects?
  
  - Is this process actually what is should be?
  
  - How can this process be more effective?
Advantages:

• It is a graphic illustration.

• The visual is easier to grasp than the verbal.

• The information is more focused.

• It reveals interdependence of steps in the process.

• It eliminates unnecessary steps in the process.
FLOW CHART

A FLOW CHART IS A PICTORAL REPRESENTATION OF THE SEQUENCE OF EVENTS IN LOGICAL ORDER.

FLOW CHARTS MAY INDICATE PROBLEM SOLVING LOGIC OR PROCESS FLOW.
PROBLEM SOLVING LOGIC FLOW CHART

PROBLEM: LAMP WILL NOT LIGHT

START

CHECK PLUG

CHECK BULB

CHECK WALL SOCKET

CHECK LAMP CORD

CHECK LAMP SWITCH

CHECK LAMP SOCKET
PROCESS FLOW CHART

1

LOAD CONVEYOR (MANUAL)

UNLOAD CONVEYOR (AUTOMATIC)

DIP (AUTOMATIC)

LOAD CONVEYOR (AUTOMATIC)

DRY

UNLOAD CONVEYOR (MANUAL)

TRANSPORT TO FOUNDRY

2

LOAD CONVEYOR (AUTOMATIC)

UNLOAD CONVEYOR (AUTOMATIC)

DIP (AUTOMATIC)
FLOW CHARTS ALSO UTILIZE LOOPS AND BRANCHES

LOOP: A SEQUENCE OF EVENTS WHICH REPEAT UNTIL A CERTAIN CONDITION IS MET.
PROBLEM: DOES CHECKBOOK AGREE WITH BANK STATEMENT?

START

RECORD ALL CHECKS WRITTEN THIS MONTH

SUBTRACT CHECKS WRITTEN FROM BALANCE

DOES CALCULATED BALANCE AGREE WITH BANK STATEMENT

END
BRANCH: TWO PARALLEL SEQUENCE OF EVENTS; WITH THE CHOICE OF EXECUTION DEPENDING UPON A CERTAIN CONDITION.

START

STEP 1

DECISION?

STEP 2A

STEP 3A

STEP 2B

STEP 3B

STEP 4

END
WASHING FLOW CHART

LOAD CLOTHES

COLORED CLOTHES

ADD MILD DET.

SET TEMP TO WARM

WHITE CLOTHES

ADD DET. AND BLEACH

SET TEMP TO HOT

CLOSE DOOR

INSERT 25¢

PUSH PLUNGER
CHOCOLATE FUDGE FLOW
CHART

START

COMBINE IN SAUCEPAN: SUGAR, MILK, CHOC. OR COCOA, CORNSYRUP & SALT.

HEAT & STIR

IS CHOC. & SUGAR MELTED?

COOK

IS BALL SOFT?

REMOVE FROM HEAT & ADD BUTTER

COOL TO LUKEWARM

ADD VANILLA

BEAT

HAS IT LOST ITS GLOSS?

STIR IT QUICKLY

POUR IN PAN

COOL TO SET

SUIT IN SQUARES

END

NO

YES

NO

YES

NO

YES
PROBLEM SOLVING FLOW CHART

START

UNDERSTAND THE PROBLEM

IDENTIFY THE PROBLEM

ANALYZE THE PROBLEM

PLAN THE SOLUTION

TEST THE SOLUTION

SOLUTION OK?

IMPLEMENT THE SOLUTION

DID IMPLEMENTATION SOLVE THE PROBLEM?

END
Lesson Objectives….

To help you make the most effective use of this manual and your time in learning the concepts described, we have listed below your study objectives for this lesson. These objectives tell you where you are going in this lesson and what you can expect to learn.

Please read these objectives carefully and keep them in mind as you read and study this lesson. You should be able to accomplish each of these objectives upon completion of this lesson.

• Identify/list the steps in constructing a Fishbone Chart

• Describe how/why Fishbone Charts are an effective tool.

• Identify possible uses of fishbone Charts in your area.

• Participate effectively in constructing a Fishbone Chart in your Team.
Fishbone Chart / Ishikawa Diagram

Definition:

This is a method for identifying and charting all of the possible causes of a problem. This method is important because all of the possible causes of a problem must be known before a genuine solution can be identified and implemented. It was developed in 1950 by Kaoru Ishikawa at the University of Tokyo.

Purpose:

- To identify all of the possible causes of a problem, and provide a method for showing (charting) the causes so that appropriate, effective action can be taken.

- To take the “guess work” out of the problem solving.

- To show the relationship between the causes and the effect they have on the process.

- To provide a tool to systematically break down the sometimes complex causes of a problem. The Cause and Effect Diagram also fulfills the need for sorting through and prioritizing causes.

- To eliminate time-consuming and frustrating efforts at problem solving.

- To find the REAL cause or causes of a problem.
Reminders:

Most problems are the result of a number of different causes. When a problem is identified, it must be analyzed to identify/define all of the possible causes before solutions are identified and put into action.

Two “pitfalls” to effective problem solving:

• Assuming the cause(s) is/are known without analyzing the problem.

• Identifying a problem and immediately providing a solution.

A Total Quality Attitude in a Total Quality Culture demands a Total Quality Approach to Problem Solving. To get real solutions that are permanent and work requires finding and addressing all the real causes of the problem. No short cuts!
How to construct:

1. Identify and clearly define the problem, the “effect”, or the quality characteristic that requires improvement.

2. Write the specific problem / effect or the quality characteristic that requires improvement in a rectangle or square on the right side of the page.

3. Draw the main line across the page to the problem identified.

4. Ask the question, “What are the Major Causes and of the Problem?”

In most cases, especially in a manufacturing setting, the four M’s of production are Materials, Methods, Manpower, and Machines. These will serve effectively as the MAJOR CAUSES.

5. Place two of the MAJOR CAUSES above the main line, and two below the main line, with arrows drawn diagonally to the line and slanted toward the problem.
6. Identify the **MINOR CAUSES** related to or contributing to the **MAJOR CAUSE**. Focus on each **MAJOR CAUSE** and identify the factors which contribute to that cause. Draw and arrow pointing to the **MAJOR CAUSE** for each **MINOR CAUSE**. These become the “bones” in the Fishbone Chart. **MINOR CAUSES** are identified by asking the questions “How?” or “Why?” The answer becomes the **MINOR CAUSES**.

![Fishbone Chart Diagram]

Be sure to show **MINOR CAUSES** as one word or very brief phrases. Always avoid phrases such as, “bad part”. Instead, write the name of the part, and use **SUB-CAUSES** to describe what characteristic caused it to be “bad”.

7. List the **SUB-CAUSES** related to or contributing to each **MINOR CAUSE**. Your purpose is to factor down each cause from **MAJOR** to **MINOR** to **SUB-CAUSES**. Draw an arrow for each **SUB-CAUSE** to the **MINOR CAUSE** to which it relates.
Keep asking the question “How?” and “Why?” Make each answer a SUB-CAUSE and ask the question again. Factor these down to one word answers, if possible.

8. Review the Fishbone Chart.

- Be sure all items which contribute to (or cause) the problem have been identified and listed.


- Identify the top priority “causes”.

- Determine which problem solving method(s) will be used next.

- Use the next problem solving method to continue the process.
A cause-and-effect (or Fishbone) diagram is a simple yet effective tool that facilitates the investigation into the causes of a problem. Fishbone diagrams are most effective when used by a group of people working on a problem. While they are most frequently applied to product quality problems, they are just as appropriate for other industrial and non-industrial problems.

When cause-and-effect diagrams are used for product quality problems, the goal is usually to find the sources of variation. The diagram is started as indicated below with the problem on the right and the basic process components represented by the main branches (sources of variation).
A. Decide on a problem (effect) and write this on the right side of your diagram. Draw an arrow from the left side to your problem.

B. Write the prominent factors which could be causing your problem above or below the main arrow, directing a branch arrow for each to your main arrow.

C. Onto each branch arrow, write any factors which could effect these items. Call these twigs. Add twigs to the twigs if necessary. Continue in this manner until you have found the causing factor.

- If your diagram has only branched and no twigs, then probably your knowledge of the process is too limited and it’s time to enlist the help of others to uncover other possible causes.

Make the most use of your diagram. Work hard at finding the cause. After you find what you believe is the causing factor, repeat the steps you took through your cause-and-effect diagram which led you to this factor. If you get lost in your diagram or you can’t tie the real factor down, then the diagram causes are not the real causes of the problem. Reconstruct the steps you took being sure to include any factors not previously written in.

Log any specific data (ex. Time, material) relative to the cause right on the diagram to lead you to prompt action in the correct area.
PROBLEM SOLVING METHOD
BRAINSTORMING

PURPOSE:

Generate new Ideas

Identify:
• Problems
• Causes
• Solutions

STEPS/RULES:

Introduce Brainstorming and get Agreement to use the method.

Identify Topic

Select and instruct recorder(s).

Set a time period.

Establish ground rules:
• All ideas accepted
• No criticism
• No discussion
• Everyone participates
• No evaluation
PROBLEM SOLVING METHOD
BRAINSTORMING

PURPOSE:

STEPS/RULES:

Begin idea generation:

• as many as possible
• quantity not quality
• popcorn effect

Allow for occasional “collection” times

Stay with the process
Until all ideas are
Exhausted, or allotted
Time is used.
PROBLEM SOLVING METHOD
PARETO CHART

PURPOSE:

Set priorities
20 / 80 Rule
Determine most Important category

STEPS/RULES:

Classify data in categories
Set time period
Collect data
Show total from each Item
Draw graph with scale on Side
Draw bars
Develop legend
PROBLEM SOLVING METHOD
PARETO CHART

PURPOSE:

Determines all the
Possible causes of
One problem

STEPS/RULES:

Draw diagram

Problem in box on
Right side.

Major Causes-Four M’s
Of production

Minor Causes

Subcauses

Ask “how” and “why”
PROBLEM SOLVING METHOD
FLOW CHART

PURPOSE:

- Graphic presentation
  Of process, job, or system
- Map of system
- Training Tool
- Add / delete step
  In our process
- Analyze process
- Determine causes

STEPS/RULES:

- Identify system/ process
to be charted
- Write a sample description
  Of each step of the process
- No dead ends
- Same degree of detail
- Use correct symbols:
  - Action/Activity
  - Decision
  - Reference letter
  - Start / Stop
  - Review flowchart
# STATISTICAL METHOD

## X, R CHART

**PURPOSE:**

<table>
<thead>
<tr>
<th>To understand were the process is running</th>
<th>Use measurable (variable) data</th>
</tr>
</thead>
<tbody>
<tr>
<td>To control the process</td>
<td>Decide on time period For data collection</td>
</tr>
<tr>
<td>To know when to adjust the process and when</td>
<td>Decide how many measurements in subgroup</td>
</tr>
<tr>
<td>To leave it alone</td>
<td>Collect data-note changes in the process</td>
</tr>
<tr>
<td>Analyze how the process behaves</td>
<td>Find X and R for each Subgroup</td>
</tr>
<tr>
<td></td>
<td>Calculation worksheet</td>
</tr>
<tr>
<td></td>
<td>Plot data-Range chart first</td>
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<tr>
<td></td>
<td>Add control limits</td>
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<tr>
<td></td>
<td>Use with data collected in Subgroups</td>
</tr>
<tr>
<td></td>
<td>Interpret chart</td>
</tr>
</tbody>
</table>
STATISTICAL METHOD
MOVING RANGE CHART

PURPOSE:

Same as X, R Chart:
To understand were
The process is running
To control the process
To know when to adjust
The process and when
To leave it alone
Analyze how the process behaves

STEPS/RULES:

Use measurable data
Decide on time period for
Data collection
Range is difference
Between 1st & 2nd
measurement,
2nd & 3rd, etc.
Calculation worksheet
Plot data range first
Add control limits
Use individual
Measurements
No subgroup
Interpret chart
### STATISTICAL METHOD
**p CHART**

<table>
<thead>
<tr>
<th>PURPOSE:</th>
<th>STEPS/RULES:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shows the % defective</td>
<td>Use with measurable (attribute) data-go/no, good/bad, visual judgement</td>
</tr>
<tr>
<td>Analyze how the Process behaves</td>
<td>Determine subgroup size - Must be at least 25</td>
</tr>
<tr>
<td></td>
<td>Decide on time periods</td>
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<tr>
<td></td>
<td>Collect data- Note changes in process</td>
</tr>
<tr>
<td></td>
<td>Determine fraction</td>
</tr>
<tr>
<td></td>
<td>Defective</td>
</tr>
<tr>
<td></td>
<td>Determine % defective</td>
</tr>
</tbody>
</table>
STATISTICAL METHOD
p CHART

PURPOSE:

STEPS/RULES:

- Calculation worksheet
- Draw scale on Chart
- Plot data – % defective
- Add control limits
- Interpret Chart
ANALYZING THE PROCESS
TYPES OF DATA

DATA

- YES/NO
- GOOD/BAD
- PASS/FAIL

ATTRIBUTE

- MEASURABLE

VARIABLE
POPULATION & SAMPLING

Population:

• All items produced of a particular products

Random Sampling:

• A technique used to gain information about population characteristics.

Sampling Guidelines:

• Select frequency of sampling

• Choose subgroup periods to enhance feedback

• Subgroup should be large enough to have a good chance of having some non-conformities.

• Select samples in a random manner (use random numbers table), or collect samples in such a way as to ensure that every piece of the population has an equal chance of being selected.
Characteristics:

• When producing a product, you must act on the basis of data.

• Random sampling will result in obtaining representative results from the population (Central Limit Theorem).

• The Central Limit Theorem explains why random samples can be used to estimate the characteristics of an entire population.

• If the population is normally distributed, samples from the population is normally distributed, regardless of the sample size.

• If the population is not normally distributed the average \((x)\) of the sample groups selected from the population will be normally distributed for sample sizes of thirty or more.

• Critical information which is required to understand the process can be obtained when a sample size of thirty or more is drawn from a population. Sample average and sample standard deviations under the above conditions approximate population averages and standard deviations.
COLLECTING DATA

Purpose:

Collecting data from the actual process is the first step in identifying problems in that process. Sample data is used because of the large number of items being produced.

It would be quite a task, and not very cost effective, to check all items in the total population being produced. Thus, the use of sample data.

The key is for each sample selected from the total population to have an equal chance of being selected. This is what is referred to as random sampling.

Through the collection of samples you will get the raw data you need to identify the problems in the process.

You must ask four questions before collecting sample data:

- Why do you want to collect the data?
  - One purpose for collecting sample data would be to identify what problems you have in the process.
  - If you know there are defects occurring in a process, you want to know what the defects are and how often they occur.
• In order to find out what is really happening in the process, you will collect the samples on a random basis. This will provide a good representation of what is actually happening in the process.

• Through this method, you will get an accurate understanding of the characteristics of the products you are producing in your process over a given period of time.

• What type of data will you collect?

In our process, there are a number of variables which impact the product quality. Considering the variables which affect your product quality, you must decide what type of data needs to be collected so that you can identify where the problem(s) occur(s). These variables include the quality of the parts or material used in your process, the machinery involved, and the persons operating the machines and/or running the process.

Another possibility is the collection of data on the types of defects which are the results of the total process.

• What are the characteristics of the data you will collect?

When you have established the purpose of your data, and identified the type of data you will collect, you must determine the characteristics of the data to be collected.
There are two basic types of data:

- **Variable** – This is measurable data, such as weight, size, height, diameter, length, pressure, etc. You will collect this data from the actual items produced.

- **Attribute** – Countable data is sometimes called “go/no go“ data. It is the data we need to collect. You will be counting the number of defects (or the number of defectives) in a given sample.

In other words, you have to ask if you can measure it or if you will just count it.

- **Who will collect the data and when will it be collected?**

You will answer these questions as you determine the type of data to be collected and how the process operates. You can collect samples periodically, and they may be collected by the person involved in the process. Records are important. You must be careful to record the person who collected the data, the date, methods or instruments used, and the time.
HISTOGRAM

There is a saying that “one picture is worth a thousand words”. A histogram is a graphntation that can be helpful both in understanding the sample data and in preparing presentations to communicate to others what the data represents.

CONSTRUCTING A HISTOGRAM

A) Count the data points. Let “N” equal the total.

B) Find the range (R) of the data, (largest sample value minus the smallest sample value)

C) Determine number of classes or cells (K) you will use to construct your histogram using the following table.

<table>
<thead>
<tr>
<th>Number of Data (N)</th>
<th>Number of Classes (K)</th>
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</thead>
<tbody>
<tr>
<td>Under 50</td>
<td>5 – 7</td>
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<tr>
<td>50 – 100</td>
<td>6 – 10</td>
</tr>
<tr>
<td>100 – 250</td>
<td>7 – 12</td>
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<tr>
<td>over 250</td>
<td>10 – 20</td>
</tr>
</tbody>
</table>

D) Determine class or cell interval (h) by dividing the range R by the number of classes or cells (K). \( h = \frac{R}{K} \)

Round “h” off if necessary to make class division easier.

E) On graph paper draw horizontal and vertical axis.

F) The horizontal axis boundaries will start at the smallest sample value and mark off the class interval until the largest sample value is surpassed.

G) Place an “X” for each sample value up the vertical axis that corresponds with the class interval.

H) continue “G” until all sample values have been placed in the appropriate area.
RANDOM SAMPLE OF THE WEIGHTS OF THE ADULT MALE

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HISTOGRAM

WEIGHTS OF THE ADULT MALES

- 300-309
- 290-289
- 270-279
- 260-269
- 250-259
- 240-249
- 230-239
- 220-229
- 210-219
- 200-209
- 190-199
- 180-189
- 170-179
- 160-169
- 150-159
- 140-149
- 130-139
- 120-129
- 110-119
- 100-109
- 90-99
### COPPER CUT - LENGTH

**SPEC. LIMITS** 3.400 ± .010

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</table>
1. - NORMAL CURVE

2. - PROCESS CAPABLE BUT NOT CENTERED

3. - PROCESS CENTERED BUT USING 100% OF TOLERANCE

4. - PROCESS NOT CENTERED USING 100% OF TOLERANCE

5. - PROCESS CENTERED BUT NOT CAPABLE

6. - OVALITY
   - 2 SET-UPS OR LOTS
   - SHIFT CHANGE

7. - OVALITY
   - 2 SET-UPS PR LOTS
   - 2 MACHINES
   - OVER ADJUST - MENT MADE

8. - SET-UP PEICES INCLUDED

84
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<tr>
<th></th>
<th>LSL</th>
<th>USL</th>
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| 9 | - GAGING NOT PRECISE ENOUGH  
- CELL SIZE TOO LARGE  
- EXCELLENT PROCESS |   |   |   |
| 10| - FUDGED DATA, ALL READINGS PUT WITHIN SPEC |   |   |   |
| 11| - PROCESS IS CENTERED, BUT NOT CAPABLE |   |   |   |
| 12| - 100% SORTING OF LOT |   |   |   |
| 13| - SAMPLE SIZE NOT LARGE ENOUGH |   |   |   |
| 14| - 2 CUSTOMERS, PARTS CLOSE TO NOMINAL SOLD TO DIFFERENT CUSTOMER |   |   |   |
**HISTOGRAM**

**COPPER CUT - LENGTH**
**SPEC. LIMITS 3.400 ± .010**

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**AVERAGE (X) = 3.400**
**STANDARD DEVIATION = .002**

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THE NORMAL CURVE

\( \sigma = \text{Sigma} = \text{Standard Deviation} \)

Normal Curve is divided into 6 equal segments.

Example:

\[ \bar{X} = .500 \]
\[ \sigma = .011 \]

\[ \begin{array}{cccc}
.497 & .498 & .499 & .500 \\
.501 & .502 & .503 & \\
\end{array} \]
PROCESS
CAPABILITY
INTRODUCTION

When a process is in statistical control and all special causes of variation have been eliminated, the process capability can be studied. A capable process is one which:

1. Is in statistical control
2. The individual measurements are normally distributed.
3. The process variation consumes no more than 75% of the specification tolerance. This is a comfortable relationship between process variation and specification limits.

The Standard Deviation

The standard deviation ($\sigma$) is a measure of variability. Just as weight may be measured in pounds, and length in inches, the variation of process is measured in terms of standard deviation units. The standard deviation takes on the same units (pounds, inches, etc.) as the measurements. The Greek letter $\sigma$ (sigma) is used to indicate one standard deviation. Approximately 99.7% of the area under the normal curve lies between X plus and minus three standard deviations (Figure 66).

An example of a capable process is shown in Figure 67.

The standard deviation from control charts can easily be estimated by dividing the average range ($r$) by the factor $d_2$. Refer to Appendix F for factors. The $d_2$ factor depends on the sample size. When using a sigma chart, the estimated standard deviation can be found by dividing the average standard deviation ($s$) by the factor $c_4$.

Example: $R = .003 \ n = 5 \quad \sigma = \frac{R}{d_2} = \frac{.0023}{d_2} = .001$

Example: $s = .001 \ n = 5 \quad \sigma = \frac{s}{c_4} = \frac{.001}{.940} = .0011$
CONTROL CHART METHOD – CAPABILITY RATIOS (CR) AND CAPABILITY INDEXES (Cp/Cpk/CpU)

Steps in Studying Process Capability

1. Make sure the process is in statistical control.
2. Individual measurements, not averages, should be normally distributed (Figure 68). This is often tested using a frequency distribution or a histogram for the individual measurements. Another test for the normal distribution or a histogram is kurtosis (see glossary, Appendix H).

Note: In practice, do not expect the distribution to be perfectly normal. the distribution should closely approximate a normal shape.
Figure 67. An example of a Capable Process (C/P = Blueprint)

Figure 68. Frequency distributed of Individuals – Not Averages
3. Calculate the estimates standard deviation (R divided by $d_2$).

4. Draw lines on the frequency distribution which reflects the grand average (X) and each three sigma limit ($3\sigma$). Also draw lines on the distribution which reflect the nominal and both specification limits (Figure 69).

5. If the process is centered as shown in Figure 69, a capability ratio (CR) or capability index (Cp) can be used. The CR is calculated by dividing $6\sigma$ by the total specification tolerance. The Cp is the reciprocal of the CR, calculated by dividing the total specification tolerance by $6\sigma$. 

Figure 69. Specification and Process information Placed on the Distribution
Capability Ratio

\[
CR = \frac{6\sigma}{\text{Total specification tolerance}} = \frac{.006}{.008} = 0.75
\]

Capability Index

\[
C_p = \frac{\text{Total specification tolerance}}{6\sigma} = \frac{.008}{.006} = 1.33
\]

Note: The Cp should not be less than 1.33, which means that the process spread only consumes 75% of the tolerance.

Note: Capability ratios (or capability indexes) should only be used when processes are centered on specification limits.

Cpk Index

When the process is not centered on specification limits, a Cpk index can be used. The Cpk index provides a worst case capability index which compensates for processes which are not centered on specification limits. The Cpk index is the difference between the grand average (X) and the nearest specification limit divided by 3σ.

\[
C_{pk} = \frac{\text{USL} - X}{3\sigma} \quad \text{or} \quad \frac{X - \text{LSL}}{3\sigma}
\]

*Use whichever specification limit is closer to X.

USL – upper specification limit
LSL – lower specification limit
X – the grand average
Example: In Figure 70, the upper specification limit (USL) is closer to X so the Cpk index is:

\[
Cpk = \frac{USL - X}{3\sigma}
\]

\[
= \frac{.504 - .502}{3(.001)}
\]

\[
= \frac{.002}{.003}
\]

\[
Cpk = 0.67
\]

Note: The Cpk index assumes that the process average is not centered, but it does fall on or between specification limits.

Figure 70. An Off-Centered Yet Capable Process

For a process to be called capable, the Cpk index should be 1.33 minimum. This index relates to the goal of a process spread which only consumes 75% of the specification tolerance.
Predicting the Percent Yield of a Process

When the process is not centered on specification limits, the yields (or percent of good parts) can be predicted using the Table of Areas under the Normal Curve (Appendix E). This table involves the use of a simple equation to calculate a Z score, then the Z score is used to find the area.

Note: The areas found in the normal curve (Appendix E) are decimal fractions. You must convert these areas to a percentage. Once the Z score is found, it is used to find the area under the curve.

Example: A Z score is calculated to be 2.6. The area related to a Z score of 2.6 is .4953 (see table in Appendix E). The decimal .4953 represents 49.53% of the product is expected to fall between the specification limit and the grand average.

Referring to Figure 70, there are two Z scores to calculate. The Z score is the difference between a specification limit (X) and the grand average (X) divided by one standard deviation (σ).

\[
Z_{\text{upper}} = \frac{USL - X}{\sigma} \quad \text{and} \quad Z_{\text{lower}} = \frac{X - LSL}{\sigma}
\]

\[
= \frac{.504 - .502}{.001} \quad \text{and} \quad = \frac{.502 - .496}{.001}
\]

\[
= .002 \quad \text{and} \quad = .006
\]

\[
Z_{\text{Upper}} = 2 \quad \text{and} \quad Z_{\text{lower}} = 6
\]

A value of \(Z = 2\) in the Table represents .4772 or 47.72%.

A value of \(Z = 6\) cannot be found in the table. For practical purposes, when the calculates value (e.g., \(Z = 6.0\)) is not found, use the highest Z value in the table. Therefore, use \(Z = 4.0\) or 49.99%.
These two areas (47.72% and 49.99%) represent the expected percentage of good parts (within specification limits); therefore they can be added.

\[
\begin{array}{c}
47.73% \\
+ 49.99% \\
\hline
97.71%
\end{array}
\]

The percent yield (97.71%) for this process represents the probability of good parts that can be expected if nothing about the process or specification changes. The probability of nonconforming parts is equal to 100% minus 97.71% or 2.29% in this case.

Also because the process distribution is over the upper specification limit, the 2.29% nonconforming parts are expected to be over the upper specification limit. Prediction and tracking the yield using “Z” scores can often provide a more realistic approach to capability assessment than the capability indexes (CR, Cp, Cpk, CpU, and others not covered in this book).

**The reason Processes Must Have Clearance**

All normal distribution have a six-sigma spread which represents 99.73% of the distribution. From the center of the distribution (X) there are three equal standard deviations to the right and three equal standard deviations to the left (Figure 71).

If you have normal distribution, and you know the value of one standard deviation, then you can accurately predict what the process will do from a given center (X), which is usually the setup value.

\[
\text{Example: } \sigma = .001 \quad X = .500
\]

The process is in control and the distribution of individuals is normal (figure 72). If the process is set up on .500, 99.7% of the product will be produced between .497 and .503 when the standard deviation is .001.
Figure 71. The Normal Distribution and Six-Sigma Spread

Figure 72. A Process In Control, Normally Distributed, and Centered on Specification Nominal (.500)
Figure 74. Extra Clearance at the Tails of the Distribution

SINGLE SPECIFICATION LIMIT

There are standards which only reflect a single limit of tolerance such as:

Geometric Tolerances: Runout, concentricity, parallelism, flatness, straightness, etc.

Maximum/Minimum Limits: .500 maximum .375 minimum

Surface Finish: AA32

In these cases, process capability concerns itself only with the single limit. Therefore, a Z score computed between the specification limit and the average of the process in order to find the percent of product which is expected to be between the average and the single limit. The other area will represent 50% good product in most cases (Figure 75).
Example: Specification: Runout within .10 total indicator reading TIR).

\[
\text{Grand Average (X)} = .008 \text{ TIR}
\]

\[
\sigma = .0006
\]

The upper Z score is 3.33 and the area under the normal curve for a Z o f3.33 is 4.996 or 49.96%. Therefore, 49.96% of the product will be between .008 and .010 TIR and the other 50% of the product will be less than .008. Thus, the yield is 50% + 49.96% = 99.96% good parts.
CONTROL CHARTS
SPC AND THE CONTROL CHART

DATA

FREQUENCY COUNTS

ATTRIBUTE

NUMBER OF DEFECTS PER SAMPLE OR UNIT

NUMBER OF DEFECTIVE UNITS (PASS/FAIL)

C CHART

NUMBER OF DEFECTS PER SAMPLE

FIXED SUBGROUP SIZE

U CHART

NUMBER OF DEFECTS PER UNIT

FIXED SUBGROUP SIZE

P CHART

FRACTION DEFECTIVE

FIXED SUBGROUP SIZE

NP CHART

NUMBER DEFECTIVE

FIXED SUBGROUP SIZE

X/R CHART

FIND MEAN AND RANGE

FIXED SUBGROUP SIZE
Table for Selection of Subgroup Sizes and Intervals

Appendix

A

No absolute rule can be used for how often we should sample. The realities of the factory layout, production run size, and the cost of sampling must be balanced with the value of the data obtained. In general, it is best to sample at close intervals at the beginning and increase the interval when the process results permit. The following tables (Ref: Mil-Std-414 Variables Sampling Plans) can be used for estimating the amount and frequency of sampling.

<table>
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<tr>
<th>Production Rate per Shift</th>
<th>Total No. of Parts to Be Sampled per Shift</th>
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<tr>
<td>1 to 65</td>
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<td>3201 to 8000</td>
<td>60</td>
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<tr>
<td>8001 to 22000</td>
<td>85</td>
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</table>

Example: A process produces 3,000 parts per shift. Using the table, we should consider sampling 50 parts during the shift. If the control chart uses subgroups of five each, then 50/5 = 10, and therefore 10 subgroups should be taken during the shift. Therefore, on an eight-hour shift, samples would be taken every 78 minutes or so.
BENEFITS OF CONTROL CHARTS

1. Control charts are simple and effective – The charts are maintained easily at the job station by the operator.

2. Control charts give the people closest to the operation reliable information on when action should be taken and when action should not be taken.

3. A process “in statistical control” is predictable. Producer and customer can rely on consistent quality and stable costs.

4. Control charts allow for improvements to reduce common cause variation. The effects of even small changes on the system can be identified quickly and effectively thereby:

   A. Increasing the percentage of output that meets customer expectation.

   B. Decreasing scrap and rework (Improve cost/unit)

   C. Increasing the total yield of acceptable output (Increase productivity)

5. Control charts provide a common language at all levels for communication about the performance of a process:

   A. Shift to Shift

   B. Production departments (operators, foreman) to support departments (maintenance, engineering)

   C. Supplier and customer
Preliminary Consideration

1. Establish an environment suitable for action. Communication channels must be open, fear must be eliminated, and people must be trained.

2. Define the process. The process must be understood relative to other operations/processes both upstream and downstream. (Secondary and third operations, assembly equipment).

3. Determine the characteristics to be monitored. Efforts should focus on the changes that promise the greatest chances for improvement.

   A. Repeat problems (characteristics) as shown on inspection reports, scrap, rework.

   B. Characteristics critical to fit and function of the parts.

   C. Correlation between characteristics. (One tool controls several dimensions, monitor only one characteristic)

   D. Customer needs

   E. Review with production employees. They are most familiar with their process.

4. Define the measurement system. Specify what information is to be gathered where, under what conditions? Accuracy of data requires accuracy in measurement.

5. Minimize unnecessary variation. Avoid obvious problems that can be eliminated without control charts.
Updating Control Chart Limits

While the revision of control chart limits applies to the initial computation of limits for a given set of data, the updating of control chart limits pertains to the modification of existing limits on an ongoing chart.

An obvious time for updating the control limits is following a change in the process. It is a poor use of a control chart to make it prove what is already known. Instead, one should use the chart to discover that which is not known. So when a deliberate change is made, it is logical to collect data following the change and these new data may be used to compute new control limits. While the new data are being collected following the change and prior to the computation of the new control limits, the new data may be plotted against the old limits as a means of verifying the change in process. If a change is indicated, then the new limits are needed. If the new data “fit in with” the old limits, there is little need to update them.

Another time to consider updating the control limits is when the limits are “trial control limits”. Trial control limits computed from a limited amount of data. Of course, when there is only a finite amount of data available this issue is moot. One may always compute control limits using the data available, and any signals found using trial control limits are likely to be real signals. Thus, one does not have to wait until a large amount of data has been obtained before computing control limits. But when the limits for an ongoing control chart are computed from the first few subgroups, and then additional data is collected, it is generally recommended that the limits be updated when 20 to 30 subgroups are available. This recommendation of 20 to 30 subgroups is essentially a piece of insurance. By using 20 to 30 Subgroup Ranges in the computation of the Average Range the effect of any extreme value will be diluted and minimized. Of course, a single Subgroup Range that is, say, 10 times bigger than the Average Range will still dominate the computation and inflate the Average Range, but Subgroup Ranges that are just outside the control limits will have a fairly small impact when averaged in with 20 to 30 other values.

When updating trial control limits one may also elect to use either the delete or revise approach or the Median Range approach outlines in the preceding section. The objective is to use the data available to obtain reasonable and useful limits in as straightforward a manner as possible.

Finally, once the control limits are computed using about 100 observations there will generally be little change in the limits with further updates. Unless the process is changed, or changes in some fundamental way, the limits should not need further updates. The practice of automatically recomputing control limits every time a control chart form is filled up, and then using these latest limits on the next sheet, may result in the failure to detect low trends in the process. Likewise, the automatic updating of control chart limits in some computer programs will, by default, use all of the data available, even though some of those data may no longer be appropriate for the current process.

The control chart is a versatile tool for use in real-time situations. Therefore, one should always actively control the manner in which the control chart limits are computed in order to be sure that the limits are appropriate for the current process. The computation of the limits cannot be divorced from the context for chart.
VARIABLES CONTROL CHART

The control chart is a line graph that is kept at the work area. It is used to record the results of each sample. It also shows the control limits, that if exceeded, should trigger investigation.

CONTROL CHARTS HAVE TWO BASIC USES:

1. As a judgment to give evidence whether a process has been operating in a state of statistical control and to signal the presence of special cause of variation so that corrective action can be taken.

2. As an operation, to maintain and monitor the state of statistical control, by extending the control limits for real-time decisions.
VARABLES CONTROL CHART
(X & R)

DEFINITIONS:

\( \bar{X} \) (called X-bar) – sum of the variables divided by the number of variables (average)

\( \bar{X} \) (called X-double bar) – average of the X-bar’s

Range (R) – the difference between the largest and smallest variable.

\( \bar{R} \) (called R-bar) – the average of the ranges

Control Limits – these are the limits within which we expect the process sample averages and ranges to vary within.

UCL\(_X\) - Upper Control Limit of the averages.

LCL\(_X\) - Lower Control Limit of the averages

UCL\(_R\) - Upper Control Limit of the ranges

USL – Upper specification limit

LSL – Lower specification limit
VARIABLES CONTROL CHART

1. **GATHER DATA**

   A. Subgroup Size – usually five pieces but can vary depending on the process.

   B. Subgroup Frequency – the subgrouping frequency should make sense in terms of production to aid in analysis and correction of problems found. (ex. Time sequence, every hour or production sequence, every 100 pieces)

   C. Data collection period should be long enough to capture all likely sources of variation affecting the process. Control limits should be calculated after 15 to 20 subgroups have been gathered.

2. **CALCULATIONS**

   A. From each subgroup

      - SUM
      - AVERAGE
      - RANGE

   B. Control Limits

      - X and R

      - UCLx = X + A2 R
      - LCLx = X - A2 R
      - UCLr = D4R

      NOTE: Refer to appendix to determine value of constant factors A2 and D4 depending on sample size.
AVERAGE OR MEAN

Definition:

The mean represents the average value for all values contained in a sample group. It is one of the statistical methods used to describe the measure of location for sample data.

\[ \bar{X} = \frac{\sum X}{n} \]

Where:

\( \bar{X} \) = Average Value

\( \sum \) = Sum of (or “add together”)

\( X \) = Individual Value

\( n \) = The number of individual samples in one subgroup

RANGE

Definition:

Range is determined by subtracting the smallest value from the largest value in a group of sample data.

It is used to describe the amount of variation in a group of sample data.

LARGEST VALUE

\[ \text{LARGEST VALUE} \quad \text{Minus} \quad \text{SMALLEST VALUE} \]

\[ = \quad \text{Range} \]

The Range of your subgroup will provide more information than the Average alone.
Determine $\bar{X}$ and $R$ for the above $X$-Bar and $R$ Values.

$$X = \frac{\sum X}{k}$$

$$\bar{R} = \frac{\sum R}{k}$$

Where $k$ is the total number of subgroups.
Lesson Objectives…

To help you make the most effective use of this manual and your time in learning the concepts described, we have listed below your study objectives for this lesson. These objectives tell where you are going in this lesson and what you can expect to learn.

Please read the objectives carefully and keep them in mind as you read and study the lesson. You should be able to accomplish each of these objectives upon completion of this lesson.

• Construct an X, R Chart

• Determine the conditions for selecting a Variable Control Chart.

• Identify an Out-Of-Control condition using Variable Control Charts.

• Identify natural variation.

• Define how X, R Control Charts can be used to analyze and control a process.
Guidelines:

• Initial Decisions
  • Decide what to monitor.
  • How many readings in each sample group (3, 4, 5, etc.)
  • Time intervals (15 min., 30 min., 60 min., per skid, per bin, per case)?
• Collect data and make notes.
• Find average (X) and range (R) for each sample group.
• Complete a calculation worksheet.
• Plot data – range Chart first (See “Making a Scale”).
  • Range Chart must be in control before completing Average Chart.
• Is the chart process “in-Control”?
  • Assignable Cause Variation
  • Hugging
  • Trends
  • Jumps
  • Runs
  • Cycles

If the process is not stable, identify assignable causes of variation, and eliminate them to improve the process.
Symbols And Definitions:

Variables - Measures values of a characteristic.

Common Cause - Faults of a system, common to a process.

Assignable (Special) Cause - Specific to a machine, person, material or method. The operator, supervisor or technical support person can usually identify and correct.

Control Chart - A statistical quality control tool used to study and control processes.

In-Control - A process in which only common causes of variation are operating; a system which is predictable.

Out-Of-Control - Both common and special causes of variation exist; an unstable system.

Natural Tolerance - Natural variability of the process.

Engineering Tolerance - Specification limits. (Lines [upper and lower limits] which define how much variation is acceptable to the customer, internal and external.)

Control Limits - Lines (upper and lower limits) which define the amount of variation to be expected if the process is in control.

Subgroup - Several consecutive samples.
Subgroup Size - The number of consecutive samples inspected at one time.

UCL - Upper Control Limit

CL - Centerline

LCL - Lower Control Limit

X - Denotes an individual sample value.

\bar{X} - The average of two or more measurements.

\bar{X} = \frac{\Sigma X}{n} - The average of a set of \bar{X} values, also called the grand average (The average of the averages).

R - The difference between the largest and the smallest values in any set of data.

n - The number of sample measurements in any given subgroup.

\bar{R} - The average of the ranges.

k - The number of subgroups.

\Sigma - The sum of a series of numbers.

\sigma (Sigma) - A measure of the variation within a set of data.
Hugging - A pattern which occurs when the points stay close to the centerline.

Or

- A pattern which occurs when the points stay close to the upper control limit, or the lower control limit.

Jump - Occurs when a tremendous shift occurs between consecutive points plotted on a Control Chart.

Trend - Formed when a series of seven or more consecutive points continue to rise and fall in one direction.

Cycle - A series of points that display a similar or repeated pattern of time.

Run - A series of seven or more points above or below the center line.
Making A Scale:

- Always make the Range Chart first (bottom Chart).

- Range Chart starts from zero. Go ahead and put the zero on the bottom line.

- Scan the range values and pick out the largest number. Compare this number (largest) to the UCLR. Of these two values, the large will indicate how high the scale must go. It may be possible to skip line(s) between each number. Spread out the data. The Chart is much easier to read this way.

- After the Range Chart is plotted, interpret the results. If the Range Chart is “In-Control”, you may proceed to the Average Chart.

- The Average Chart does not start from zero. Scan the averages (not the individual readings) and select the highest and lowest X. Compare to the UCLx and LCLx as previously done with the Range Chart.
CHOOSING A SCALE FOR THE CONTROL CHART GRAPHS

The choice of scales for the average chart and the range chart is partially a matter of individual preference. The following guidelines are offered to assist those who feel the need of some help. They are based on approximations that will yield the right scale, provided the range of the first subgroup is not extremely large or extremely small.

GUIDELINE 1: Pick a scale that is easy to use. If the forms have every fifth line emphasized, then the distance between these heavy lines should be made to represent either one unit, or five units, or ten units. With these choices the small lines will represent, respectively, 0.2 units, 1 unit or 2 units. (Another possible choice would be to let each heavy line represent 2 units, so that each small division would correspond to 0.4 units.)

GUIDELINE 2: The spread of values needed for the average chart will generally be between 3 A2R and 4 A2R, where R is the range of the first subgroup. In the example above, the first subgroup range was 5 thousandths and A2 = 0.729. Thus 3 A2R = 10.95 thousandths, and 4 A2R = 14.6 thousandths. By letting the distance between the heavy lines represent one thousandth of an inch, a scale covering nine thousandths could be placed on the chart shown. Since nine thousandths is close to a smaller value of 10.95, this was the scale chosen. (An alternative scale would be to let the heavy lines represent two units each, whereupon the scale would cover eighteen thousandths.)

GUIDELINE 3: The values needed for the average chart should be centered near the average of the first subgroup.

GUIDELINE 4: The values needed for the range chart will generally begin with zero and continue to a value that is between 3 and 4 times as large as the range of the first subgroup.

GUIDELINE 5: Since the ranges will always be expressed as integer multiples of the smallest unit of measurement, it is convenient to let each small division represent the smallest unit of measurement. If the measurements are to the nearest tenth of a pound, let each division represent one-tenth of a pound. If the measurements are to the nearest five degrees, then let each division represent five degrees. In the example given above, the smallest unit of measurement was one thousandth of an inch, so each division was set equal to one-one thousandth of an inch.

These guidelines are based on the assumption that the average and range for the first subgroup will be fairly typical of what will come. Instead of making this assumption, you could wait until two or three subgroups had been obtained before setting up a scale and plotting any points. This was you could use the average range and the average of the averages to set up the scale according to the guidelines above.
How To Construct An $\bar{X}$ and R Chart:

1. Data must be variable or measurable.

2. Data must be in subgroups.

3. Subgroup size usually consist of three, four or five items.

4. A minimum of 20 subgroups should be used before Control Limits are established.

5. Determine $X$, $R$, $\bar{X}$, and $R$ values

6. Calculate upper and lower Control Limits.

7. Construct Range Chart and determine if plotted data is with upper and lower control Limits. Make certain there are no patterns in the plotted points.

8. Construct $X$ Chart and determine if plotted data is with upper and lower Control Limits.

9. If chart is in control, variation is random.

10. Determine process capability using $C_p$ and $C_{pk}$ formula.

11. If process is stable, construct a Histogram to determine the shape or distribution of data.
Review:

In this lesson I have learned to construct an X, R Chart. This Control Chart uses measurable or ____________________data.

X, R Charts analyze where a process is operating. After the points are plotted (represented measurements)__________________ are added to show whether or not the amount of variation in your process is excessive.

One characteristic of the X, R Chart is that the typical sample size is either________, ________, or _________. Also, the minimum number of subgroups is _____________________________.

__________ Cause variation is within the natural variation of the process. To change this involves either solving on the spot or in your team with the guidance of _____________________.

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CALCULATION WORKSHEET

CONTROL LIMITS

\[ \bar{R} = \frac{\sum X}{k} \]

\[ \bar{X} = \frac{\sum X}{k} \]

\[ UCL_R = D_4 \bar{R} = \]

\[ A_2 \bar{R} = \]

\[ UCL_x = \bar{X} + A_2 \bar{R} = \]

\[ LCL_x = \bar{X} - A_2 \bar{R} = \]

TABLE OF CONSTANTS

<table>
<thead>
<tr>
<th>n</th>
<th>A₂</th>
<th>D₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.880</td>
<td>3.268</td>
</tr>
<tr>
<td>3</td>
<td>1.023</td>
<td>2.574</td>
</tr>
<tr>
<td>4</td>
<td>0.729</td>
<td>2.282</td>
</tr>
<tr>
<td>5</td>
<td>0.577</td>
<td>2.114</td>
</tr>
</tbody>
</table>

n = Subgroup Size
k = Number of Subgroups

Part Number _______________
Job Number _______________
Operator _______________
Date of Collection ___________
GENERAL RULES FOR $\bar{X}$ & R CHARTS

1. All places at the top of the Form 1778 Process Control Chart will be completed by the operator with the correct information each time a chart is made. The start and stop dates will be recorded in the date space when the chart is started and completed.

2. Zero set procedures are encouraged to simplify calculations and reduce errors.

3. All measurements must be made with the same type calibrated measuring instrument and to the maximum sensitivity of that instrument. Recorded actual readings – don’t round off!

4. The person doing the sample must initial the entry at the bottom of the charts.

5. A trial scale will be put on the chart after subgroups and points will be plotted.

6. Trial control limits will be calculated and penciled in on the chart after five subgroups. Final control limits can be calculated and placed on the chart after twenty subgroups if there have been no major process changes.

7. Samples must be taken in the time frame required or a reason must be written on the chart explaining why it could not be done.

8. If a subgroup falls out of the control limits or shows a drastic shift in either range or average, the math and simple measurements should be checked and if necessary the samples retained for immediate verification by an inspector, facilitator, or another team member. If the original result proves true, a second subgroup should be taken and recorded immediately. If it confirms a process change, an assignable cause should be investigated and corrective action taken before production resumes.

9. If an out of tolerance measurement is found, it should be verified immediately by an inspector, facilitator, or team member and the manufacturing process stopped or adjusted. All suspect parts must be segregated to eliminate the out of tolerance parts. Production may begin when this is done and the process has been corrected.

10. If a change is made in the process, it must be noted on the back of the chart and signed by the person making the change. Also another subgroup should be taken and recorded to prove the change corrected the problem or improved the process.

William R. DeSilvey
10/28/93
Rev. 01 06/21/93
MOVING RANGE CHARTS

Lesson Objectives:

To help you make the most effective use of this manual and your time in learning the concepts described, we have listed below your study objectives for this lesson. These objectives tell where you are going in this lesson and what you can expect to learn.

Please read the objectives carefully and keep them in mind as you read and study the lesson. You should be able to accomplish each of these objectives upon completion of this lesson.

• Construct a Moving Range Chart.

• Determine the conditions for selecting a Moving Range Chart

• Identify an Out-Of-Control condition using Moving range Charts

• Define how Moving Range Charts can be used to analyze and control a process.

• Calculate Moving Range values as the difference between individual measurements. Record the difference between the first and second individual values, then between the second and third, and continue this method until finished (two item moving Range).

• \( \bar{R} \) is the average of all the moving ranges. (Range Charts).

• \( X \) is the average of the individual measurements. (Individual Reading Chart)
• Calculate Control Limits on the Moving Range Chart and then on the Individual Readings Chart.

• Select Chart scales for the Moving Range and individual measurement values.

• After the Range and Individual Reading Charts are in control, the process will be predictable. Successive Range Chart values are related since they have a point in common. Therefore, you must take care in interpreting trends or Out-Of-Control conditions on a Moving Range Chart.

• If the process is stable, identify the Common Causes present to reduce variability and improve the process.
Definitions:

RUN - A point, or series of points, above or below a line.

UCL - Upper Control Limit.

LCL - Lower Control Limit.

CL - Centerline

CONTROL LIMITS - Lines (Upper and Lower Limits) which define the amount of variation to be expected if the process is In-Control.

\( \bar{X} \) - The average of the individual measurements.

R - The difference between the largest and smallest individual values in any set of data.

n - The number of individual measurements used when calculating range values.

\( \sigma \) (SIGMA) - A measure of dispersion or variability in a set of data.
CALCULATION WORKSHEET

CONTROL LIMITS

\( n \) = The number of individual values used when determining a range value

\( \bar{R} \) = The sum of the Range values
\( \text{The number of Range Values} \)

\( \bar{X} \) = The sum of the individual values
\( \text{The number of individual values} \)

\( UCL_R = D_4 \bar{R} \)

\( LCL_R = D_3 \bar{R} \)

\( \hat{\sigma} = \frac{\bar{R}}{d_2} \)

\( UCL_x = \bar{X} + 2\hat{\sigma} \)

\( LCL_x = \bar{X} - 2\hat{\sigma} \)

TABLE OF CONSTANTS

<table>
<thead>
<tr>
<th>( n )</th>
<th>( A_2 )</th>
<th>( D_4 )</th>
<th>( d_2 )</th>
<th>( d_3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.880</td>
<td>3.268</td>
<td>1.128</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1.023</td>
<td>2.574</td>
<td>1.693</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0.0729</td>
<td>2.282</td>
<td>2.059</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0.577</td>
<td>2.114</td>
<td>2.326</td>
<td>0</td>
</tr>
</tbody>
</table>
MOVING RANGE CHART

A chart for individual measurements. Principal kinds of data for which this chart should be used are:

- Accounting figures (shipments, efficiencies, absences, accidents, maintenance cost, etc.)
- Production data such as temperatures, pressures, gas consumption, etc.

Definitions and directions for making a moving range charts:

1) Start with a series of individual numbers. \( \geq 20 \) preferred, but not <10.

2) take the difference (range) between the first and second numbers and record it; then the difference between the second and third numbers, etc. continue to the last number. (Note: Calculate the differences without regard to sign).

3) Take the averages of the original numbers in the series (X).

4) Take the average of the “Ranges” from step two (2). This is called the moving range – MR.
   \[
   \text{Note: } MR = \frac{(R_1 + \ldots + R_{n-1})}{(n-1)}
   \]

5) Multiply MR by \( \pm 2.66 \) to obtain control limits – control limits - X \( \pm 2.66 \) MR.

6) Plot the original numbers, X and control limits.

7) Interpret chart – look for trends, whether fluctuations are narrow or wide, if pattern stay away from one the control limits, and obvious peculiarities in the pattern (cycles, bunching, etc.).
Example/Problem:

Construct a moving range chart for the following data, and evaluate (discuss) your results.

**TONS OF PRODUCT PRODUCED BY A GROUP OF WORKERS**

<table>
<thead>
<tr>
<th></th>
<th>Tons Produced</th>
<th>Change From Preceding Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>JAN (LAST YEAR)</td>
<td>25.0</td>
<td></td>
</tr>
<tr>
<td>FEB</td>
<td>25.3</td>
<td>.3</td>
</tr>
<tr>
<td>MAR</td>
<td>33.8</td>
<td>8.5</td>
</tr>
<tr>
<td>APR</td>
<td>36.4</td>
<td>2.6</td>
</tr>
<tr>
<td>MAY</td>
<td>32.2</td>
<td>4.2</td>
</tr>
<tr>
<td>JUN</td>
<td>30.8</td>
<td>1.4</td>
</tr>
<tr>
<td>JUL</td>
<td>30.0</td>
<td>.8</td>
</tr>
<tr>
<td>AUG</td>
<td>32.3</td>
<td>6.4</td>
</tr>
<tr>
<td>SEPT</td>
<td>23.6</td>
<td>8.7</td>
</tr>
<tr>
<td>OCT</td>
<td>28.1</td>
<td>4.2</td>
</tr>
<tr>
<td>NOV</td>
<td>27.0</td>
<td>1.1</td>
</tr>
<tr>
<td>DEC</td>
<td>26.1</td>
<td>.9</td>
</tr>
<tr>
<td>JAN (THIS YEAR)</td>
<td>29.1</td>
<td>3.0</td>
</tr>
<tr>
<td>FEB</td>
<td>40.1</td>
<td>11.0</td>
</tr>
<tr>
<td>MAR</td>
<td>40.6</td>
<td>.5</td>
</tr>
<tr>
<td></td>
<td>460.4</td>
<td>53.6</td>
</tr>
</tbody>
</table>
INDIVIDUAL AND MOVING RANGE CHARTS

Individual Charts apply when:

1. The cost of a sample is extremely high. This is often true with destructive tests.

2. The items being made take a long period of time to produce or to test or measure.

In these environments, it would be impossible or impractical to take a normal (5) sample size. The individual chart can be utilized for such situations. However, there are certain limitations to an individual chart.

1. They are not as sensitive as $X$ and $R$ charts to process changes.

2. Large number of samples should be taken (preferably 100 or more) before any conclusions about process averages and standard deviation can be made.

Data Collection

Individual values ($X$) represents sample size of one measurement.

Range – Variation is defined as difference between successive individual values. (Moving Range – MR)

Control Limits

$$UCL_{MR} = \overline{MR} \ (D_4)$$

$$UCL_X = \overline{X} + E_2MR$$

$$LCL_X = \overline{X} - E_2MR$$
# Variable Control Chart

## (Individuals & Moving Range)

### Data Table

<table>
<thead>
<tr>
<th>Department</th>
<th>Tank #</th>
<th>Tank Capacity</th>
<th>Previous Cpk</th>
</tr>
</thead>
<tbody>
<tr>
<td>401</td>
<td>#1</td>
<td>#23</td>
<td>1300 gal.</td>
</tr>
<tr>
<td>1.88</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Sodium Hydroxide</th>
<th>Full Charge</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N/A</td>
<td>3 Tests: Daily</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date</th>
<th>Tested By</th>
<th>Tested Results</th>
<th>Amount Added</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-28</td>
<td>06</td>
<td>4.97</td>
<td>10 OB</td>
</tr>
<tr>
<td>11-29</td>
<td>RR</td>
<td>5.10</td>
<td>10 OB</td>
</tr>
<tr>
<td>10-30</td>
<td>BB</td>
<td>5.20</td>
<td>10 OB</td>
</tr>
<tr>
<td>11-29</td>
<td>06</td>
<td>5.47</td>
<td>10 OB</td>
</tr>
<tr>
<td>11-30</td>
<td>RR</td>
<td>5.08</td>
<td>10 OB</td>
</tr>
<tr>
<td>11-31</td>
<td>BB</td>
<td>5.03</td>
<td>10 OB</td>
</tr>
<tr>
<td>11-4</td>
<td>RR</td>
<td>4.97</td>
<td>10 OB</td>
</tr>
<tr>
<td>11-5</td>
<td>BB</td>
<td>5.08</td>
<td>10 OB</td>
</tr>
<tr>
<td>11-6</td>
<td>RR</td>
<td>5.08</td>
<td>10 OB</td>
</tr>
<tr>
<td>11-7</td>
<td>BB</td>
<td>5.08</td>
<td>10 OB</td>
</tr>
<tr>
<td>11-8</td>
<td>RR</td>
<td>5.08</td>
<td>10 OB</td>
</tr>
<tr>
<td>11-9</td>
<td>BB</td>
<td>5.08</td>
<td>10 OB</td>
</tr>
<tr>
<td>11-10</td>
<td>RR</td>
<td>5.08</td>
<td>10 OB</td>
</tr>
<tr>
<td>11-11</td>
<td>BB</td>
<td>5.08</td>
<td>10 OB</td>
</tr>
<tr>
<td>11-12</td>
<td>RR</td>
<td>5.08</td>
<td>10 OB</td>
</tr>
<tr>
<td>11-13</td>
<td>BB</td>
<td>5.08</td>
<td>10 OB</td>
</tr>
<tr>
<td>11-14</td>
<td>RR</td>
<td>5.08</td>
<td>10 OB</td>
</tr>
<tr>
<td>11-15</td>
<td>BB</td>
<td>5.08</td>
<td>10 OB</td>
</tr>
<tr>
<td>11-16</td>
<td>RR</td>
<td>5.08</td>
<td>10 OB</td>
</tr>
<tr>
<td>11-17</td>
<td>BB</td>
<td>5.08</td>
<td>10 OB</td>
</tr>
<tr>
<td>11-18</td>
<td>RR</td>
<td>5.08</td>
<td>10 OB</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Diet</th>
<th>#5</th>
<th>UCL = 5.26</th>
<th>LCL = 4.74</th>
<th>Specifications: 4.00 - 6.00</th>
</tr>
</thead>
</table>

### Chart

- **Individuals Range Chart**
  - UCL = 5.36
  - LCL = 4.74
  - Nom = 5.00
  - 17, 0.06, 0.05, 0.11, 0.05, 0.11, 0.05, 0.06, 0.06, 0.11

- **Moving Range Chart**
  - UCL = 0.33
  - LCL = 0
  - Nom = 0.10
  - 0.50
CHART INTERPRETATIONS (X AND MR)

INDIVIDUAL CHART –

The interpretation of individual charts is similar to X and R charts, however some caution should be taken. As pointed out earlier, the samples should be taken before any definite statements about the process can be made.

MOVING RANGE (MR) CHART –

Review the MR chart for points beyond the control limits as signs of the existence of special causes. Note that successive moving ranges are correlated, since they have a point in common, care must be taken when interpreting trends because of this.
BASIC CHART INTERPRETATION

The Eight Basic Statements of Control

When control charts are used, there is an easy method to determine if the process is in statistical control or not.

The following eight statements can be used to see if any control chart is in control. The statements must be answered true or false while looking at the control chart in Figure 41. If all of the statements are true the process is in control. If any statement is false, the process is not in control. Several false answers on one process usually means that the process is in a worsened condition.

<table>
<thead>
<tr>
<th>Statements</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. There are no plotted points outside the control limits (points plotted on a limit do not count).</td>
<td>T</td>
</tr>
<tr>
<td>2. The total number of points above the centerline is close to the total number of points below the centerline.</td>
<td>T</td>
</tr>
<tr>
<td>3. The plotted points seem to be randomly falling over and under the centerline.</td>
<td>T</td>
</tr>
<tr>
<td>4. There are no consecutive runs of 7 or more points on one side of the centerline.</td>
<td>T</td>
</tr>
<tr>
<td>5. Only a few of all of the points are near the control limits.</td>
<td>T</td>
</tr>
<tr>
<td>6. There are no upward or downward trends of 6 or more points heading directly toward either control limit.</td>
<td>T</td>
</tr>
<tr>
<td>7. The plotted points do not appear to be hugging the centerline with little distance between them.</td>
<td>T</td>
</tr>
<tr>
<td>8. There are no straight line patterns.</td>
<td>T</td>
</tr>
</tbody>
</table>
Test 1. One point beyond zone A

Test 2. Nine points in a row in zone C or beyond

Test 3. Six points in row steadily increasing or decreasing

Test 4. Fourteen points in a row alternating up and down

Test 5. Two out of three points in a row in zone A or beyond

Test 6. Four out of five points in a row in zone B or beyond

Test 7. Fifteen points in a row in zone C (above and below centerline)

Test 8. Eight points in row on both sides of centerline with none in zones C

Figure 42. Tests for Special Causes (Courtesy of ASQC Journal of Quality Technology, October 1994)
Notes on Tests for Special Causes

1. These tests are applicable to X charts and to individuals (X) charts. A normal distribution is assumed. Tests 1, 2, 5, and 6 are to be applied to the upper and lower halves of the chart separately. Tests 3, 4, 7, and 8 are to be applied to the whole chart.

2. The upper control limit and the lower control limit are set at three sigma above the centerline and three sigma below the centerline. For the purpose of applying the tests, the control chart is equally divided into six zones, each zone being one sigma wide. The upper half of the chart is referred to as A (outer third), B (middle third) and C (inner third). The lower half is taken as the mirror image.

3. When a process is in a state of statistical control, the chance of (incorrectly) getting a signal for the presence of a special cause is less than five in a thousand for each of these tests.

4. It is suggested that Tests 1, 2, 3, and 4 be applied routinely by the person plotting the chart. The overall probability of getting a false signal from one or more of these is about one in a hundred.

5. It is suggested that the first four tests be augmented by Tests 5 and 6 when it becomes economically desirable to have earlier warning. This will raise the probability of a false signal to about two in a hundred.

6. Tests 7 and 8 are diagnostic tests for stratification. They are very useful in setting up a control chart. These tests show when the observations in a subgroup have been taken from two (or more) sources with different means. Test 7 reacts when the observations in the subgroup always come from both sources. Test 8 reacts when the subgroups are taken from one source at a time.

7. Whenever the existence of a special cause is signaled by a test, this should be indicated by placing a cross just above the last point if that point lies above the centerline, or just below if it lies below the centerline.

8. Points can contribute to more than one test. However, no point is ever marked with more than one cross.

9. The presence of a cross indicates that the process is not in statistical control. It means that the point is the last one of a sequence of points (a single point in Test 1) that is very unlikely to occur if the process is in statistical control.

10. Although this can be taken as a basic set of tests, analysts should be alert to any patterns of points that might indicate the influences of special causes in their process.

Figure 43. Notes on Tests for Special Causes (Courtesy of ASQ Journal of Quality Technology, October 1984)
The previous eight basic statements of control are effective for a “quick look” to determine whether statistical control exists, but the following is a more definite set of rules which can be used for individuals and averages charts. Figure 42 represents eight tests for special causes (out-of-control conditions). The figure divides the plus and minus three standard deviations from the mean into zones A, B, and C for ease of interpretation. Notes on these tests for special causes are shown in Figure 43.

**X Chart Patterns and Possible Causes**

Figures 44-48 show some examples of X chart conditions and some possible causes.

<table>
<thead>
<tr>
<th>CONDITION/DESCRIPTION</th>
<th>POSSIBLE CAUSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCL</td>
<td>1. Change in machine setting</td>
</tr>
<tr>
<td>2. Different operator</td>
<td></td>
</tr>
<tr>
<td>3. Different material, method, process</td>
<td></td>
</tr>
<tr>
<td>LCL</td>
<td>4. Minor failure of a machine part</td>
</tr>
<tr>
<td>Figure 44. Jump Shift (Run) Pattern (High or Low)</td>
<td>5. Measuring equipment setting/technique</td>
</tr>
<tr>
<td>6. Adjustment on individuals (overcontrol)</td>
<td></td>
</tr>
<tr>
<td>7. New gage</td>
<td></td>
</tr>
<tr>
<td>8. Fixture change</td>
<td></td>
</tr>
<tr>
<td>9. Parts changed</td>
<td></td>
</tr>
<tr>
<td>Figure 45. Trend Pattern (Either Direction)</td>
<td>1. Tool wear</td>
</tr>
<tr>
<td>2. Gradual equipment wear</td>
<td></td>
</tr>
<tr>
<td>3. Seasonal effects (temperature/humidity)</td>
<td></td>
</tr>
<tr>
<td>4. Dirt/chip buildup on workholding devices</td>
<td></td>
</tr>
<tr>
<td>5. Operator fatigue</td>
<td></td>
</tr>
<tr>
<td>6. Change in coolant temperature</td>
<td></td>
</tr>
<tr>
<td>Figure 46. Recurring Cycles</td>
<td>1. Different incoming materials</td>
</tr>
<tr>
<td>2. Cold startup</td>
<td></td>
</tr>
<tr>
<td>3. Seasonal effects (temperature/humidity)</td>
<td></td>
</tr>
<tr>
<td>4. Voltage fluctuations</td>
<td></td>
</tr>
<tr>
<td>5. Merging of different processes</td>
<td></td>
</tr>
<tr>
<td>6. Chemical or mechanical properties</td>
<td></td>
</tr>
<tr>
<td>7. Periodic rotation of operators</td>
<td></td>
</tr>
<tr>
<td>8. Measuring equipment not precise</td>
<td></td>
</tr>
<tr>
<td>9. Calculation and plotting mistakes</td>
<td></td>
</tr>
<tr>
<td>10. Machine won’t hold setting</td>
<td></td>
</tr>
<tr>
<td>Figure 47. Two-Universe Pattern</td>
<td>1. Large differences in material quality</td>
</tr>
<tr>
<td>2. Two or more machines using the same chart</td>
<td></td>
</tr>
<tr>
<td>3. Within the piece variation not considered (such as taper/roundness)</td>
<td></td>
</tr>
<tr>
<td>4. Large differences in the method of measurement of the product</td>
<td></td>
</tr>
</tbody>
</table>
Range Chart Patterns and Possible Causes

Figures 49-54 show some range chart conditions and possible causes for those conditions.

1. Sudden increase in gear play
2. Greater variation in incoming material
3. Inexperienced operator
4. Miscalculation of ranges
5. Excessive speeds and feeds
6. New operator
7. Change in methods
8. Long term increase in process variability
9. Gage drift
10. New tools
11. Fixture change

Figure 49. Jump Shift (Run) Pattern (Above the Center Line)

1. Decrease in operator skill due to fatigue
2. A gradual decline in the homogeneity of incoming material
3. Some machine part/fixture loosening
4. Gage drift
5. Deterioration of maintenance
6. Tool wear

Figure 50. Trend Pattern (Increasing)

1. Improved operator skill
2. A gradual improvement in the homogeneity/uniformity of incoming material
3. Better maintenance intervals/program
4. Previous operation is more uniform in its output

Figure 51. Trend Pattern (Decreasing)

1. Operator fatigue and rejuvenation due to periodic breaks
2. Lubrication cycles
3. Rotation of operators, fixtures, gages
4. Differences between shifts
5. Worn tools
6. Differences between machine needs

Figure 52. Recurring Cycles
Interpreting Average and Range Charts Together

Average and range charts must be interpreted together as well as separately. A stable process will have points distributed between control limits on the charts randomly. If the process is stable, the points on the averages chart and the ranges chart should not tend to follow each other. Lack of stability will sometimes cause the two charts to move together.

Example: If a process is positively skewed, then the points tend to correlate positively with each other (points are high on both charts). If a process is negatively skewed, then the points tend not to correlate (points on the averages chart will follow points on the ranges chart but in opposite directions).

Skewness is a measure of the symmetry of the distribution (see glossary, Appendix H). Positive skewness is when the distribution slopes downward to the right and negative skewness is when the distribution slopes downward to the left.

TYPE I AND TYPE II ON CONTROL CHARTS

There are two errors which can occur when interpreting control charts which are similar to sampling inspection. In sampling inspection the two types of errors are:

Alpha Risk – The risk of rejecting a good lot, which is a risk to the producer.

Beta Risk – The risk of accepting a bad lot, which is a risk for the consumer.
In control charting the Alpha Risk is called a Type I error and the Beta Risk is called a Type II error. The Type I error is a false alarm where the chart appears to be out of statistical control when it is in control. The Type II error is a false alarm where the chart appears to be in statistical control when it is not in control.

INTERPRETATION OF RANGE CHARTS

A. Range charts shows uniformity or consistency

B. If the range chart is narrow, product is uniform. If the range chart is wide, the product is out-of-control, something is operating on the process in s non-conforming manner.

C. Analyze the data points on the range chart for the following:
   - Points beyond the control limit.
   - Patterns or trends within the control limits.
   - Any other non-random pattern.
INTERPRETATION OF RANGE CHARTS

1. Points beyond the control limit.
   
   A. Calculation or plotting error

   B. The spread of the distribution (piece-to-piece variability) has increased (worsened) at that point.

   B. Measurement system has changed.
INTERPRETATION FOR RANGE CHARTS

2. Patterns or trends within control limits.

   A. Patterns and trends are evidence of non-control or a change in the process spread and are an early warning of unfavorable conditions.

   B. Patterns and trends can also indicate favorable conditions that should be captured for product improvement.

   C. Indicators are:

      * 7 points in a row on one side of the average range (R). (Run above or below the R).

      * 7 points in a row that are consistently increasing (run up) or consistently decreasing (run down).

   D. Run above the average range (R) or a run up indicates:

      * Greater spread in the output values which could be from special causes.
      * Change in measurement system.

   E. Run below the average range (R) or a run down indicates:

      * Smaller spread in output values, that is an improvement.
      * Change in measurement system.
PROCESS NOT IN CONTROL FOR RANGES
(Long runs above the $\bar{R}$)

$UCL_R$  

$\bar{R}$

PROCESS NOT IN CONTROL FOR RANGES
(Long run up)

$UCL_R$  

$\bar{R}$
INTERPRETATION FOR AVERAGE (X) CHARTS

A. Average chart shows where process is centered.

B. If the X chart is normal, the center of the process is not shifting. If the X chart shows a trend, the center of the process is moving gradually up or down. If the X chart is erratic and out-of-control, something is changing the center rapidly and inconsistently.

C. Analyze the data points on the range chart for the following:

* Points beyond the control limits
* Patterns or trends within the control limits.
* Any other non-random pattern
INTERPRETATION OF AVERAGE (X) CHARTS

1. Points beyond the control limits
   
   A. Calculation or plotting error
   
   B. The process has shifted
   
   C. Measurement system has changed
INTERPRETATION OF AVERAGE (X) CHARTS

2. Patterns or trends within control limits

A. Patterns and trends are evidence of non-control or a change in capability. Comparison of patterns between the ranges and averages charts may be useful.

B. Patterns and trends can also indicate favorable conditions that should be captured for product improvement.

C. Indicators are:

* 7 points in a row on one side of the process average (X) (Run above or below the X)

* 7 points in a row that are consistently increasing (run up) or consistently decreasing (run down)

D. Run above or below the X indicates:

* The process average has changed (and may still be changing)

* Measurement system has changed
INTERPRETATION OF AVERAGES ($\bar{X}$) CHARTS

3. Any other non-random pattern

   A. Spread of data points within control limits
   
   B. Cycles

   PROCESS NOT IN CONTROL FOR AVERAGES
   (Points too close to the $\bar{X}$)

   PROCESS NOT IN CONTROL FOR AVERAGES
   (Points too close to the control limits)

   PROCESS NOT IN CONTROL FOR AVERAGES
   (Cycle pattern present)
ATTRIBUTE CONTROL CHARTS

Lesson Objectives…

To help you make the most effective use of this manual and your time in learning the concepts described, we have listed below your study objectives for this lesson. These objectives tell where you are going in this lesson and what you can expect to learn.

Please read the objectives carefully and keep them in mind as you read and study the lesson. You should be able to accomplish each of these objectives upon completion of this lesson.

- Construct Attribute Control Charts (p, np, c, u)
- Determine the conditions for selecting an Attribute Control Chart.
- Identify an Out-Of-Control condition using Attribute Control Charts.
- Define how Attribute Control Charts can be used to analyze and control a process.
**Attribute Chart**

A defect is a characteristic of a part which is unacceptable. One item, part, unit, or document may have many defects. Below are two examples of defects. Complete the list with examples which relate to your process.

- Number of scratches on one appliance.
- Missing zip code on purchase order.
- ____________________________.
- ____________________________.
- ____________________________.
- ____________________________.

A defect is an entire item, part, unit, or document which is unacceptable. One item (etc.) may not have multiple defectives. Below are two examples of defectives. Complete this list with examples from your process.

- Warped part
- Cracked glass
- ____________________________.
- ____________________________.
- ____________________________.
- ____________________________.
### Attribute Chart

**Symbols and Terminology:**

<table>
<thead>
<tr>
<th><strong>ATTRIBUTE:</strong></th>
<th>Type of data which is not measured. A decision of good/bad, go/no is made. This is sometimes referred to as countable data.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CONFORMING</strong></td>
<td>Good item (Meets requirements)</td>
</tr>
<tr>
<td><strong>NON-CONFORMING</strong></td>
<td>Items which are not acceptable or do not perform to standard.</td>
</tr>
<tr>
<td><strong>IN-CONTROL</strong></td>
<td>Term used to describe a process where all causes of variant are inherent in the process (Common Cause Variation). This usually refers to a control charts when points are between control limits with no abnormal patterns. (A process which is predictable)</td>
</tr>
<tr>
<td><strong>CL</strong></td>
<td>Centerline</td>
</tr>
<tr>
<td><strong>LCL</strong></td>
<td>Lower Control Limit</td>
</tr>
<tr>
<td><strong>N</strong></td>
<td>The total number of items in a subgroup.</td>
</tr>
<tr>
<td><strong>n</strong></td>
<td>The number of individual items in a subgroup.</td>
</tr>
</tbody>
</table>
Attribute Chart

COMMON CAUSE - Inherent or natural variation in the process. These represent the “trivial many.” (Pareto’s 20/80 rule)

ASSIGNABLE CAUSE - Also called “special cause”, refers to variation in the process which is local in nature and may be resolved by the team and the supervisor. The causes may be specific to a machine, person, material, or method. This represents the “vital few.” (Pareto’s 20/80 rule)
p CHARTS

Definition:

This is an Attribute Charts which is used to measure the percentage of defective items.

Characteristics:

• Sample sizes may be constant or may vary.

• If the sample size varies more than 25% of the average sample size, the control limits must be re-calculated.

• This is the only Attribute Charts which expresses the plotted data as a percent. (%)

How To Construct:

1. Initiate data collection with Team.

   • Determine who will collect data.

   • Determine how data will be collected.

   • Determine sample number in each subgroup (must be at least 25).

   • Determine number of subgroups to be used (minimum of 20).

2. Collect Data. The plotted points will be the number of defective for each sample group.
Attribute Chart

3. Compute the average number of defectives for all sample groups (np).

\[ np = \frac{\text{total of defectives all groups}}{\text{total number of sample groups (k)}} = \frac{3+4+11+7+0}{23} = 4.56 \]

4. Compute UCLnp and LCLnp

\[
\begin{align*}
UCL & = np + 3 \sqrt{np \left(1 - \frac{np}{n}\right)} \\
& = 4.56 + 3 \sqrt{4.56 \left(1 - \frac{4.56}{50}\right)} \\
& = 4.56 + 3 \sqrt{4.56 \times (1 - .0912)} \\
& = 4.56 + (3 \times 2.0357) \\
& = 10.7 \\
\end{align*}
\]

\[
\begin{align*}
LCL & = np - 3 \sqrt{np \left(1 - \frac{np}{n}\right)} \\
& = 4.56 - 3 \sqrt{4.56 \left(1 - \frac{4.56}{50}\right)} \\
& = 4.56 - 3 \sqrt{4.56 \times (1 - .091)} \\
& = 4.56 - 3(4.144128) \\
& = 1.6 \\
\end{align*}
\]

Do not convert to a percent. This will be done after all of the worksheet is complete.
5. Calculate control limits.

\[
UCL_p = \bar{p} + 3 \sqrt{\frac{p(1-p)}{n}}
\]

\[
= 0.091 + 3 \sqrt{\frac{0.091(1-0.091)}{149.8}}
\]

\[
= 0.091 + 3 \sqrt{0.000552}
\]

\[
= 0.091 + 0.0705
\]

\[
= 0.16
\]

\[
LCL_p = \bar{p} - 3 \sqrt{\frac{p(1-p)}{n}}
\]

\[
= 0.091 - 3 \sqrt{\frac{0.091(1-0.091)}{149.8}}
\]

\[
= 0.091 - 3 \sqrt{0.000552}
\]

\[
= 0.091 + 0.0705
\]

\[
= 0.0205
\]

6. Convert \( p \), \( UCL_p \), and \( LCL_p \) to percent (if \( LCL_p \) is a negative number (-), use zero (0)).

*Attribute Chart*
### Attribute Chart

**Example Data:**

<table>
<thead>
<tr>
<th>Subgroup Size (n)</th>
<th>150</th>
<th>150</th>
<th>150</th>
<th>150</th>
<th>150</th>
<th>150</th>
<th>150</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defectives (np)</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>8</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>Fraction Defective</td>
<td>.027</td>
<td>.013</td>
<td>.006</td>
<td>.006</td>
<td>0</td>
<td>.05</td>
<td>.08</td>
<td>.02</td>
</tr>
<tr>
<td>Percent Defective</td>
<td>2.71</td>
<td>.3</td>
<td>.6</td>
<td>.6</td>
<td>0</td>
<td>5</td>
<td>8</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>150</th>
<th>150</th>
<th>150</th>
<th>160</th>
<th>160</th>
<th>150</th>
<th>150</th>
<th>150</th>
<th>150</th>
<th>150</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>6</td>
<td>5</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>9</td>
<td>12</td>
<td>6</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>.06</td>
<td>.04</td>
<td>.03</td>
<td>.05</td>
<td>.05</td>
<td>.04</td>
<td>.06</td>
<td>.08</td>
<td>.04</td>
<td>.02</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>3</td>
<td>5.6</td>
<td>5</td>
<td>4.7</td>
<td>6</td>
<td>8</td>
<td>4</td>
<td>2.6</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>150</th>
<th>150</th>
<th>150</th>
<th>150</th>
<th>150</th>
<th>150</th>
<th>125</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>8</td>
<td>8</td>
<td>18</td>
<td>11</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>.04</td>
<td>.053</td>
<td>.053</td>
<td>.12</td>
<td>.073</td>
<td>.066</td>
<td>.032</td>
</tr>
<tr>
<td>4.7</td>
<td>5.3</td>
<td>5.3</td>
<td>12</td>
<td>7.3</td>
<td>6.7</td>
<td>3.2</td>
</tr>
</tbody>
</table>

To find fraction defective and percent defective, see step number three.
### p Chart Worksheet

**Process** ___________________________ **Team** ___________________________

**Sampling Method**

<table>
<thead>
<tr>
<th>$n =$</th>
<th>$\bar{d} =$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N =$</td>
<td>$\bar{p} =$</td>
</tr>
<tr>
<td>$\text{UCL}_{p} =$</td>
<td>$\text{LCL}_{p} =$</td>
</tr>
</tbody>
</table>

**Date**

<table>
<thead>
<tr>
<th>$N =$ Sample size X No. of subgroups $(n \times k)$</th>
</tr>
</thead>
</table>

\[
\bar{p} = \frac{d}{N}
\]

Upon completion of entire worksheet convert to percentage to plot.

\[
\text{LCL}_{p} = \bar{p} - 3 \sqrt{\frac{\bar{p}(1-\bar{p})}{n}}
\]

\[
\text{UCL}_{p} = \bar{p} + 3 \sqrt{\frac{\bar{p}(1-\bar{p})}{n}}
\]
**Attribute Chart**

**np Chart Worksheet**

<table>
<thead>
<tr>
<th>Process</th>
<th>Team</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling Method</td>
<td>Date</td>
</tr>
</tbody>
</table>

| n = |  
| k = |  
| u = |  
| n\(\bar{p}\) = |  
| \(\bar{p}\) = |  
| UCLnp = |  
| LCLnp = |  

\[
n\bar{p} = \frac{\text{total # defective units}}{k}
\]

\[
\bar{p} = \frac{np}{n}
\]

\[
UCLnp = n\bar{p} + 3\sqrt{n\bar{p}(1-\bar{p})}
\]

\[
LCLnp = n\bar{p} - 3\sqrt{n\bar{p}(1-\bar{p})}
\]

**NOTES:**

This chart records quantities of defective units. The subgroup size must be constant.

np Chart measures process output as actual number of defective items. "p Charts" reflect percentages.

If LCL is negative - use zero.

\(n\bar{p}\) the average number of defective units. This is also the centerline.

n number of samples in one subgroup.

k total number subgroups

np number of defectives found in one subgroup. Plot these points.
**Attribute Chart**

2. Collect Data

3. Compute the average number of defects $\overline{c}$.

\[
\overline{c} = \frac{\text{total number of defects found}}{\text{number of time periods (k)}}
\]

or

\[
\frac{7+9+6+12+9+16+18+22+15}{22} = \frac{114}{22}
\]

$\overline{c} = 5.18$

4. Compute UCLc and LCLc =

\[
\begin{align*}
\text{UCLc} & = \overline{c} + 3 \sqrt{\overline{c}} \\
& = 5.18 + 3 \sqrt{5.18} \\
& = 5.18 + 6.83 \\
& = 12
\end{align*}
\]

\[
\begin{align*}
\text{LCLc} & = \overline{c} - 3 \sqrt{\overline{c}} \\
& = 5.18 - 3 \sqrt{5.18} \\
& = 5.18 - 6.83 \\
& = -1.6
\end{align*}
\]

If LCL is a negative number, use zero.
Attribute Chart

**c Chart Worksheet**

Process __________________________ Team __________________________

Sampling Method __________________________ Date __________________________

\[
\begin{align*}
 n &= \\
k &= \\
\bar{c} &= \\
\text{UCLc} &= \\
\text{LCLc} &= \\
\bar{c} &= \frac{\text{total \# defects found}}{k} \\
\text{UCLc} &= \bar{c} + 3 \sqrt{\bar{c}} \\
\text{LCLc} &= \bar{c} - 3 \sqrt{\bar{c}} \\
n &= \text{number of samples in one subgroup.} \\
k &= \text{total number of subgroups.} \\
\bar{c} &= \text{average \# of defects per unit.}
\end{align*}
\]

**NOTES:**

n must be constant on c Chart Therefore, the control limits will also be constant.

When an item contains many defects, use a "c" Chart instead of a "p" Chart.

When LCLc equals a negative number, use zero.

The Centerline is \(\bar{c}\).
Attribute Chart

3. Compute $u$ (average number of defects per unit).

$$u = \frac{\text{defects in one unit (c)}}{\text{number of samples per unit (n)}}$$

\[
\frac{7}{5} = 1.4, \quad \frac{9}{5} = 1.8, \quad \frac{6}{5} = 1.2, \quad \frac{1}{5} = .2, \quad \ldots
\]

4. Compute $\bar{u}$ (grand average).

$$\frac{\Sigma \text{ of all Defects}}{\Sigma \text{ of all units inspected}}$$

5. Compute UCL$_u$ and LCL$_u$

\[
\begin{align*}
\text{UCL}_u &= \bar{u} + 3 \sqrt{\frac{\bar{u}}{n}} \\
&= .96 + 3 \sqrt{\frac{.96}{4.529}} \\
&= .96 + 3 \sqrt{.212} \\
&= .96 + 1.38 \\
&= 2.34
\end{align*}
\]
### Attribute Chart

#### u Chart Worksheet

<table>
<thead>
<tr>
<th>Process</th>
<th>Team</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Sampling Method</th>
<th>Date</th>
</tr>
</thead>
</table>

| \( n = \) | \( U = \) |
| \( k = \) | \( UCL_u = \) |
| \( \bar{u} = \) | \( LCL_u = \) |

\[
\bar{u} = \frac{\text{total \# defects found}}{\text{total \# units inspected}}
\]

\[
UCL_u = \bar{u} + 3\sqrt{\frac{\bar{u}}{n}}
\]

\[
LCL_u = \bar{u} - 3\sqrt{\frac{\bar{u}}{n}}
\]

**NOTES:**

Use instead of c Chart if subgroup size not constant.

Plotted points represents the average number of defects per unit.

\( u \) plotted points - found by \( c + n \) in each subgroup. This is average defects per unit.

\( c \) defects per unit.

\( \bar{u} \) average number defects also, called centerline.

\( n \) unit size.
Attribute Chart

• Points below the LCL are often desirable however, as they move closer to the desired zero defects (defective).

• A point on or near the Lower Control Limit indicates that a desirable condition may exist and should be investigated.
Attribute Chart

Review:

Attribute Charts are used with ________________ type data, when making ________________ decisions. The four basic types of Attribute Charts are ________, __________, _________, _________. The ________________ and ________________ are used to monitor defects per units.

p Charts are different from the other Attribute Charts as the plotted points are _________________________________.

Explain the difference between a defective and a defect:

_______________________________.

_______________________________.

Give an example of how an Attribute Chart will help in your process: _________________________________.

_______________________________.
<table>
<thead>
<tr>
<th>PART NAME</th>
<th>PART NO.</th>
<th>OPERATION (PROCESS)</th>
<th>FREQUENCY</th>
<th>p</th>
<th>c</th>
<th>np</th>
<th>u</th>
</tr>
</thead>
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<tr>
<td>DEPARTMENT</td>
<td>MACHINE</td>
<td>AVG.</td>
<td>UCL.</td>
<td>LCL.</td>
<td>AVG. SAMPLE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
</tbody>
</table>

PERCENT
SAMPLE SIZE
TOTAL

DISCREPANCIES
DATE
TIME
OPERATOR

JOB NUMBER
Interpret for Process Control – p chart

* The purpose of the control chart is to identify when a the process is operation out-of-control (Special cause variation present) so that appropriate action me be taken.

* Analyze the control chart for the following:

1. Points beyond the control limits.
2. Patterns or trends within the control limits.
3. Any other non-random pattern.
CHART INTERPRETATION

1. Points beyond the control limits.

   * Points beyond the control limits are evidence of non-control at that point and the presence of special cause variation.

   * Points above the upper control limit:
     A. Calculation or plotting error
     B. Process performance has worsened
     C. The measurement system has changed

   * Points below the lower control limit:
     A. Calculation or plotting error.
     B. Process performance has improved.
     C. The measurement system has changed.
2. Patterns or trends within control limits

* Patterns and trends are evidence of non-control or a change in the level of performance.

* Patterns and trends can indicate also favorable conditions that should be captured for product improvement.

* Indicators are:

A. 7 points in a row on one side of the process average ($\bar{p}$) (Run above or below the average)

B. 7 points in a row that are increasing inconsistently (run up) or decreasing inconsistently (run down)

* A run above the average or run up indicates:

A. Process performance has worsened.

B. A change in the measurement system.

* A run below the average or run down indicates:

A. Process performance has improved.

B. A change in the measurement system.

**CAUTION:** When the number non-conforming (np) is small in each subgroup (five or less) the above guidelines may not be applicable.
CHART INTERPRETATION

Process not in control (Long run above or below average)

Process not in control (Long run up or down)
3. Any other non-random patterns:

* Non-random patterns such as cycles, the overall spread of data within the control limits and relationships among values within subgroups may provide an indication of special cause variation.

* More than 2/3 of the data points should lie within the middle third of the region within the control limits.

A. If more than 2/3 of the data points are in the middle third of the region between the control limits, possible causes include:

   - Calculation and/or plotting error

   - Each subgroup contains data from two or more process systems

   - The data has been edited.

B. If less than 2/3 of the data points lie within the middle third of the region between the control limits, possible causes include:

   - Calculations and/or plotting error

   - Each subgroup contains data from two or more process streams with dramatically different variability. (ex. Mixed material lots)
CHART INTERPRETATION

Process not in control (Points too close to the average)

Process not in control (Points too close to the control limits)
PROCESS CAPABILITY – p CHARTS

1. Eliminate special cause variation

* Process capability is the variation due to common causes, that is, the variation experienced after all causes of special variation have been eliminated.

* Special causes of variation must be identified, analyzed, corrected and prevented from reoccurring to determine process capability.

2. Calculate process capability

* Process capability is reflected in the process average non-conforming (p) when all special cause variation has been eliminated (ex. All points are in control).

* Historical data may be used to determine process capability (p) provided that values associated with special cause variation has been removed from the system. (25 or more subgroups)

3. Evaluate Process Capability

* The process capability (p) reflects the future level of performance that can be expected by management.

* Capability (p) will remain constant during future production as long as system changes are not introduced.

* Management must take steps to improve the process if the average non-conforming (p) is not acceptable.

4. Improve process capability

* Management action must be directed to the system to reduce inherent common cause variation.
* Tools used by management to identify and eliminate special cause variation may not be appropriate to identify and eliminate common cause variation.

* The p Chart is an effective device to monitor and analyze management action to reduce common cause variation.

* Special causes of variation must be eliminated. The p chart will then reflect the new process capability (p).

* Management should continue to improve process capability. Process capability improvement is necessary!
MEASUREMENT SYSTEM ANALYSIS

Measuring equipment is subject to variation. Therefore, an analysis of a process cannot be meaningful unless the measuring instruments used to collect data are both accurate and repeatable.

Definitions used in measurement system analysis:

1. **GAGE ACCURACY** – is the difference between the observed average of measurements and the true average. Establishing the true average is best determined by measuring with the most accurate measuring equipment available.

2. **GAGE REPEATABILITY** – the variation in measuring obtained when one operator uses the same gage for measuring the identical characteristics of the same part.

3. **GAGE REPRODUCABILITY** – the variation in the average of measurements made by different operators using the same gage when measuring identical characteristics of the same part.

4. **GAGE STABILITY** – refers to the difference in the average of at least two sets of measurements obtained with the same gage on the same parts taken at different times.

5. **GAGE LINEARITY** – the difference in the accuracy values through the expected operating range.
MEASUREMENT SYSTEM ANALYSIS

Preliminary Considerations:

1. How many operators are to be involved?

2. How many sample parts are to be measured?

3. What number of repeat reading will be needed?

Conducting the study: Even though the number of operators, the number of trials and the number of parts may be varied, one should conduct the study according to the following steps:

1. Refer to operators A, B, and C, and number the parts 1 through 10 so that the numbers are not visible to the operators.

2. Calibrate the gage.

3. Let operator A measure 10 parts on a random order an enter results on data sheet.

4. Repeat step 3 with operators B and C.

5. Repeat the cycle, with 10 parts measured in another random order, for the number of trial required.

6. Steps 3 through 5 may be modified for large size parts, unavailability of parts or when operators are on different shifts.

7. Enter all observations to derive Gage R and R.
## GAGE REPEATABILITY AND REPRODUCIBILITY DATA SHEET (Long Method)

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Operator A-</th>
<th>Operator B-</th>
<th>Operator C-</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1st Trial</td>
<td>1st Trial</td>
<td>1st Trial</td>
</tr>
<tr>
<td>2</td>
<td>2nd Trial</td>
<td>2nd Trial</td>
<td>2nd Trial</td>
</tr>
<tr>
<td>3</td>
<td>3rd Trial</td>
<td>3rd Trial</td>
<td>3rd Trial</td>
</tr>
<tr>
<td>4</td>
<td>Range</td>
<td>Range</td>
<td>Range</td>
</tr>
<tr>
<td>5</td>
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<td></td>
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<td>9</td>
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<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Calculations

\[
\bar{R} = \text{Sum of } R
\]

\[
\bar{X} = \frac{\text{Sum of } X}{\text{Number of Samples}}
\]

\[
D_4 = 3.27
\]

\[
(\bar{R}) \times (D_4) = UCL_R
\]

\[
(\bar{X}) \times (\text{Min. } \bar{X}) = \text{Max. } \bar{X}
\]

\[
\bar{X} \text{ Diff.}
\]

* Limit of individual R's. Circle those that are beyond this limit, identify the cause and correct. Repeat these readings using the same appraiser and unit as originally used or discard values and reassess and recompute \( \bar{R} \) and the limiting value, \( UCL_R \) from the remaining observations.

### Notes:

---

---
Gage Repeatability and Reproducibility Report

Part No. & Name __________________________
Characteristic __________________________
Specification ____________________________

Gage Name ____________________________
Gage No. ______________________________
Gage Type _____________________________

Date ____________________________
Performed By: ________________________

From Data Sheet:

**MEASUREMENT UNIT ANALYSIS**

**REPEATABILITY - EQUIPMENT VARIATION (E.V.)**

\[ E.V. = \left( \bar{R} \right) \times \left( K_s \right) \]

\[ = (__) \times (__) = \]

\[ n = \text{number of parts} \]
\[ r = \text{number of trials} \]

**REPRODUCIBILITY - APPRAISER VARIATION (A.V.)**

\[ A.V. = \sqrt{\left(\bar{X}_{\text{avg}}\right)^2 - \left[\frac{\text{E.V.}}{\text{n x r}}\right]^2} \]

\[ = \sqrt{(__) \times (__)^2 - (__)^2 / (__)^2} = \]

**REPEATABILITY AND REPRODUCIBILITY (R & R)**

\[ R & R = \sqrt{\text{E.V.}^2 + \text{A.V.}^2} \]

\[ = \sqrt{(__)^2 + (__)^2} = \]

**% TOLERANCE ANALYSIS**

\[ \% \text{ E.V.} = 100 \left(\frac{\text{E.V.}}{\text{TOLERANCE}}\right) \]

\[ = 100 \left(\frac{(__)}{(__)}\right) \]

\[ \% \text{A.V.} = 100 \left(\frac{\text{A.V.}}{\text{TOLERANCE}}\right) \]

\[ = 100 \left(\frac{(__)}{(__)}\right) \]

\[ \% \text{ R & R} = \sqrt{\text{E.V.}^2 + \text{A.V.}^2} \]

\[ = \sqrt{(__)^2 + (__)^2} = \]

**NOTE:** All calculations are based upon predicting 5.15 \( \sigma \)
(99% of the area under normal curve).

* A negative value under the square root sign causes the appraiser variation to default to zero.

6/20/84
INTERPRETATION OF R AND R STUDY

GENERAL GUIDELINES

1. Gage R and R (combined)
   - Under 10% error - Acceptable
   - 10% to 30% error – May be acceptable based upon importance of the application, gage cost, and cost of repairs.
   - Over 30% error – Generally not acceptable. Make every effort to identify the problem and get it corrected.

2. Reproducibility % is large:
   - The operator is not properly trained in how to use and read the gage instrument.
   - Calibration on the gage dial are not clear.

3. Repeatability % is large:
   - The gage instrument needs maintenance.
   - The gage should be redesigned to be more rigid.
   - The clamping or location for gaging needs to be improved.
MEASUREMENT SYSTEM ANALYSIS

Preliminary Considerations:

1. How many operators are to be involved?

2. How many sample parts are to be measured?

3. What number of repeat reading will be needed?

Conducting the study: Even though the number of operators, the number of trial and the number of parts may be varied, one should conduct the study according to the following steps:

1. Refer to operators A, B, and C, and number the parts 1 through 10 so that the numbers are not visible to the operators.

2. Calibrate the gage.

3. Let operator A measure 10 parts on a random order and enter results on data sheet.

4. Repeat step 3 with operators B and C.

5. Repeat the cycle, with 10 parts measures in another random order, for the number of trials required.

6. Steps 3 through 5 may be modified for large size parts, unavailability of parts or when operators are on different shifts.

7. Enter all observations on data sheet and perform calculations to derive Gage R and R.
APPENDIX
# MATHEMATICAL SYMBOLS

<table>
<thead>
<tr>
<th>SYMBOLS</th>
<th>DEFINITION</th>
<th>OPERATION</th>
<th>EXAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>PLUS</td>
<td>(ADD)</td>
<td>2+2=4</td>
</tr>
<tr>
<td>-</td>
<td>MINUS</td>
<td>(SUBTRACT)</td>
<td>2-2=0</td>
</tr>
<tr>
<td>X</td>
<td>TIMES</td>
<td>(MULTIPLY)</td>
<td>2X3=6</td>
</tr>
<tr>
<td>•</td>
<td>TIMES</td>
<td>(MULTIPLY)</td>
<td>2•2=6</td>
</tr>
<tr>
<td>2(X)</td>
<td>TIMES</td>
<td>(MULTIPLY)</td>
<td>2(3)=6</td>
</tr>
<tr>
<td>2A</td>
<td>TIMES</td>
<td>(MULTIPLY)</td>
<td>2X the value of A</td>
</tr>
<tr>
<td>÷</td>
<td>DIVIDED BY</td>
<td>(DIVIDE)</td>
<td>6÷2=3</td>
</tr>
<tr>
<td>/</td>
<td>DIVIDED BY</td>
<td>(DIVIDE)</td>
<td>6/2=3</td>
</tr>
<tr>
<td>a/b</td>
<td>a DIVIDED BY b</td>
<td>(DIVIDE)</td>
<td>( \frac{6}{3} = 2 )</td>
</tr>
<tr>
<td>( )</td>
<td>THE QUANTITY</td>
<td>(COMPUTE OPERATION IN ( ) FIRST)</td>
<td>2(1+2)=2(3)</td>
</tr>
<tr>
<td>√</td>
<td>SQUARE ROOT</td>
<td>(SQAURE ROOT OF)</td>
<td>9=3</td>
</tr>
<tr>
<td>Σ</td>
<td>THE SUM OF</td>
<td>(ADD ALL VALUES)</td>
<td>X, when X = 7,9,10 = 7+9+10 =26</td>
</tr>
</tbody>
</table>
DEFINITION OF SPC SYMBOLS

$X$ the value of an individual measurement or a single observation.

$\bar{X}$ the Mean or Average values of all values for a group of samples.

$\bar{\bar{X}}$ the Grand Average of all the Averages for a group of samples.

$R$ the Range, which measures the amount of dispersion or scatter contained in a group of samples.

$\bar{R}$ the Average range of all Ranges for a group of samples.

$C$ the number of Defects per sample.

$\bar{C}$ the average number of Defects per sample or unit inspected.

$np$ the number of Defectives for all sample groups.

$\bar{np}$ the average number of Defectives for all sample groups.

$p$ the fraction or percentage of Defectives for all sample groups.

$\bar{p}$ the average fraction or percentage of Defectives for all sample groups.

$u$ the average number of Defects per sample. A sample in this case may be a unit or a group of units.

$\bar{u}$ the average number of Defects for all sample groups.

$UCL$ the Upper Control Limit (equivalent to $+3\sigma$)

$CL$ the Central Line (equivalent to the Mean or Average Value)

$LCL$ the Lower Control Limit (equivalent to $-3\sigma$)

$USL$ the Upper Specification Limit

$LSL$ the Lower Specification Limit

$\Sigma$ the symbol used to indicate “the sum of”

$k$ the total number of sample groups or sub-groups.

$n$ the number of individual sample measurements or observation contained in a sample group.
\( N \) the total number of sample measurements or observations in a population.

\( \sigma \) the Standard Deviation which measures the amount of dispersion or scatter contained in a group of samples. This is also referred to as sigma.

\( \overline{\sigma} \) the average Standard Deviation for a group of samples that can be used to estimate the value of the population’s Standard Deviation.

\( +3\sigma \) three Standard deviations to the right of the Mean (positive)

\( -3\sigma \) three Standard Deviations to the left of the Mean (negative)

\( MR \) Moving Range

\( \overline{MR} \) the average of a series of Moving Ranges

\( d_2 \) factor for estimating Standard Deviation

\( A_2 \) factor for estimating \( \overline{X} \) chart limits

\( D_4 \) factor for estimating Upper Control Limit on R chart
<table>
<thead>
<tr>
<th>NUMBER OF OBSERVATIONS IN SUBGROUP n</th>
<th>CHART FOR AVERAGES FACTORS FOR CONTROL LIMITS A₂</th>
<th>CHART FOR RANGES</th>
<th>CHARTS FOR INDIVIDUALS FACTORS FOR CONTROL LIMITS E₂</th>
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<tbody>
<tr>
<td></td>
<td>d₂</td>
<td>D₃</td>
<td>D₄</td>
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<tr>
<td>2</td>
<td>1.88</td>
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<td>3.258</td>
<td>0.284</td>
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<td>0.249</td>
<td>3.336</td>
<td>0.308</td>
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<tr>
<td>20</td>
<td>0.180</td>
<td>3.735</td>
<td>0.414</td>
</tr>
</tbody>
</table>
FORMULAS

I. Variable Data

A. \( \bar{X} \) CHARTS

1. \( \bar{X} = \) Average of the values in each sample

2. \( \bar{X} = \) Average of the \( \bar{X} \) value

3. \( \text{UCL}_X = \bar{X} - A \frac{R}{X} \)

4. \( \text{LCL}_X = \bar{X} - A \frac{R}{X} \)

B. \( R \) CHARTS

1. \( \bar{R} = \) Sum of \( R \) values divided by the number of samples

2. \( \text{UCL}_R = D_4 \bar{R} \)

3. \( \text{LCL}_R = D_3 \bar{R} \)

C. INDIVIDUAL AND MOVING RANGE

1. \( X = \) Individual Value

2. \( MR = \) Moving Range

3. \( \bar{MR} = \) Sum of the moving range values divided by number of samples.

4. \( \text{UCL}_X = \bar{X} + E \frac{MR}{X} \)

5. \( \text{LCL}_X = \bar{X} - E \frac{MR}{X} \)

6. \( \text{UCL}_R = D_4 \bar{MR} \)

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II. Attribute Data

A. p CHARTS
1. \( p = \frac{\text{number of rejects in subgroup}}{\text{number of inspected in subgroup}} \) : fraction defective
2. \( \bar{p} = \frac{\text{total number of rejects}}{\text{total number inspected}} \) : average fraction defective
3. \( \text{UCL}_p = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \) NOTE: \( n = \) number of possibilities per sample
4. \( \text{LCL}_p = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \)

B. np CHARTS
1. \( np = \text{number of defective or non-conforming units} \)
2. \( \bar{np} = \text{average number of defective or non-conforming units} \)
3. \( \text{UCL}_{np} = \bar{np} + 3\sqrt{\frac{\bar{np}(1-\bar{p})}{n}} \)
4. \( \text{LCL}_{np} = \bar{np} - 3\sqrt{\frac{\bar{np}(1-\bar{p})}{n}} \)

C. c CHART
1. \( c = \text{number of defects or non-conformities in a subgroup} \)
2. \( \bar{c} = \text{average number of defects or non-conformities} \)
3. \( \text{UCL}_c = \bar{c} + 3\sqrt{\bar{c}} \)
4. \( \text{LCL}_c = \bar{c} - 3\sqrt{\bar{c}} \)

D. u CHART
1. \( u = \text{number of defects or non-conformities per unit in a subgroup} \)
2. \( \bar{u} = \text{average number of defects or non-conformities per unit} \)
3. \( \text{UCL}_u = \bar{u} + \frac{3\sqrt{\bar{u}}}{\sqrt{n}} \)
4. \( \text{LCL}_u = \bar{u} - \frac{3\sqrt{\bar{u}}}{\sqrt{n}} \)
III. Standard Deviation (Sigma \( \sigma \))

A. \[ \sqrt{\frac{\sum (X - \bar{X})^2}{N^*}} \]

\text{NOTE: use N-1 when sample size is less than 30}
\text{use N when sample size is 30 or above}

B. \[ \frac{\bar{R}}{d_2} \] = Average range divided by \( d_2 \) factor

IV. Capability Ratio (C. R.)

\text{Capability Spread or 6 \( \sigma \)}
\text{Specification Spread or Tolerance}

V. Capability Index (CpK)

\text{Lesser of:}

\[ \frac{USL - X}{3\sigma} \] or \[ \frac{X - LSL}{3\sigma} \]
GLOSSARY OF TERMS

ASSIGNABLE CAUSES

The causes of variation that are not considered to be normal or common causes. Assignable causes of variation can be identified, corrected and eliminated within a process.

ATTRIBUTE DATA

Data that is countable. For example, data that is classified as Good/Bad, Accepted/Rejected, Defective/Non-Defective, etc.

AVERAGE

The “sum” of all values in a group divided by the number of values. The Average is also called the Mean (X).

CAPABILITY

The maximum amount of inherent variation of a process. This is also referred to as the Process’s Normal Distribution (the values of 6σ).

CAPABILITY RATIO

The ration of the process capability to the design tolerance or specification spread. The ideal Capability Ratio should be .75 or less in order to maintain an acceptable level of Statistical Process Control.

CAUSE-AND-EFFECT DIAGRAM

A method of analyzing the potential sources or causes of variation. This is often used to identify and determine the possible causes for problems.

CHANCE-CAUSE SYSTEM

Various factors contributing to the amount of variation contained in any given process.

CHARACTERISTIC

A property or trait that distinguishes one item from other similar items.

COMMON CAUSE

Natural causes of variation that can be expected to occur in any process that cannot be changed or eliminated unless the process itself is changed.
CONSECUTIVE SELECTION

A selection method that is often used for machine-dominant operations whereby several items in a row are selected from a population.

CONTROL (as applied to “process”)

A condition which monitors, analyzes and maintains the amount of variation contained in any given process to that which is strictly due to common or natural causes of variation.

CONTROL CHART

A graphic chart with control limits and plotted values of some statistical measure for a series of samples or subgroups, over a period of time.

CONTROL LIMITS

Limits on a control chart that serve as a guide and a basis for action to the inherent variation (Normal Distribution) of the plotted statistic.

CONTROLLED PROCESS (IN-CONTROL)

A process in which all, or nearly all, of the plotted statistics fall within the established control limits. A process which repeats itself in a predictable manner.

CpK

Capability of a process with respect to the design specifications.

DATA

Facts (numerically expressed) used as a basis for decisions and conclusions.

DEFECT

Each instance that any item or unit fails to meet or conform to a single quality characteristic or standard imposed on it.

DEFECTIVE

A unit that fails to conform to the stated quality standards thereby making the entire unit unacceptable. A Defective may contain one or more defects.
DISTRIBUTION
The frequency of all possible results.

FISHBONE DIAGRAM
See Cause-and-Effect Diagrams

FRACTION REJECTED
The ratio of Defective pieces to the total number of all pieces inspected, usually expressed as a decimal.

HISTOGRAM
A pictorial display which illustrates the characteristics of a mass of data.

INSPECTION LOT
A specific quantity or similar units offered for inspection and acceptance at one time.

ITEM
A single member of an inspection lot, usually, though not necessarily, a single article or unit.

LOT
See INSPECTION LOT

MEAN
The arithmetical “average” that is computed by dividing the Sum of all samples by the number of samples. Also called the Average values and symbolically expressed as X.

MEDIAN
The “middlemost” value contained in a group of data such that half the values are above and half are below it.

MOVING RANGE
The difference between successive pairs of numbers in a series of numbers.
NON-CONFORMANCE

Any item or group of items that do not meet the established quality standards or specifications.

NORMAL DISTRIBUTION

The natural distribution of all values that can occur when a process is operating In-Control. Also referred to as the Normal or Bell-shaped Curve.

ONE HUNDRED PERCENT INSPECTION

The inspection of all items in the inspection lot.

OUT-of-CONTROL (as applied to a process)

The amount of variation that exceeds the limits of its Normal Distribution that can be identified and attributed to a special or assignable cause.

PARETO CHART

A bar chart that is used to define problems and set priorities by listing the various problems or causes of a particular problem according to their frequency of occurrence.

PERCENT DEFECTIVE

The ratio of Defective pieces to the total number of pieces inspected, multiplied by 100.

POPULATION

The entire group of items from which data or samples are drawn.

PROBABILITY

The chance or likelihood that some future or unknown event will (or will not) occur, usually expressed as a number between 0 and 1.

PROCESS

An operation or series of operations that are combined to produce a change. i.e., a part, product, unit, etc.

PROCESS CAPABILITY

A measure of the inherent or natural variation of a process. The Normal Distribution (6 σ) of any given process.
RANDOM SAMPLE or SELECTION

Selection of an item from a population such that each has equal chance of being selected.

RANGE

The difference between the largest and smallest values in a sample which indicates the spread or dispersion in the data.

SAMPLE

A group of items taken from a population (the entire lot) which is used to make decisions and draw conclusions about the population.

SAMPLING INSPECTION

Evaluation of the quality of material by inspecting only a portion of the material.

SIGMA (σ)

The small Greek letter that is used to denote the Standard Deviation.

SPECIFICATION LIMITS

Limits of the tolerance within which a process should run if its product is to be made according to design.

STANDARD DEVIATION

A measure of dispersion (scatter or spread) of a set of data or values around its MEAN.

STATISTIC

Numerical data that summarizes a group or series of events

STATISTICAL PROCESS CONTROL

A method of mathematically analyzing process results to determine if the process is behaving predictably.
SATISFACTORY CONTROL

X & R Control Charts

A process is operation in satisfactory control with respect to a measurable quality characteristic if all, or nearly all, of the points are plotted within the control limits and are randomly distributed around the Mean or central Line (CL); and all, or nearly all, of the points are within the stated specifications.

X & MR Control Charts

A process is operating in satisfactory control with respect to a measurable quality characteristic if all, or nearly all, of the points are plotted within the control limits and are randomly distributed around the Mean or Central Line (CL); and all, or nearly all, off the points are within the stated specifications.

SUBGROUP

A collection of individual pieces from a common source, possessing a similar set of quality characteristics from which a random sample is selected.

THREE SIGMA UNITS

Calculated limits based upon observed data. The validity of these limits is based upon the assumption that the data was selected from a “normal” or nearly normal distribution.

TOLERANCE

The allowable design deviation from a nominal values. The specification limits define the total allowable tolerance.

UNIT

One of a number of similar items, objects, pieces, etc.

UPPER AND LOWER CONTROL LIMITS (UCL and LCL)

These values are calculated limits, each three “sigma” distance from the Mean or Central Line, and between which 99.73% of the individual values or items from a Normal Distribution will fall.

VARIABILITY

The normal scatter or dispersion with in any group of data.
VARIABLE DATA

Data that is measurable. That is, one can measure the precise characteristic of a given item.
### Table of Areas Under the Normal Curve

#### Appendix

- **E**

#### Example

**Example:** For a Z score of 1.24, the shaded area under the curve is 0.3925 or 39.25% of the total area.

**Note:** If the calculated Z score is higher than 4.0, use 4.0 instead.

#### Figure 90. Table of Areas Under the Normal Curve

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