Section 4

BASIC TOOLS FOR ANALYZING DATA

Overview

The tools in this section will allow you to examine your data from several different viewpoints. They will help you organize data so that your process can "talk" to you and tell you what is happening (or not happening). These tools also allow you to package data so that it is easily understood by others. This can be important when you go to sell your proposed solutions to those in decision-making positions.

But, before we jump to solutions, we need to understand some other things these tools can do for us.

What Can These Tools Do For Me?

They are educational

Even those who might not know a lot about a particular process can learn quite a bit merely by using some of these tools. You will learn about your process and the proper application of the tool at the same time.

They serve as a great guide for discussions

Discussing problems or improvement opportunities can often get side-tracked. Using the tools outlined in this chapter will help keep you focused.

They allow you to be proactive in searching out "root causes"

Properly applying these tools will allow you to address the root causes of your problem instead of just the particular symptoms causing you pain. They allow you to take action that is both effective and efficient.

They allow you to convert raw numbers to usable information

Numbers, by themselves, can be meaningless. They need to be collected properly and then packaged so as to make their information clear to all.

They show the level of understanding (or lack of) of your process

They have a wide application to many processes and problems

They are generally easy to use and understand

Key Concepts

There are several key concepts that need to be understood prior to applying the tools to your process. These concepts form the background against which all your data should be viewed.

Statistical Process Control (SPC)

Statistical process control (based on Shewhart's PDCA and control charts) is a process in which you seek to:

* Select and define a process
* Measure that process
* Stabilize that process (eliminate any "special causes" of variation)
* Control that process (reduce any "common causes)
* Continuously improve the process

Basically, you are using numbers (statistics) to understand your process traits and characteristics so you will be able to make it do what you want it to do (control).

Goals of Process Improvement

Your goal should be to increase customer satisfaction and on-time delivery of your products and services. Additionally, you should seek to reduce the cycle time and waste involved in your process producing those services or products.

Variation

No two products or services will ever be exactly alike. This difference is known as variation. Dr. Deming teaches that to produce quality, you must be able to produce outcomes that are predictably uniform while at the same time satisfying customer needs. Reducing or controlling the amount of variation is crucial to improving your process.

"Common Cause" Variation

Common cause variation is due to factors inherent to the process itself. Variation in a process which occurs due to the normal operation of the process, or because of how that process is being managed, it is generally considered to be beyond the control of the individual. Examples might include improper material being provided, poor instructions, etc.

"Special Cause" Variation

Special cause variation occurs as a result of factors external to the process itself. Examples might be a power failure, a machine breaking down, an accident, etc. Special cause variations are exceptions to the normal way things occur.

Tampering

Treating special causes as if they were common causes (or vice versa) is called tampering. It is crucial each of us first understand what the voice of our process (and our customers) are really saying BEFORE we take action. Good intentions and "gut" feelings are not enough. We must use our data, apply the tools show in this section to analyze that data properly for root causes, and then take appropriate actions. Dr. Shewhart has shown that approximately 99% of the causes of variation within a statistically stable process are common causes and can be significantly reduced through informed control. Using data and the tools in this section will provided you the ability to exercise that "informed control" on your process.

Problems, Blame and the 85/15 Rule

TQM is a philosophy grounded in improving a process at every point to maximize the value that process can produce for the customer. It requires us to adopt a new attitude towards our problems. We need to see problems as "areas of opportunity" - to better meet customer needs, eliminate those things causing us "pain," and to increase our effectiveness and efficiency.

Additionally, TQM asks us to forget placing blame and to focus instead on fixing or preventing the problems we have discovered. The 85/15 Rule states that up to 85% of the problems with a process exist due to the process itself and lie within the control of management not the individual worker. Dr. Deming has stated the ration is even higher (96/4).

1-10-100 Rule

Basically, this rule states it is cheaper and easier to fix a problem at the point in a process it occurs. Failure to do so costs you a factor of at least 10 for every step further down the process from you it takes to catch the problem and fix it.

The tools in this section are designed to allow you to discover what your problems are, why they are occurring, how big a problem they are, and how to fix, prevent, and improve your work processes.

FLOWCHART

What it is:

A flowchart is a graphic representation of all the major steps of a process. It can help you:

- Understand the complete process.
- Identify the critical stages of a process.
- Locate problem areas.
- Show relationships between different steps in a process.

How to use it:

Identify the process. Define the start point and finish point for the process to be examined.

Describe the current process. Chart the whole process (i.e., lay out all the steps) from beginning to end. You can use the symbols shown on the next page to improve the clarity of your flowchart, but don't get hung up on symbols.

(Optional) Chart the ideal process. Try to identify the easiest and most efficient way to go from the "start block" to the "finish block." While this step isn't absolutely necessary, it does make it easier to do the next step.

Search for improvement opportunities. Identify all the areas that hinder your process or add little or no value. If you did the optional step, examine all areas that differ from your ideal process and question why they exist.

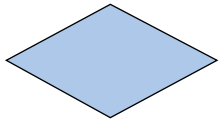
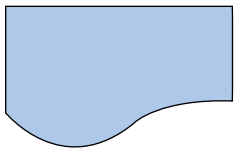
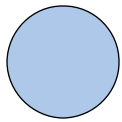
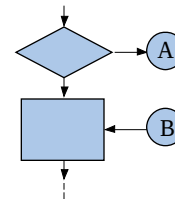
Update your chart. Build a new flowchart that corrects the problems you identified in the previous step.

Helpful hint:

You can put the steps of your process on index cards or sticky-back notes. This lets you rearrange the diagram without erasing and redrawing and prevents ideas from being discarded simply because it's too much work to redraw the diagram.

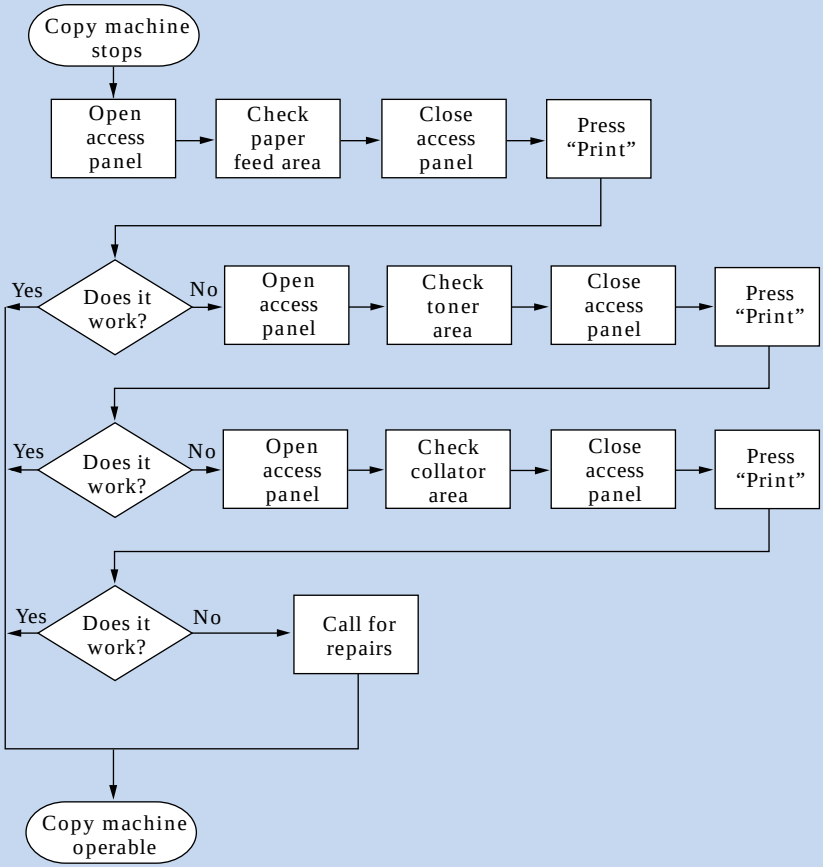
These are standard flowchart symbols. When you are developing a flowchart, especially in a group environment, **the goal is to *chart the process.* Don't waste time debating which shape a symbol should be**. A flowchart that doesn't use these symbols can be just as useful as a chart that does.

Standard Flowchart Symbols

This symbol...	*Represents...*	*Some examples are:*
	Start/Stop	Receive trouble report Machine operable
	Decision Point	Approve/Disapprove Accept/Reject Yes/No Pass/Fail
	Activity	Drop off travel voucher Open access panel
	Document	Fill out trouble report
	Connector (to another page or part of the diagram)	

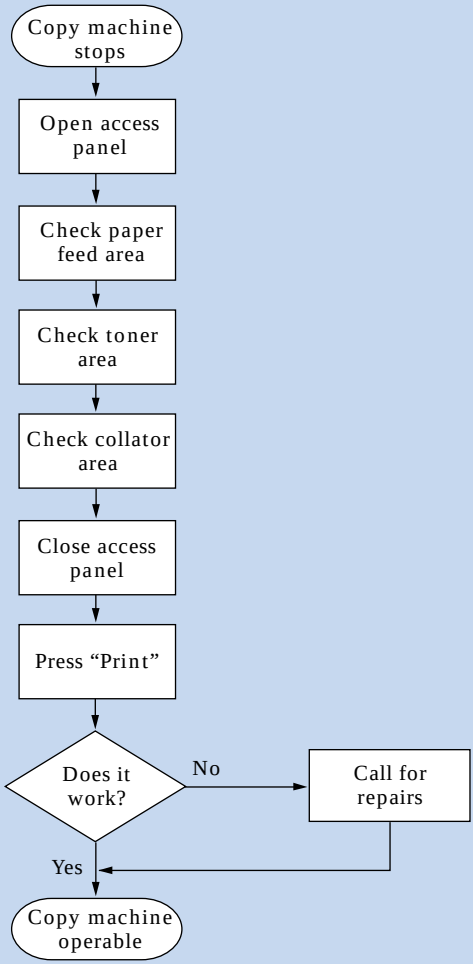
Flowchart Example

Before it was eventually replaced, a copy machine suffered frequent paper jams and became a notorious troublemaker. Often, a problem could be cleared by simply opening and closing the access panel. Someone observed the situation and flowcharted the troubleshooting procedure used by most people.



Flowchart Example (Concluded)

Users usually had to check several locations in the machine before they would find the problem. The next day, this flowchart for a more efficient procedure appeared beside the machine. From then on, there was less frustration and panel slamming when the machine stopped unexpectedly.



CAUSE AND EFFECT DIAGRAM

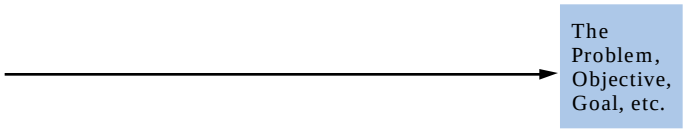
What it is:

Graphically illustrates the relationship between a given outcome and all the factors that influence this outcome. Sometimes called an Ishikawa or "fishbone" diagram, it helps show the relationship of the parts (and sub-parts) to the whole by:

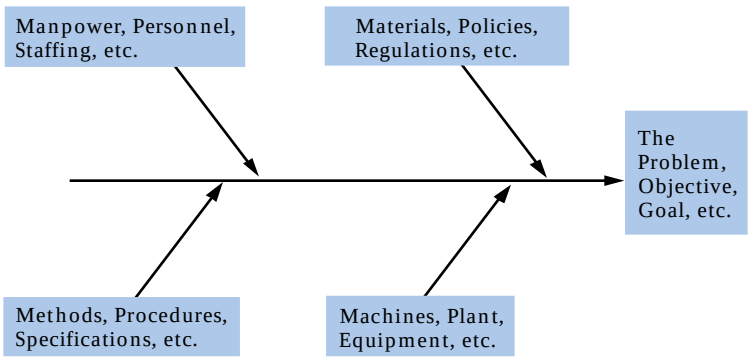
- Determining the factors that cause a positive or negative outcome (or effect)
- Focusing on a specific issue without resorting to complaints and irrelevant discussion
- Determining the root causes of a given effect
- Identifying areas where there is a lack of data

How to use it:

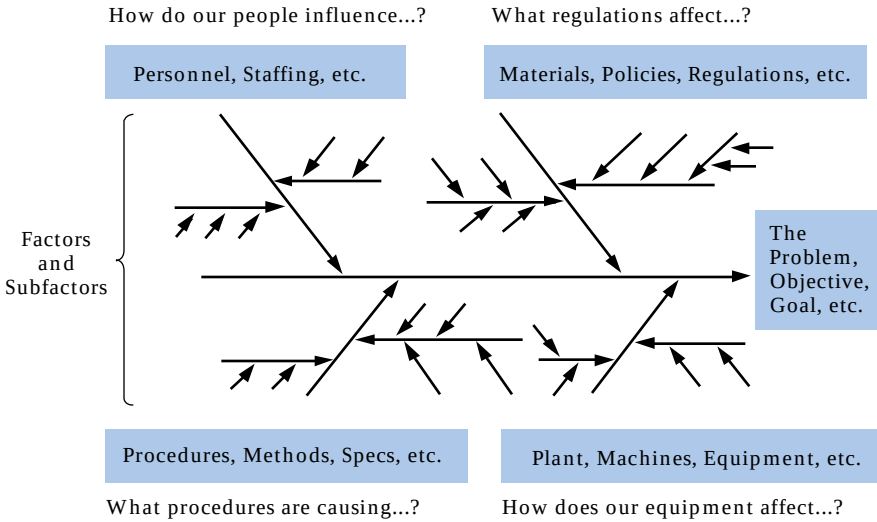
Specify the effect to be analyzed. The effect can be positive (objectives) or negative (problems). Place it in a box on the right side of the diagram.



List the major categories of the factors that influence the effect being studied. The "4 Ms" (methods, manpower, materials, machinery) or the "4 Ps" (policies, procedures, people, plant) are commonly used as a starting point.



Identify factors and subfactors. Use an idea-generating technique from Section 2 to identify the factors and subfactors within each major category. An easy way to begin is to use the major categories as a catalyst. For example, "What policies are causing . . . ?"



Identify significant factors. Look for factors that appear repeatedly and list them. Also, list those factors that have a significant effect, based on the data available.

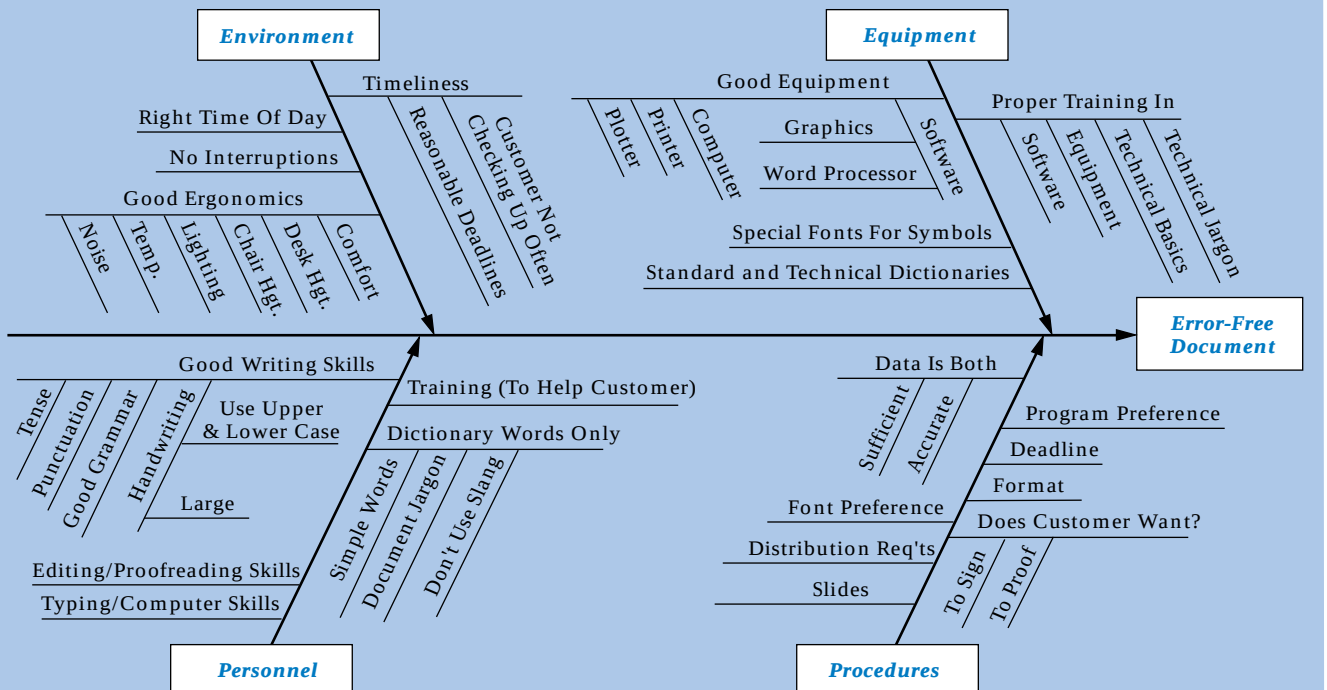
Categorize and prioritize your list of causes. Keep in mind that the location of a cause in your diagram is *not* an indicator of its importance. A sub-factor may be the root cause to all of your problems. You may also decide to collect more data on a factor that had not been previously identified.

Helpful hint:

Consider using a positive effect (an objective, for example) instead of a negative effect (a problem, for example) as the effect to be discussed. Focusing on problems can produce "finger pointing," while focusing on desired outcomes fosters pride and ownership over productive areas. The resulting positive atmosphere will enhance the group's creativity.

Cause and Effect Diagram Example

The publication team for an engineering department wanted to improve the accuracy of their user documentation. As part of a first step, they created a cause and effect diagram to get a picture of what causes a document to be error-free. The diagram below illustrates what this particular team considered important at their first meeting.



PARETO CHART

What it is:

A bar chart used to separate the "vital few" from the "trivial many." These charts are based on the Pareto Principle which states that 20 percent of the problems have 80 percent of the impact. The 20 percent of the problems are the "vital few" and the remaining problems are the "trivial many." A Pareto chart can help you:

- Separate the few *major* problems from the many possible problems so you can focus your improvement efforts
- Arrange data according to priority or importance
- Determine which problems are most important, using data, not perception

How to use it:

Identify the possible problems. Use idea-generation techniques from Section 2 to list all the possible problems in a particular process.

Use existing reports, or collect new data on the process. Be sure the units of measure are consistent throughout your data. Group existing data by consistent units of measure. Select attributes to be charted so that any given occurrence will fall into one ***AND ONLY ONE*** category.

Label the chart. Label the units of measure on the left vertical axis and the categories of problems on the horizontal axis.

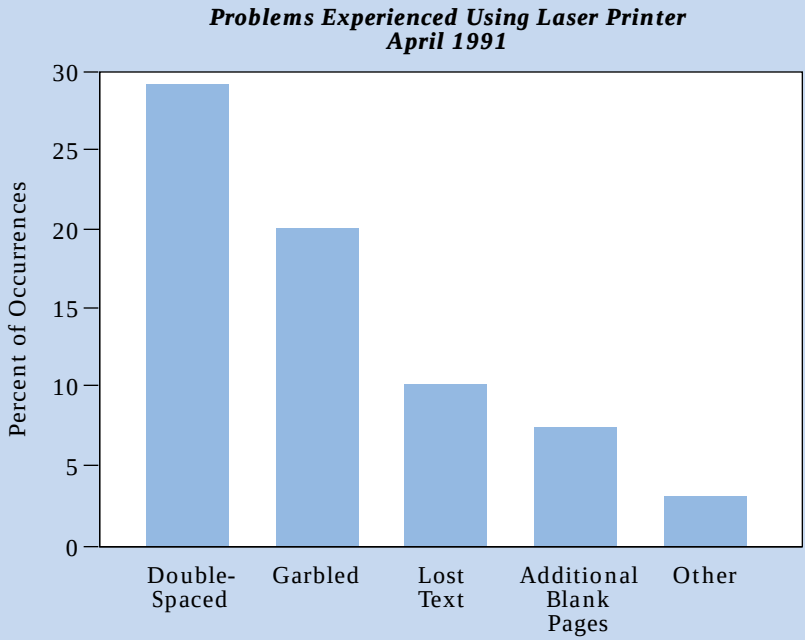
Plot the data. Order the categories according to their frequency (how many), not their classification (what kind). Use a descending order from left to right. Categories that appear infrequently, or in comparatively small numbers, can be grouped together in an "other" category.

(Optional). You can use the right vertical axis to measure the percentage of total occurrences contained within each category.

Points to remember:

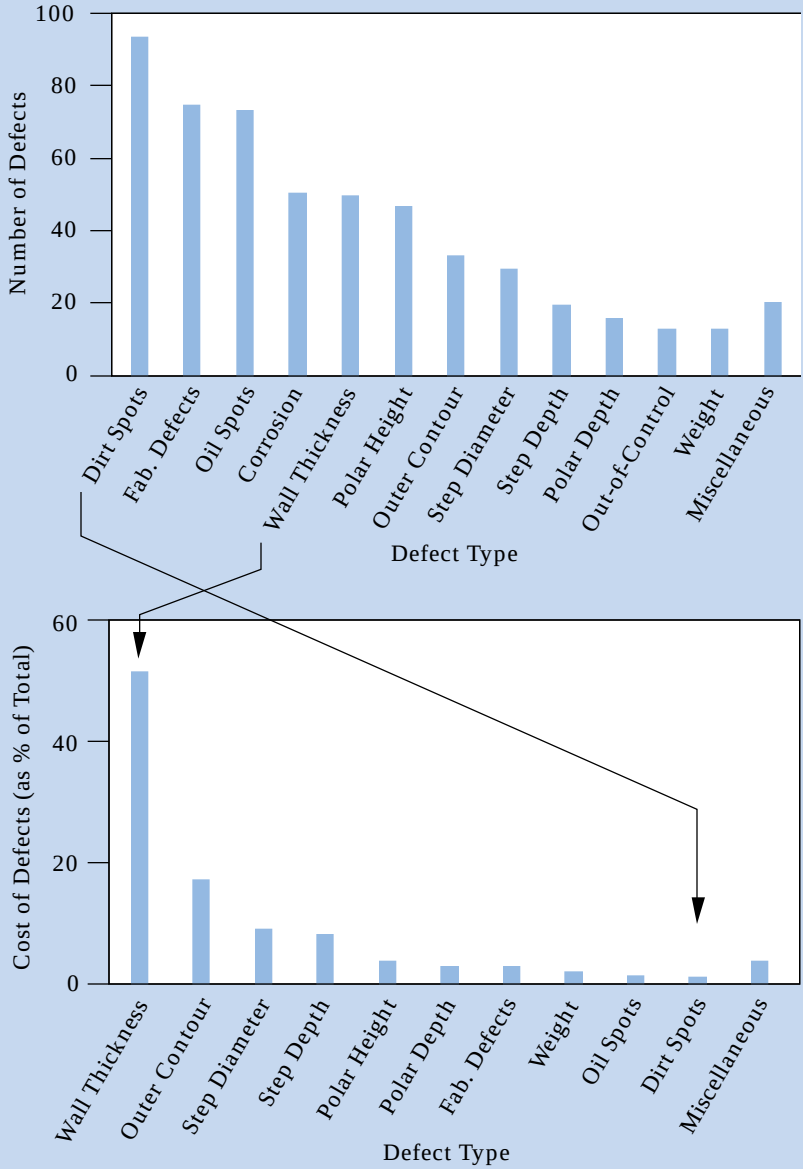
- The measurement units can significantly affect your Pareto chart. In the example shown on page 49, 100 cosmetic-type defects may account for only a fraction of the total cost, while 2 material-type defects may account for a large percentage of the cost. In such a case, you must determine whether cost or number of defects is more important.
- It is essential to use the same units of measure and clearly mark these units on the chart ($, #, %, etc.).
- Make sure that the "other" category doesn't become unreasonably large. If the "other" category accounts for more than 25 percent of your problem, you probably should try to break it down.

Pareto Chart Example



Frequency v.s.. Cost Example

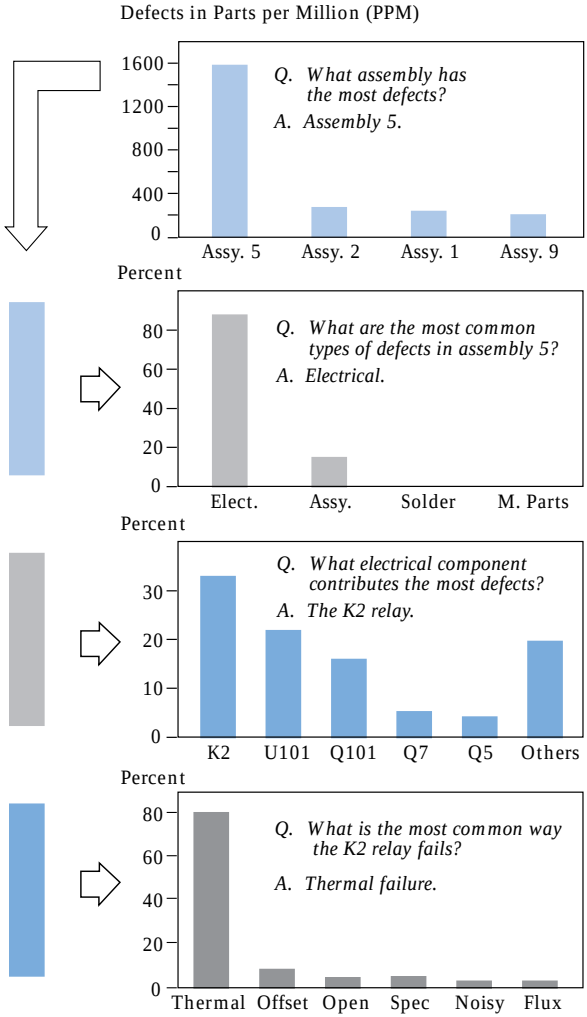
In the following example, the most common defect is dirt spots. However, wall thickness is by far the most costly.



Used with permission from Change Navigators, Inc.

Progressive Analysis

Since Paretos represent data in an ordered and prioritized manner, and do so using discrete data categories, we can use them to progress from general to specific classifications. This technique is known as Progressive Analysis and is show below:



HISTOGRAM

What it is:

A histogram is a bar graph that shows the central tendency and variability of a dataset. Histograms are sometimes referred to as frequency distributions. A histogram can help you:

- Understand the variability of a process.
- Quickly and easily determine the underlying distribution of a process.

How to use it:

Determine the type of data you want to collect. Be sure that the data is measurable, (for example, time, length, speed, etc.).

Collect the data. Collect as many measurable data points as possible. Collect data on one parameter at a time.

Count the total number of points you have collected.

Determine the number of intervals required. Use this table to determine how many intervals (or bars) the graph should have.

If you have this many data points...	*Then use this number of intervals.*
Less than 50	5–7
50–99	6–10
100–249	7–12
More than 250	10–20

Determine the range. Subtract the smallest value in the dataset from the largest. This value is the range of your dataset.

Determine the interval width. Divide the range by the number of intervals. Round your answers up to a convenient value. For example, if the range of the data is 17 and you have decided to use 9 intervals, then your interval width is 1.88. You can round this to 1.9 or 2.0. It is helpful to have intervals defined to one more decimal place than the data collected.

Determine the starting point of each interval. Use the smallest data point value as the starting point of the first interval. The starting point for the second interval is the sum of the smallest data point plus the interval width. For example, if your smallest data point is 10 and the interval width is 2, then the starting point for the second interval is 12. Label intervals along the horizontal axis.

Plot the data. Count the number of data points that fall within each interval and plot this frequency on the histogram. Keep in mind that each data point can appear in only one interval. For example, if your first interval begins with 10.0 and the second with 12.0, then all data points that are *equal to or greater than 10.0 and still less than 12.0* are counted in the first interval.

Points to remember:

- Each data point appears in *one and only one* interval.
- The number of intervals can influence the pattern your data will take.
- Don't expect the histogram to be a perfect bell curve; variations will occur. Ask yourself if the picture is reasonable and logical. But, be careful not to let your preconceived ideas influence your decision unfairly.

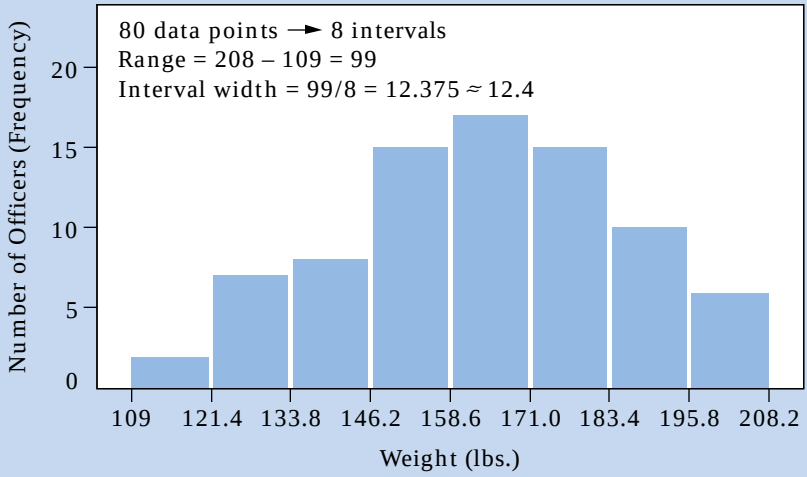
Histogram Example

This table gives the weights of 80 Coast Guard personnel.

Weights of 80 personnel

208	180	139	163	159
155	180	165	149	127
159	171	141	190	159
153	181	180	137	161
115	156	173	165	191
159	109	179	145	144
150	206	166	188	165
127	130	172	180	147
145	150	156	171	189
190	200	208	169	139
130	128	155	185	166
165	187	159	178	169
147	150	201	128	170
189	163	150	158	180
139	149	185	129	169
175	189	150	201	175

A histogram shows the distribution of the data.



SCATTER DIAGRAM

What it is:

A scatter diagram is a graph that reveals a possible relationship between two variables. It can help you:

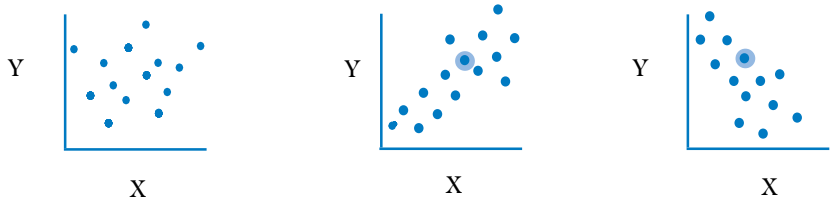
- Identify possible causes of problems
- Recognize that one important variable might be related to another

How to use it:

Collect the data in pairs. A data pair consists of two different variables that appear to have a relationship.

Construct the graph. Label the horizontal and vertical axes in an ascending fashion. Ensure that the values on the two axes correspond to the data pairs.

Plot the data. As you plot each point, look for patterns. Circle repeated points. The figures below show how to interpret scatter diagrams.



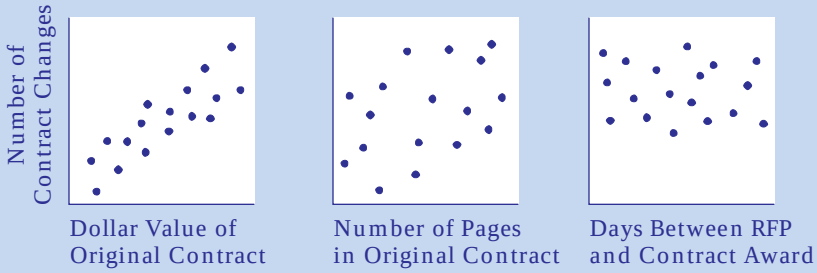
No Correlation:	Positive Correlation:	Negative Correlation:
(Y does not appear to be related to X)	(An increase in X may be related to an increase in Y)	(An increase in X may be related to a decrease in Y)

Points to remember:

- If there appears to be a relationship between two variables, they are said to be correlated. Both negative and positive correlations, as shown in the figures, are useful for continuous process improvement.
- This method only shows that a relationship exists, not that one variable causes the other. Further analysis using advanced statistical techniques can quantify how strong the relationship is between two variables.

Scatter Diagram Example

A contracting agency wanted to investigate why they had so many changes in their contracts. They used the following scatter diagrams to explore possible relationships.



RUN CHART

What it is:

A run chart is a graph that shows the changes in a process measurement over time. It can help you:

- Recognize patterns of performance in a process
- Document changes over time

How to use it:

Construct the chart. Label the vertical axis with the key measurement of the process being measured.

Collect the data. Collect data for an appropriate number of time periods, in accordance with your data collection strategy.

Plot the data. Plot each data point on the chart.

Calculate and plot the average. This provides a reference for drawing conclusions about individual data points.

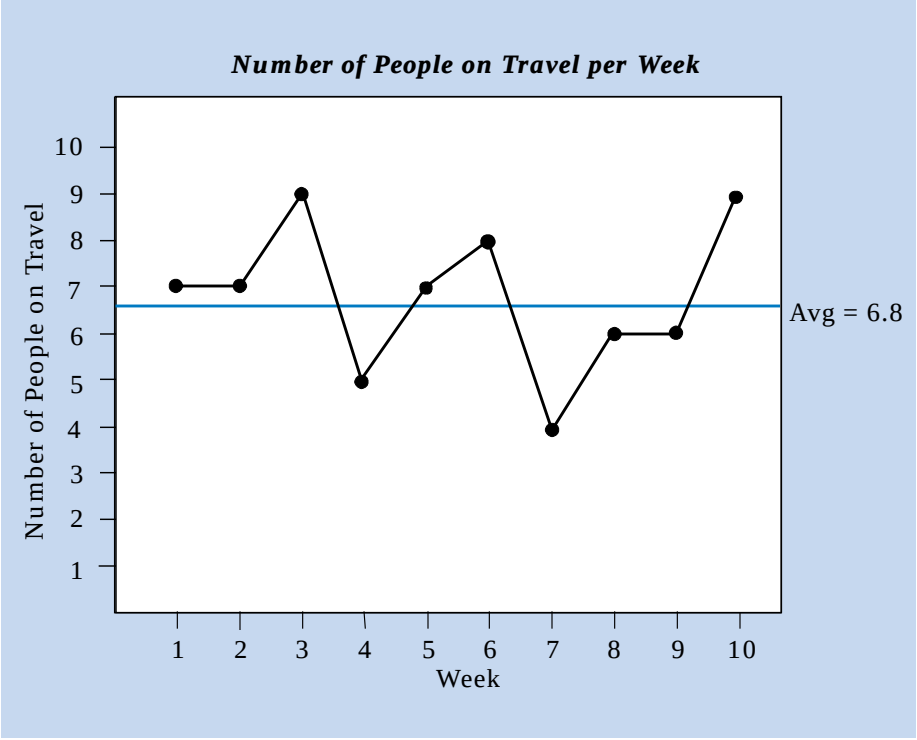
Interpret the chart. Interpret the chart using your knowledge of the process. Two possible signals that the process has significantly changed are:

- Six points in a row that steadily increase or decrease.
- Nine points in a row that are on the same side of the average.
- Other patterns to look for include significant shifts in levels, cyclical patterns and bunching of data points.

Repeat. Recompute the average for subsequent blocks of time, or after a significant change has occurred.

Run Chart Example

The run chart on the following page shows that the average number of people on travel is 6.8, and this has been fairly consistent for the past ten weeks. It is important to recognize the variability (four to nine people per week) that is inherent to this or any other process.



CONTROL CHARTS

Of all the tools for analyzing data, the control chart is the most useful. No other tool captures the voice of your process better. Control charts are used to determine whether your process is operating in statistical control. Until it is, any improvement efforts are, at best, mere process tampering. Basically, a control chart is a run chart (described earlier) that includes statistically generated upper and lower control limits.

The purpose of a control chart is to detect any unwanted changes in your process. These changes will be signalled by *abnormal* points on the graph. Extensive research by Dr. Shewhart indicated that by establishing upper and lower limits at three times the standard deviation of the process (plus and minus, respectively), 99.73% of the common cause variation would fall within these limits.

A process is said , therefore, to be in "statistical control" when the process measurements vary randomly within the control limits; that is, the variation present in the process is consistent and predictable over time.

The upper and lower control limits are not the same as tolerance or specification limits.

Control limits are a function of the way your process actually performs over time. Specification, or tolerance, limits are a function of what your process may have been designed to do and may not necessarily have any direct relationship to the actual performance of the process.

BENEFITS OF CONTROL CHARTS

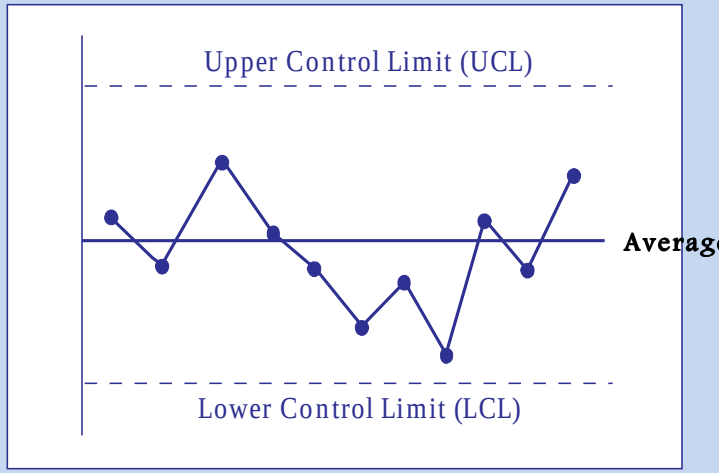
- Help you recognize and understand variability and how to control it
- Identify "special causes" of variation and changes in performance
- Keep you from fixing a process that is varying randomly within control limits; that is, no "special causes" are present. If you want to improve it, you have to objectively identify and eliminate the root causes of the process variation
- Assist in the diagnosis of process problems
- Determine if process improvement effects are having the desired affects

How to use it:

Use the figure on the next page to determine the type of control chart you need.

Control charts use two types of data: variables data and attributes data. In general, if you want to use variables data, you have to take measurements in units such as length, temperature, etc. On the other hand, attributes data requires a good/bad or go/no-go decision and counting (for example, number of defects, percent late, etc.).

Construct the control charts. Once you have determined the type of data to collect, follow the appropriate chart construction techniques described elsewhere in this section.



TYPICAL CONTROL CHART

HOW TO DETERMINE WHICH CONTROL CHART TO USE

STEP ONE: Is a Control Chart the appropriate tool to use?

STEP TWO: Determine type of data (**Attribute or Measurement)?**

STEP THREE: If ***Measurement*** use:

$\bar{X}$-R Chart (if subgroups of five or more)

X Chart (if subgroups of five or less)

If ***Attributes*** (Good/Bad, Discrete Data), use one of the following charts:

If attributes are DEFECTS: Ask, Is a constant sample size used?

If YES: np - Chart If NO: p - Chart

If attributes are DEFECTIVES: Ask, Is constant sample size used?

If YES: c - Chart If NO: u - Chart

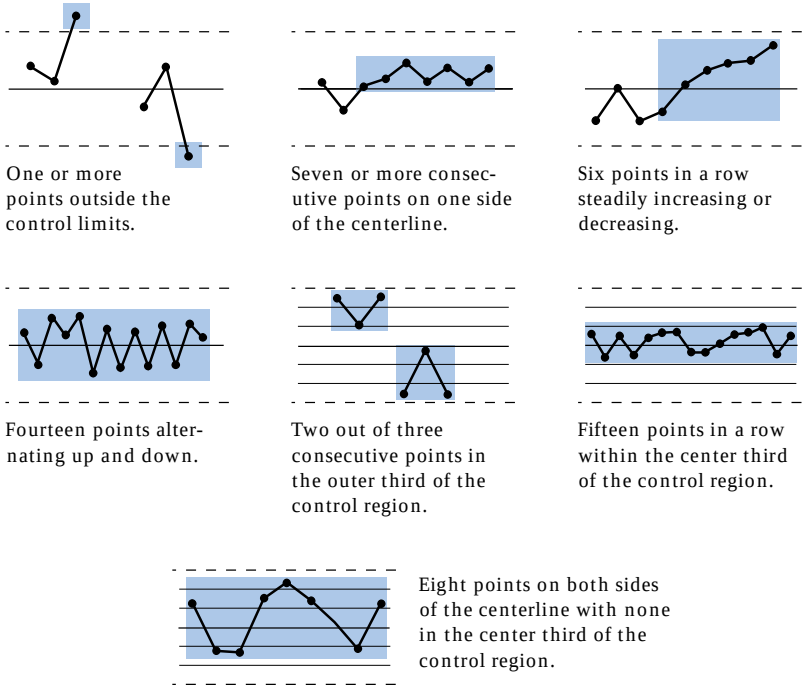
DEFECT: A failure to meet one part of an acceptance criteria

DEFECTIVE: A unit that fails to meet acceptance criteria due to one or more defects

Identify and eliminate any special or assignable causes of variation. To determine whether these causes exist, look for one or more of the seven "signals" shown on the next page. The probability that any of these seven events will occur ***at random*** is very small. That's why they're a signal that something has changed in your process.

Reduce overall variability. After you have eliminated all special causes, try to reduce the remaining variability in your process. This usually requires fundamental changes to the process, and these changes require management assistance. *To achieve continuous process improvement, it's essential to reduce variability.*

Indications That Special Causes of Variation Are Present



Common cause variations within a process are, by definition, random. Therefore, any non-randomness indicates the influence of special causes.

Points to Remember:

- Upper and lower control limits are not specification limits. They have a mathematical relationship to the process outputs. Specification limits are based on product or customer requirements.
- Be sure you have selected the correct control chart for the type of data you are collecting.
- Having a data point fall outside the control limits is only one of many different "signals" that indicate a process is out of control. If all the data points *are* within the control limits, be sure to check the other signals that indicate a "special" cause of variation.

- "Special" causes of variation can normally be eliminated by the person(s) who has direct physical control over a process. "Common" causes of variation can normally be reduced only through a fundamental change to the process. Generally, it can be said that common causes are a product of factors which are inherent to a process, while special cause variations are a product of factors which are not inherent to that process.
- There are several types of control charts. Each has its appropriate use and inherent strengths and weaknesses. Becoming familiar with each will allow you to select the best tool for your particular work area or needs.

TYPES OF CONTROL CHARTS AND THEIR USES

X CHART
Shows individual outputs of a process

$\overline{X}$ CHART
Shows average outputs of a process

R CHART
Shows how consistent a process is

P CHART
Shows fraction of defective items for UNEQUAL sample subgroups

np CHART
Shows number of defective items for equal sample subgroups

C CHART
Shows number of defects within each item for equal subgroups

U CHART
Shows number of defects within each item for UNEQUAL subgroups

CHART CONSTRUCTION TECHNIQUES

Measurement Data Control Charts:

Constructing an X Chart

- Collect at least 15-25 data points
- Calculate the moving range for n=2 by subtracting the value of each data point from the one which precedes it. Disregard positive or negative values of each result (the initial data point will have no moving range, since nothing preceded it). The reason for determining the moving range is to minimize the variation within subgroups. The subgroup variation for a sequence of individual values is represented here by the variations from one point to the next.
- Calculate the mean (average) value $\bar{x}$ for the data points as follows:

$$\bar{X} = \frac{\sum x}{n} = \frac{\text{the Sum of the individual values}}{\text{number of individuals}}$$

- Determine the average value of the range $\bar{R}$ (the "average moving range") as follows:

$$\bar{R} = \frac{\sum R}{n-1} = \frac{\text{the sum of moving ranges}}{\text{the number of moving ranges*}}$$

*Which is the same as the number of individual values minus 1

- Calculate the control limits as follows:

Upper Control Limit: $\bar{X} + A_1 \bar{R}$

Lower Control Limit: $\bar{X} - A_1 \bar{R}$

FACTOR TABLE

n	A_1
2	2.659
3	1.772
4	1.457
5	1.290

X CHART CONSTRUCTION EXAMPLE

The following table shows the number of errors that a particular PERSRU recorded per month. Utilizing this data, we shall construct an X Chart.

Month	Nbr of Errors
JAN	25.0
FEB	25.3
MAR	33.8
APR	36.4
MAY	32.2
JUN	30.8
JUL	30.0
AUG	23.6
SEP	32.3
OCT	28.1
NOV	27.0
DEC	26.1
JAN	29.1
FEB	40.1
MAR	40.6

Calculate Moving Ranges:

Month	No. Errors	Moving Range
JAN	25.0	~~~
FEB	25.3	0.3 (25.0 - 25.3)
MAR	33.8	8.5
APR	36.4	2.6
MAY	32.2	4.2
JUN	30.8	1.4
JUL	30.0	0.8
AUG	23.6	6.4
SEP	32.3	8.7
OCT	28.1	4.2
NOV	27.0	1.1
DEC	26.1	0 .9
JAN	29.1	3.0
FEB	40.1	11.0
MAR	40.6	0.5
TOTALS:	460.4	53.6

Calculate the mean: $\frac{460.4}{15} = 30.69$

Calculate the mean moving range: $\frac{53.6}{14} = 3.83$

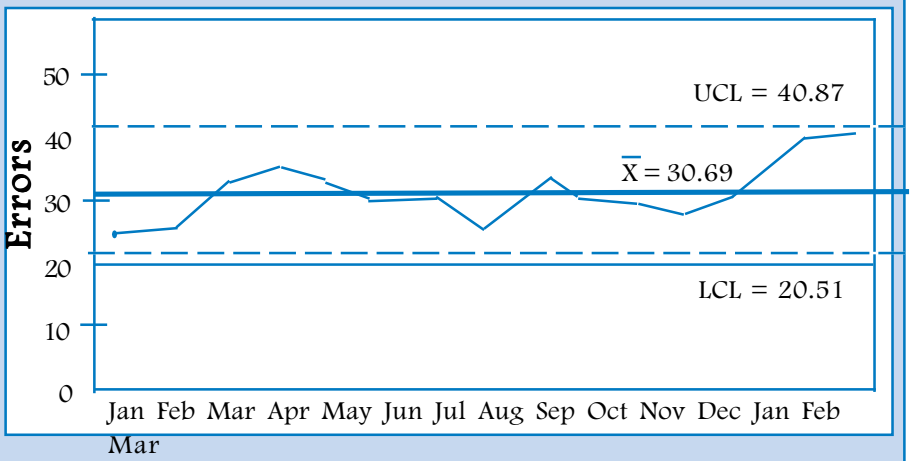
Calculate the Upper Control Limit:

30.69 + (2.659) (3.83) = 30.69 + 10.18 = **40.87**

Calculate the Lower Control Limit:

30.69 - (2.659) (3.83) = 30.69 - 10.18 = **20.51**

Constructing the Chart:



The X Chart did not show any parts outside the control limits for any of the months for which data was available. However, if we apply our other criteria for indicating the presence of special cause variation (see chart on identifying special causes of variation), we find that one indication that a special cause may exist is if there are two out of three consecutive points in the outer third of the control region (area between UCL and LCL) . This criteria seems to apply to the last two data points we have on our chart. Both FEB and MAR may need to be reviewed to see if there is some thing "special" causing the increase in errors (new YN on desk, equipment problems, etc.).

Variables Control Charts:

Constructing an $\bar{X}$ or R Chart

- Collect 10 to 20 subgroups of data, with each subgroup consisting of two or more data points. For example, a subgroup could be a week, and its data points could be days. The size of each subgroup (represented by "n") should remain constant. The total number of subgroups is represented by "K".

- Determine the average $(\bar{x})$ and range (R) for each subgroup as follows:

$$(\bar{x}) = \frac{x_1 + x_2 + \ldots + x_n}{n} = \frac{\sum x}{n}$$

$$R = x_{max} - x_{min}$$

- Determine the overall mean $(\bar{\bar{x}})$ as follows:

$$\bar{\bar{x}} = \frac{\sum \bar{x}}{K} = \frac{\text{the sum of all the subgroup averages}}{\text{the number of subgroups}}$$

- Determine the average value of the range $(\bar{R})$ as follows:

$$(\bar{R}) = \frac{\sum R}{K} = \frac{\text{the sum of all the subgroup ranges}}{\text{the number of subgroups}}$$

- Calculate the control limits and centerlines using the formulas and constants in the following two tables.

How To Calculate Control Limits and Centerlines

To calculate the...	*For an $\bar{x}$ chart, use:*	*For an R chart, use:*
Upper Control Limit	$\bar{\bar{x}} + A_2\bar{R}$	$\bar{R}D_4$
Lower Control Limit	$\bar{\bar{x}} - A_2\bar{R}$	$\bar{R}D_3$
Centerline	$\bar{\bar{x}}$	$\bar{R}$

Control Chart Constants

If you have this many observations in a subgroup n	For an $\bar{x}$ chart, use this value for A_2	For an R Chart: Use this value for D_3	For an R Chart: Use this value for D_4
2	1.88	0	3.27
3	1.02	0	2.57
4	0.73	0	2.28
5	0.58	0	2.11
6	0.48	0	2.00
7	0.42	0.08	1.92
8	0.37	0.14	1.86
9	0.34	0.18	1.82
10	0.31	0.22	1.78

- Plot the $\bar{x}$ and R charts. These charts should always be used in tandem, because the $\bar{x}$ chart shows the sample-to-sample changes in a process, and the R chart shows the variability within each sample. Recalculate the control limits every 20 subgroups, or if you see a significant change in the process average or variability. Use only the 20 most recent measurements in your calculations.

$\bar{x}$ – R Chart Example

For some reason, lunch expenses became an issue at a consulting firm. It was suggested that these expenses might become a target for budget reductions. To make sure that any decisions about new reimbursement rates would be based on data, rather than impressions, a staff member decided to apply statistical process techniques to the issue. As part of the response, the consultant collected data for ten weeks, as summarized in the table below, and prepared $\bar{x}$ and R control charts.

WEEK	MON $	TUE $	WED $	THU $	FRI $	$\bar{x}$	R
1	4.50	4.60	4.50	4.40	4.40	4.48	0.2
2	4.60	4.50	4.40	4.30	4.10	4.38	0.5
3	4.60	4.10	4.40	4.40	4.10	4.32	0.5
4	4.40	4.30	4.40	4.20	8.00	5.06	3.8
5	4.30	4.30	4.40	4.20	4.30	4.30	0.2
6	4.60	4.60	4.20	4.50	4.40	4.46	0.4
7	4.10	4.30	4.60	4.50	4.20	4.34	0.5
8	4.50	4.50	4.40	4.60	4.40	4.48	0.2
9	4.40	4.20	4.60	4.60	4.20	4.40	0.4
10	4.20	4.20	4.20	4.50	4.20	4.26	0.3

$\bar{\bar{x}} = 4.45$ $\bar{R} = 0.7$

Variables/Constants used to prepare $\bar{x}$ and R Charts:

R = the $ range for week $\bar{x}$ = the avg. $ per week x = the $ for any day

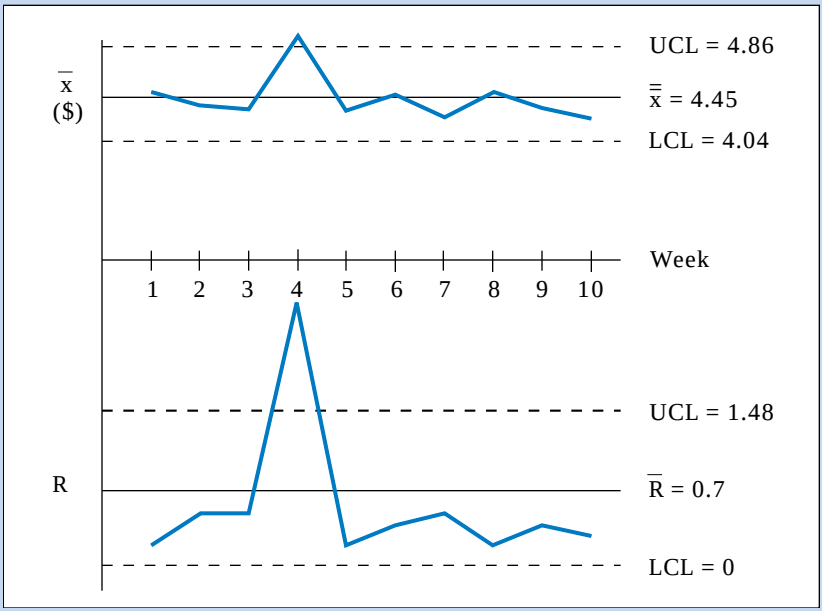
$\bar{R}$ = 0.7 (avg. of weekly ranges) n = 5 (5 days per week) A_2 = 0.58*

D_3 = 0* D_4 = 2.11* K = 10 (10 weeks) $\bar{\bar{x}}$ = 4.45 (avg. of weekly avgs.)

***Data obtained from Constants Table on previous page**

$\bar{x}$ – R Chart Example (Concluded)

$ for Lunch



Both the $\bar{x}$ and R chart did show an out of control condition in week 4. Receipts for that week revealed that this was caused by a special farewell luncheon on Friday. After removing this assignable cause, it became evident that lunch was consistently costing $4.00 to $4.50 every day. To reduce this amount, a person would have to make a fundamental change in the "process;" for example, bringing lunch from home, eating at a different place, etc.

The consultant later found out that the farewell luncheon had created an inaccurate impression back at the home office, and the new reimbursement rates would indeed reflect current costs.

Control Charts for Attributes

- Collect 10 to 20 subgroups of data. Each consisting of multiple data points arranged in a rational manner (day, lot, office, etc.). The size of each subgroup is represented by "n".
- Use the following formulas to compute the subgroup statistics and control limits for the type of chart you are using.

p Chart

$$p = \frac{\text{numberofdefectivesinasubgroup}}{\text{sizeofsubgroup(n)}} = \text{fraction or percent defective}$$

$$\bar{p} = \frac{\text{totaldefective}}{\text{totalinspected}} = \text{centerline} = \text{average fraction defective}$$

$$UCL = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = \text{upper control limit (varies by subgroup)}$$

$$LCL = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = \text{lower control limit (varies by subgroup)}$$

You can use an average subgroup size to obtain a single set of control limits if:

- The largest subgroup size is less than twice the average subgroup size, and
- The smallest subgroup size is more than half the average subgroup size.

Plot p for each subgroup.

np Chart

$\bar{p}$, n = same as for p chart, except n must be constant

$n\bar{p}$ = centerline = average number of defectives

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

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

- Plot np for each subgroup.

u Chart

$$u = \frac{\text{numberofdefectspersubgroup}}{\text{numberofunitspersubgroup}}$$

$$\bar{u} = \frac{\text{totalnumberofdefectsforallsubgroups}}{\text{totalinspected}} = \text{centerline}$$

$$UCL = \bar{u} + 3\sqrt{\frac{\bar{u}}{n}}$$

$$LCL = \bar{u} - 3\sqrt{\frac{\bar{u}}{n}}$$

- Plot u for each subgroup.

c Chart

$$c = \text{number of defects per subgroup}$$

$$\bar{c} = \frac{\text{totaldefects}}{\text{totalnumberofsubgroups}} = \text{centerline}$$

$$UCL = \bar{c} + 3\sqrt{\bar{c}}$$

$$LCL = \bar{c} - 3\sqrt{\bar{c}}$$

- Plot c for each subgroup.

Attributes Chart Example

A program director felt that changes to specifications might be excessive. To see whether these concerns were well-founded, the manager tracked the number of times a specification was changed by either an Engineering Change Proposal (ECP) or by a letter from the contracting officer. The table below summarizes the changes for a ten-week period.

Although changes to a specification are not exactly "defects," the changes are attributes data, rather than variables data, and the c chart is appropriate.

Week	1	2	3	4	5	6	7	8	9	10
Number of Specifications Changed	9	7	4	2	4	15	2	3	5	5

$$\bar{c} = \frac{56}{10} = 5.6 \text{ (changes per week)}$$

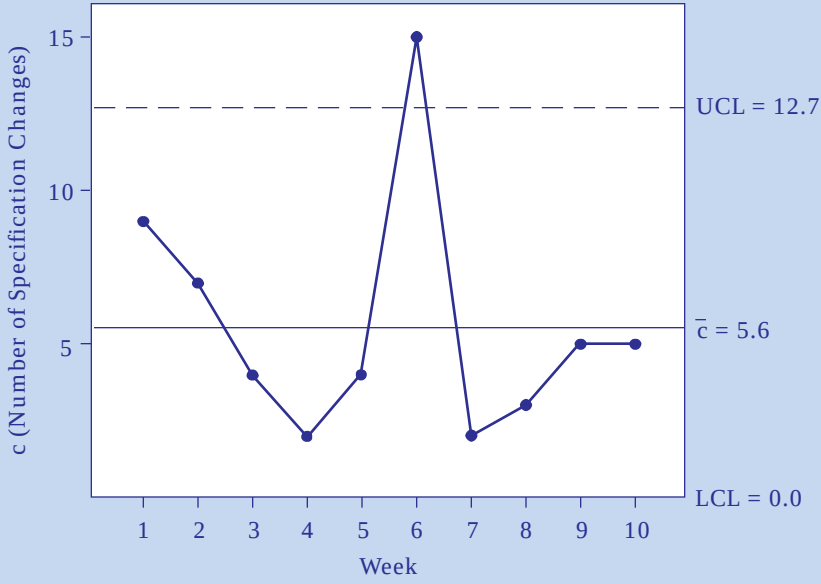
$$\text{UCL} = 5.6 + 3\sqrt{5.6} = 12.7$$

$$\text{LCL} = 5.6 - 3\sqrt{5.6} = -1.5 \Rightarrow 0$$

$$n = 50 \text{ active contracts}$$

Attributes Chart Example (Concluded)

On a c chart, week six contains a "special cause" for variation. In this case, the special cause was a design review held the previous week. Ten of the fifteen changes in week six resulted from this design review. The program director adopted this control chart as a permanent management tool.



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