QUALITY IS NEVER AN ACCIDENT, IT IS ALWAYS THE RESULT OF INTELLIGENT EFFORT.

JOHN RUSKIN

Continuous Improvement

Continuous Improvement is presented in the following topic areas:

- **Quality Control Tools**
- **Management and Planning Tools**
- **Improvement Methodologies**
- **Lean Tools**
- **Corrective and Preventive Actions**

Quality Control Tools

Quality Control Tools are presented in the following topic areas:

- **Cause-and-Effect Diagrams**
- **Flow Charts**
- **Check Sheets**
- **Histograms**
- **Control Charts**
- **Pareto Diagrams**
- **Scatter Diagrams**

The following pages describe the seven quality control tools as well as other supporting activities that make these tools more effective. The flow chart in Figure 7.1 shows how the quality tools can be used to solve a problem or improve a process. The six basic problem solving steps are:

- **Identify the problem (Select a problem to work on)**
- **Define the problem (If a problem is large, break it into smaller pieces)**
- **Investigate the problem (Collect data and facts)**
- **Analyze the problem (Find all possible causes and potential solutions)**
- **Solve the problem (Select from the available solutions and implement)**
- **Confirm the results (Was the problem fixed? Was the solution permanent?)**

Problem Solving Using Control Tools

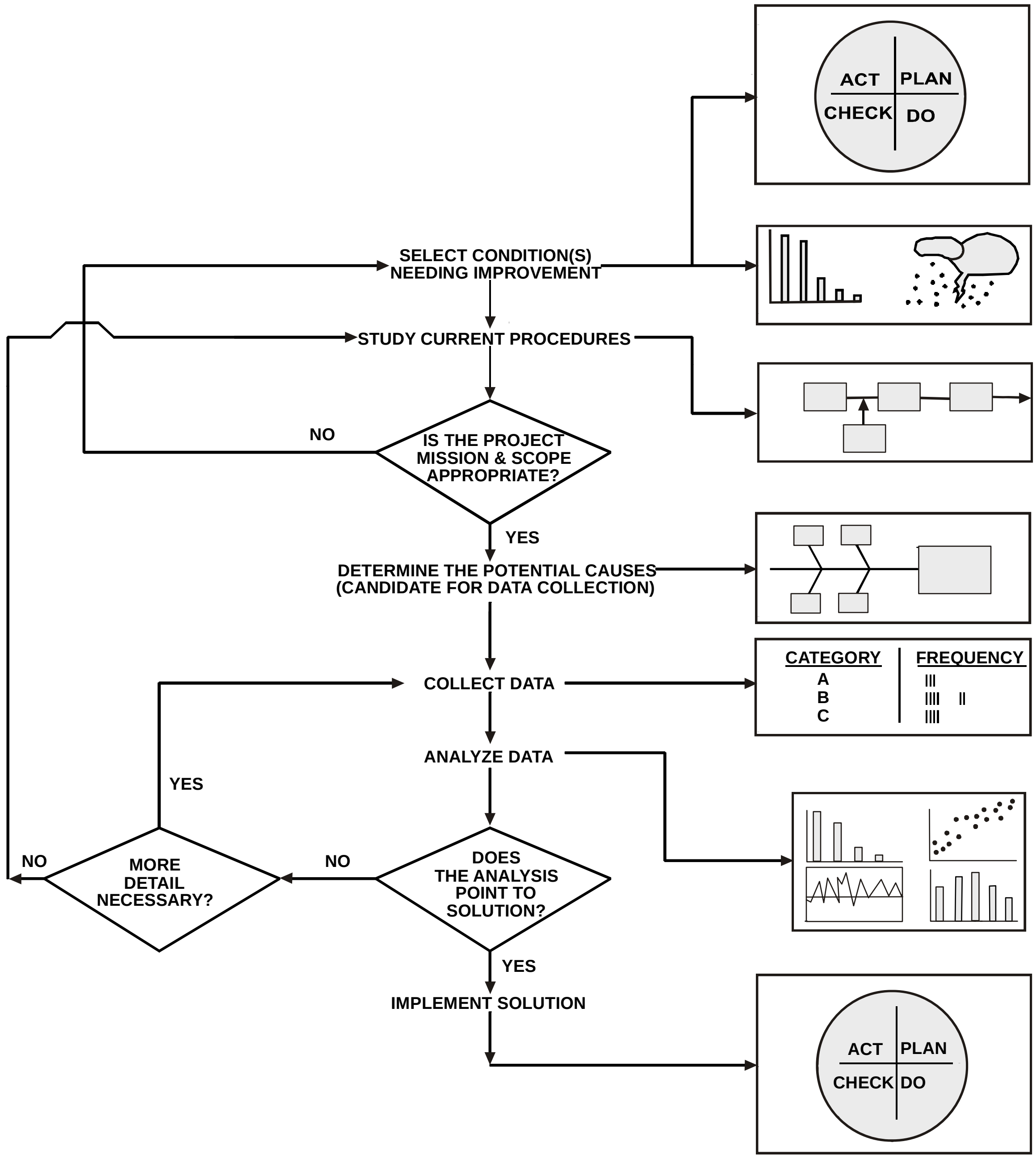


Figure 7.1 A Basic Problem Solving Methodology Showing the Use of Tools

Two extremely important steps in this process are to create a clear definition of the problem and to determine if the solution was effective in solving the original problem. Also, other problem solving techniques like PDCA and DMAIC can be used.

Cause-and-Effect Diagrams

The relationships between potential causes and resulting problems are often depicted using a cause-and-effect diagram which:

- **Breaks problems down into bite-size pieces**
- **Displays many possible causes in a graphic manner**
- **Is also called a fishbone, 4-M, or Ishikawa diagram**
- **Visually shows how various causes can combine to create a problem**
- **Follows brainstorming rules when generating ideas**

A fishbone session is divided into three parts: <u>brainstorming</u>, <u>prioritizing</u>, and <u>development of an action plan</u>. The problem statement is identified and potential causes are brainstormed into a fishbone diagram. Polling is often used to prioritize problem causes. The two or three most probable causes may be used to develop an action plan.

Generally, the 4-M (manpower, method, machine, material) version of the fishbone diagram will suffice. Occasionally, an expanded version must be used. In a laboratory environment, measurement is a key issue. For example, when discussing the brown grass in the lawn, environment is important. A 5-M and E schematic is shown in Figure 7.2.

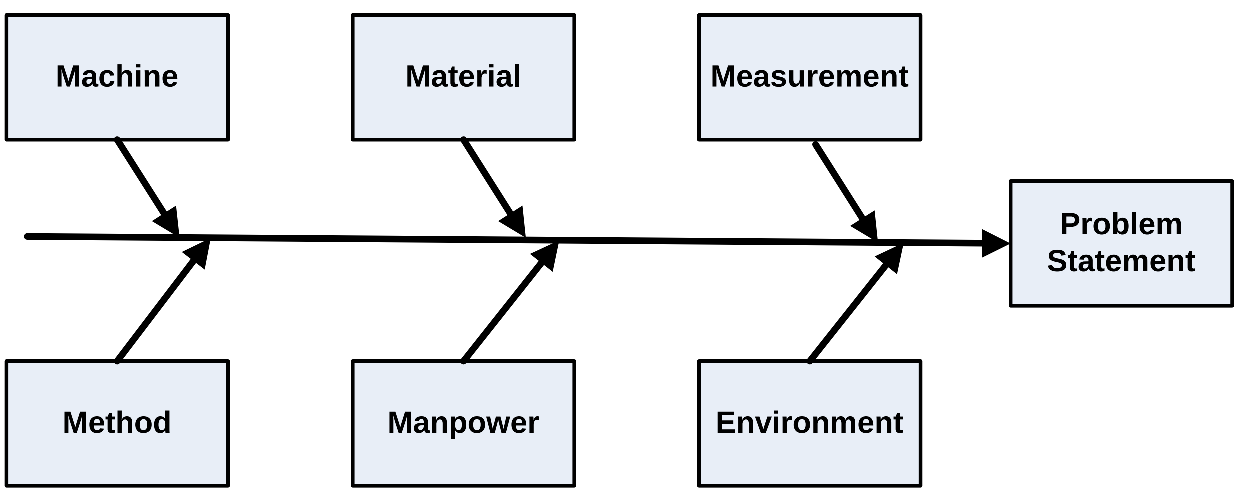


Figure 7.2 Basic Fishbone 5 - M and E Example

Cause-and-Effect Diagrams (Continued)

Figure 7.3 illustrates cause-and-effect diagram usage. A company was experiencing difficulty with inventory control of small mechanical parts. All parts were received and distributed based on weights (not actual counts).

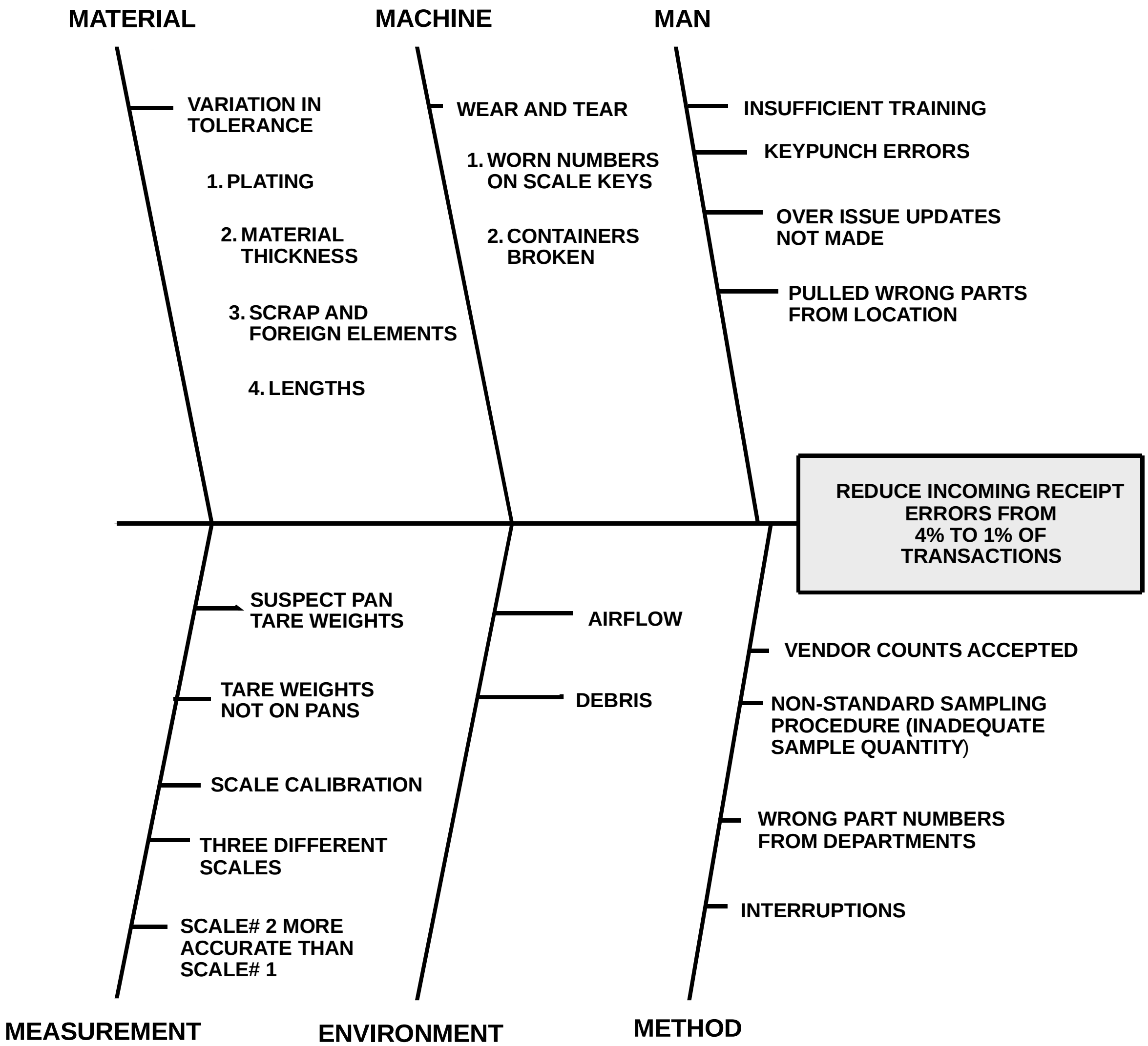


Figure 7.3 An Actual Fishbone Example

For additional examples of cause-and-effect or Ishikawa diagrams refer to: Ishikawa, K., (1982)[18]. Dr. Ishikawa attributed the first application of a cause-and-effect diagram to Tomiko Hashimoto's article, "Elimination of Volume Rotation Defects Through QC Circle Activities," Factory Work and QC, No. 33. (Hashimoto)[15].

Flow Charts

A flow chart, or process map, is useful both to people familiar with a process and to those that have a need to understand a process, such as an auditor. A flow chart can depict the sequence of product, containers, paperwork, operator actions or administrative procedures. A flow chart is often the starting point for process improvement. Flow charts are used to identify improvement opportunities as illustrated in the following sequence:

- **Organize a team for the purpose of examining the process**
- **Construct a flow chart to represent each process step**
- **Discuss and analyze each step in detail**
- **Ask the key question, "why do we do it this way?"**
- **Compare the actual process to an imagined "perfect" process**
- **Is there unnecessary complexity?**
- **Does duplication or redundancy exist?**
- **Are there control points to prevent errors or rejects? Should there be?**
- **Is this process being run the way it should?**
- **Can this process be performed differently?**
- **Improvement ideas may come from substantially different processes**

Process Flow Applications

Purchasing	**Processing purchase orders, placing actual purchases, vendor contract negotiations**
Manufacturing	**Processing returned goods, handling internal rejections, production processes, training new operators**
Sales	**Making a sales call, taking order information, advertising sequences**
Administration	**Correspondence flow, processing times, correcting mistakes, handling mail, typing letters, hiring employees**
Maintenance	**Work order processing, p.m. scheduling**
Laboratory	**Delivery of samples, testing steps, selection of new equipment, personnel qualification sequence, management of workflow**

Table 7.4 Process Flow Application Examples

Process Mapping

There are advantages to depicting a process in a schematic format. The major advantage is the ability to visualize the process being described.

Process mapping or flow charting has the benefit of describing a process with symbols, arrows and words without the clutter of sentences. Many companies use process maps to outline new procedures and review old procedures for viability and thoroughness.

Most flow charting uses standardized symbols. Computer flow charting software may contain 15 to 185 shapes with customized variations extending to the 500 range. Many software programs have the ability to create flow charts or process maps, although the information must come from someone knowledgeable about the process.

Some common flow chart or process mapping symbols are shown below:

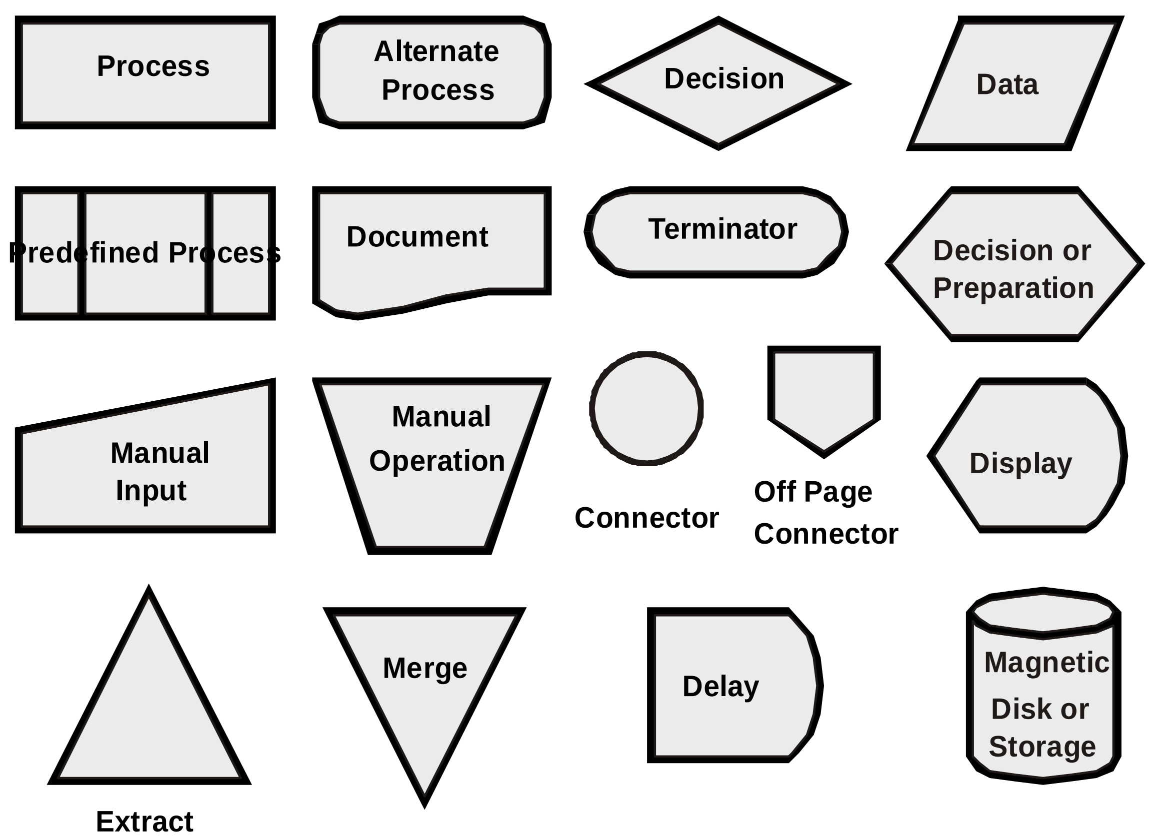


Figure 7.5 Common Flow Chart Symbols

Flow Chart Example

There here are a number of flow chart styles including conceptual, person-to-person and action-to-action. Figure 7.6 is an action-to-action flow chart. This example comes from the *Quality System Handbook* (2009)[7] by Neville Edenborough and is used with permission.

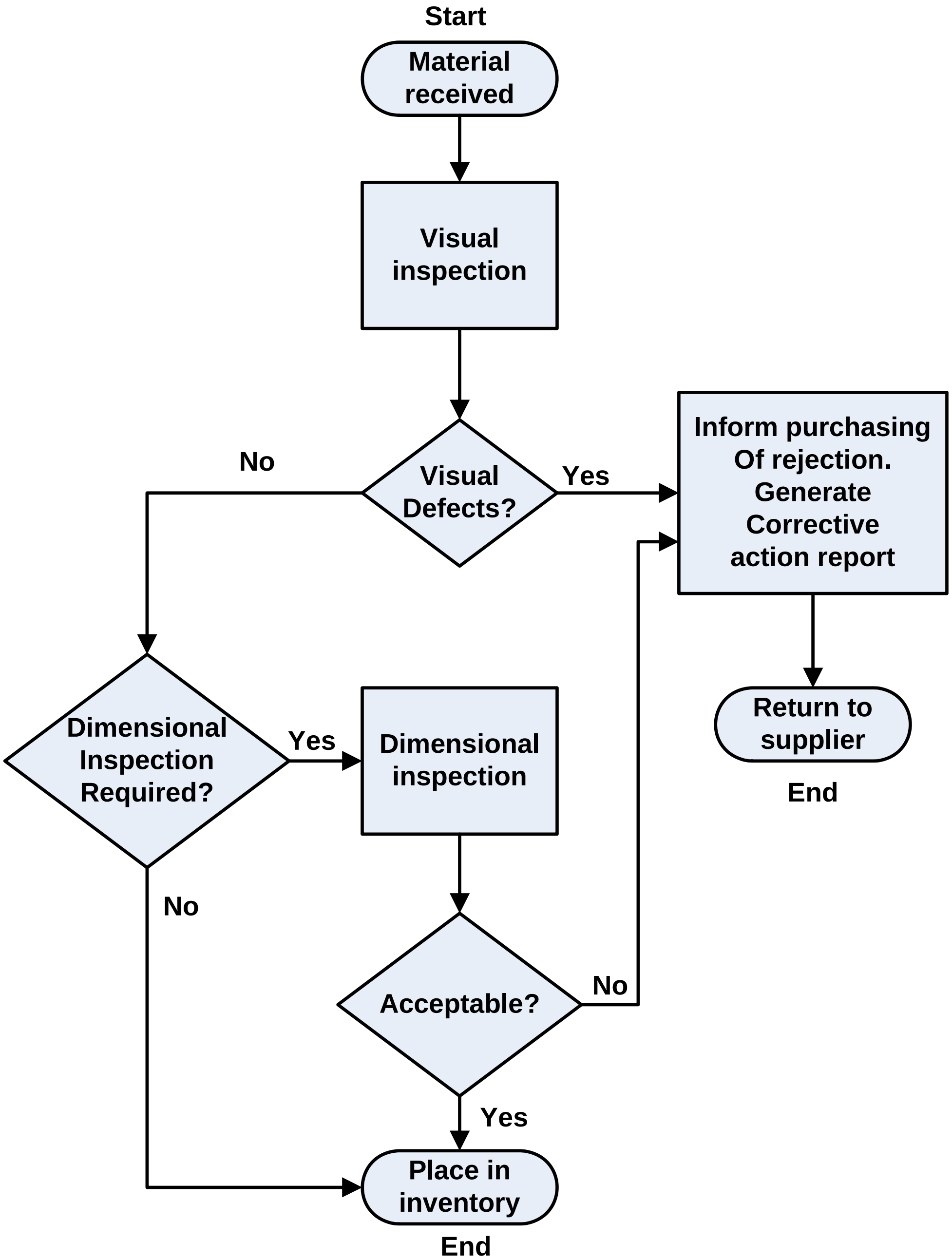


Figure 7.6 Action-to-Action Flow Chart Example

Check Sheets

Check sheets are tools for organizing and collecting facts and data. By collecting data, individuals or teams can make better decisions, solve problems faster and earn management support.

Recording Check Sheets

A recording check sheet is used to collect measured or counted data. The simplest form of the recording check sheet is for counted data. Data is collected by making tick marks in this particular check sheet.

DAYS OF WEEK							
ERRORS	**1**	**2**	**3**	**4**	**5**	**6**	**TOTAL**
Defective Pilot Light	𝍸 𝍸	𝍸	𝍸	𝍸𝍷𝍷𝍷	𝍸 𝍷𝍷	𝍸	**40**
Loose Fasteners	𝍷	𝍷𝍷𝍷		𝍸	𝍸	𝍷𝍷	**16**
Scratches	𝍷	𝍷𝍷𝍷	𝍷𝍷𝍷	𝍷	𝍷𝍷𝍷	𝍸𝍸	**21**
Missing Parts		𝍷		𝍷	𝍷		**3**
Dirty Contacts	𝍸 𝍷	𝍷𝍷𝍷𝍷	𝍸 𝍷𝍷𝍷	𝍷𝍷𝍷𝍷	𝍸	𝍸	**32**
Other	𝍷	𝍷𝍷𝍷			𝍷𝍷	𝍷𝍷𝍷	**9**
TOTAL	**19**	**19**	**16**	**19**	**23**	**25**	**121**

Figure 7.7 Typical Recording Check Sheet

The check sheet can be broken down to indicate either shift, day, or month. Measured data may be summarized by the means of a check sheet called a tally sheet. To collect measured data, the same general check sheet form is used. The only precaution is to leave enough room to write in individual measurements.

Recording Check Sheets (Continued)

Illustrated below is an example of a meeting process check sheet used to evaluate the productivity of a meeting. This is subjective data, but is very useful in some circumstances. Measured data is physically measured information, such as: the pH, the air pressure in psi or the amount of downtime in hours.

Scale: (1=Poor/10=Excellent)	Member #1	Member #2	Member #3	Member #4	Member #5
On Track					
Participation					
Listening					
Leadership					
Decision Quality					

Figure 7.8 Meeting Process Check Sheet

Checklists

The second major type of check sheet is called the checklist. A grocery list is a common example of a checklist. On the job, checklists may often be used for inspecting machinery or product. Checklists are also very helpful when learning how to operate complex or delicate equipment.

Date: ______ Area	Visual Inspection	Washed Once per Week	Supervisor (Operator)
Preheat House			
#2 Tub Room			
#3 Tub Room			
A Press Room			
B Press Room			
Finishing Room			
Roll Mill Room			

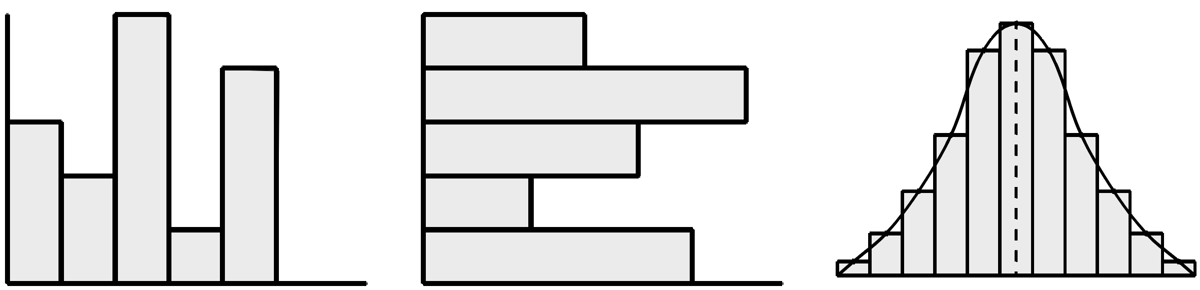
Figure 7.9 Housekeeping (24-hour) Checklist Example

Not illustrated is a locational variety of check sheet called a measles chart. This check sheet could be used to show defect or injury locations using a schematic of the product or a human.

Histograms

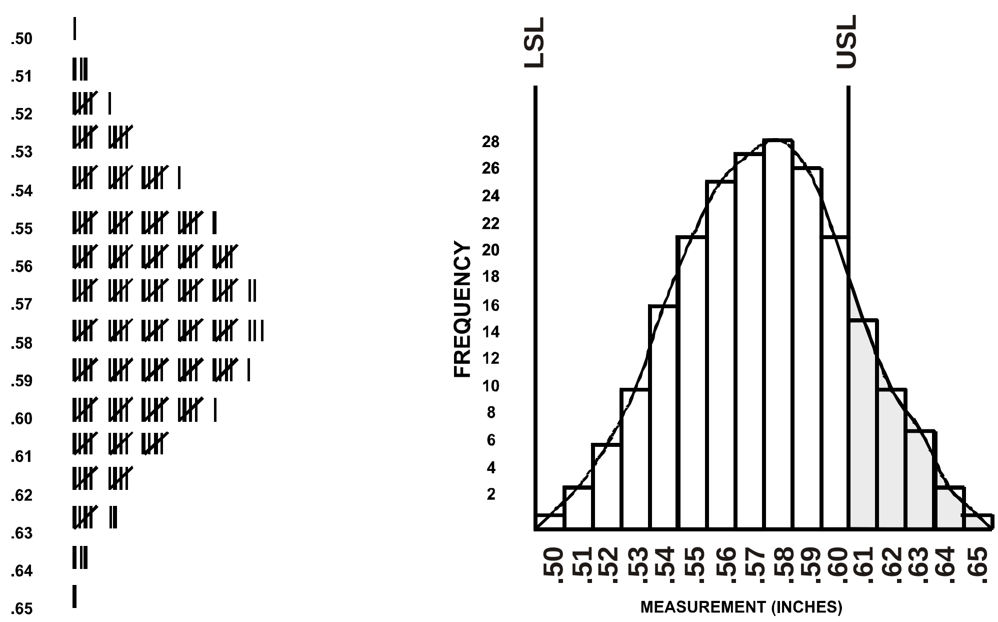
Histograms are frequency column graphs that display a static picture of process behavior. Histograms usually require a minimum of 50-100 data points in order to adequately capture the measurement or process in question.

A histogram is characterized by the number of data points that fall within a given bar or interval. This is commonly referred to as "frequency." A stable process is most commonly characterized by a histogram exhibiting unimodal or bell-shaped curves. A stable process is predictable.



COLUMN GRAPH **BAR GRAPH** **NORMAL HISTOGRAM**

Figure 7.10 Data Presentation Examples



FREQUENCY TALLY **SPECIFICATION LIMITS 0.50 - 0.60**

Figure 7.11 Histogram Construction Example

Histograms (Continued)

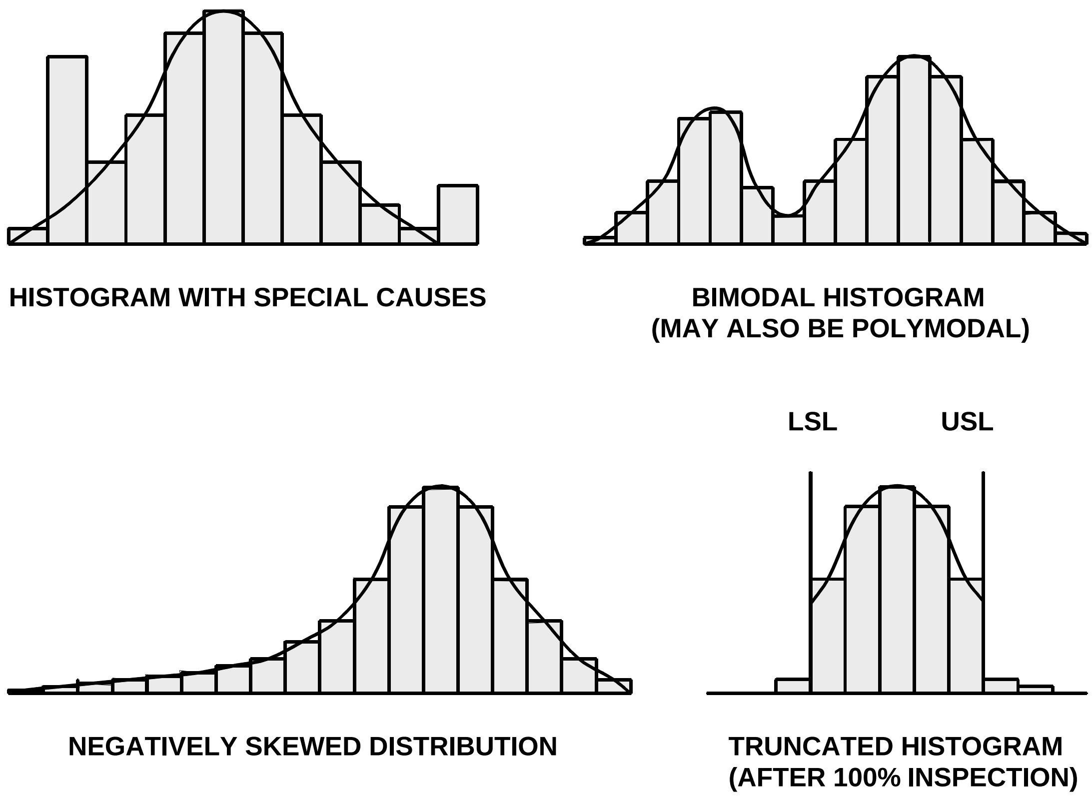


Figure 7.12 Histogram Examples

Histogram Comments

- **As a rule of thumb the number of cells should approximate the square root of the number of observations.**

- **An unstable normal distribution process is often characterized by a histogram that does not exhibit a bell-shaped curve.**

- **For a normal distribution, variation inside the bell-shaped curve is chance or natural variation. Other variations are due to special or assignable causes.**

- **There are many distributions that do not follow the normal curve. Examples include the Poisson, binomial, exponential, lognormal, rectangular, U-shaped and triangular distributions.**

Characteristics of a Normally Distributed Process

- **Most of the points (data) are near the centerline, or average**
- **The centerline divides the curve into two symmetrical halves**
- **Some of the points approach the minimum and maximum values**
- **The normal histogram exhibits a bell-shaped distribution**
- **Very few points are outside the bell-shaped curve**

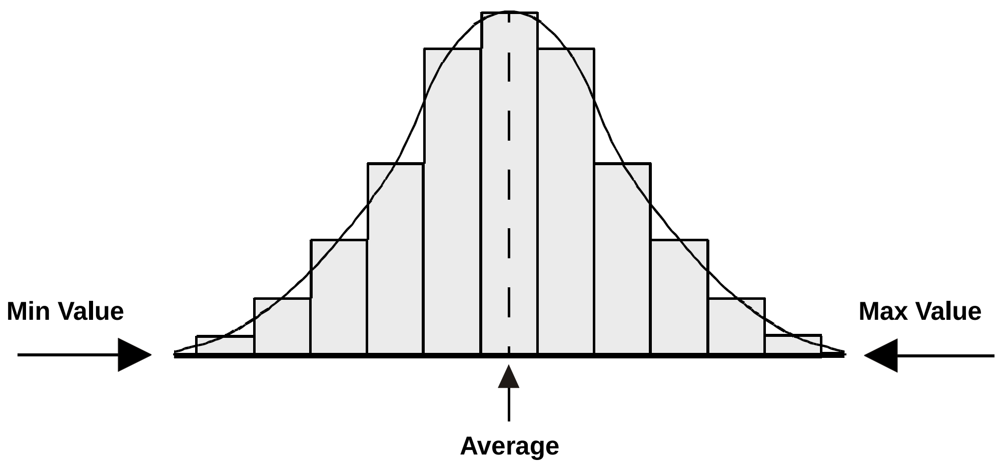


Figure 7.13 Normally Distributed Process

How Are Normal Distributions Predictable?

When all special causes of variation are eliminated, the process will produce a product that, when sampled and plotted, has a bell-shaped distribution. If the base of the histogram is divided into six (6) equal lengths (three on each side of the average), the amount of data in each interval exhibits the following percentages:

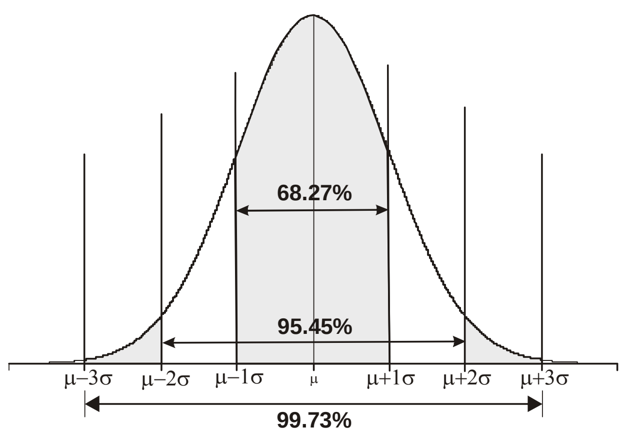


Figure 7.14 The Normal Distribution

The student should note that process capability calculations are included in Primer Section IX.

Control Charts

Control charts are effective statistical tools used to analyze variation in most processes - either manufacturing or administrative. They are line graphs that display a dynamic picture of process behavior. A process which is under statistical control is characterized by points that do not exceed the calculated control limits.

Upper control limit (UCL)

Process average

Lower control limit (LCL)

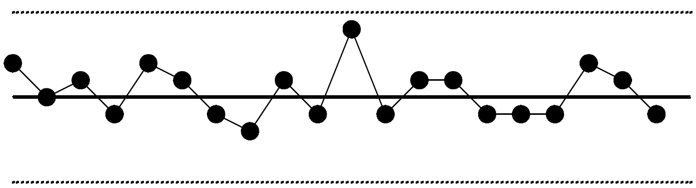


Figure 7.15 A Typical Control Chart

Control charts using variables data are generally the most costly since each separate variable (thought to be important) must have data gathered and analyzed. Variables charts are also the most valuable and useful. Control charts are included here because they are one of the original seven quality tools. The SPC discussion in Section IX presents control limit calculations, construction, and chart interpretation.

Control Chart Advantages

- **They provide a visual display of process performance**
- **They are statistically sound**
- **They can plot both attributes and variables data**
- **They can detect special and assignable behavior causes (trends or cycles)**
- **They indicate the time that things are going either good or bad**
- **Variables charts can provide an on-going measure of process capability**
- **They can be used to determine if process improvements are effective**

Control Chart Disadvantages

- **They require mathematical calculations in most cases**
- **They can provide misleading information for a variety of reasons**
- **The sample frequency can be inappropriate**
- **There may be an inappropriate chart selection**
- **The control limits can be miscalculated**
- **They can have differing standard interpretations (attributes data)**
- **The assumed population distribution can be wrong (variables data)**
- **Very small but sustained shifts can be missed (a need for CuSum charts)**
- **Statistical support may be necessary**

Pareto Diagrams

Pareto diagrams are very specialized forms of column graphs. They are used to prioritize problems or opportunities. Pareto diagrams can help teams get a clear picture of where the greatest contribution can be made.

Briefly stated, the principle suggests (in most situations) that a few problem categories (approximately 20%) will present the most opportunity for improvement (approximately 80%).

History

There is a very interesting story behind the name of Pareto diagrams. The word "Pareto" comes from Vilfredo Pareto (1848-1923). He was born in Paris after his family had fled from Genoa, Italy, in search of more political freedom. Pareto, an economist, made extensive studies about the unequal distribution of wealth and formulated mathematical models to quantify this maldistribution.

Dr. Joseph M. Juran, world renowned leader in the quality field, was preparing the *Quality Control Handbook* in the late 1940s. He needed a short name to apply to the phenomenon of the "vital few" and the "trivial many." He depicted some cumulative curves in this manuscript and put a caption under them, "Pareto's principle of unequal distribution..." The text makes it clear that Pareto only applied this principle in his studies of income and wealth; Dr. Juran applied this principle as "universal." Thus, the diagram should be called a "Juran diagram." To complicate matters more, the cumulative curve diagram itself was first used by M.O. Lorenz in 1904.
(Juran, 1999)[20]

**Vilfredo Pareto
1848-1923**

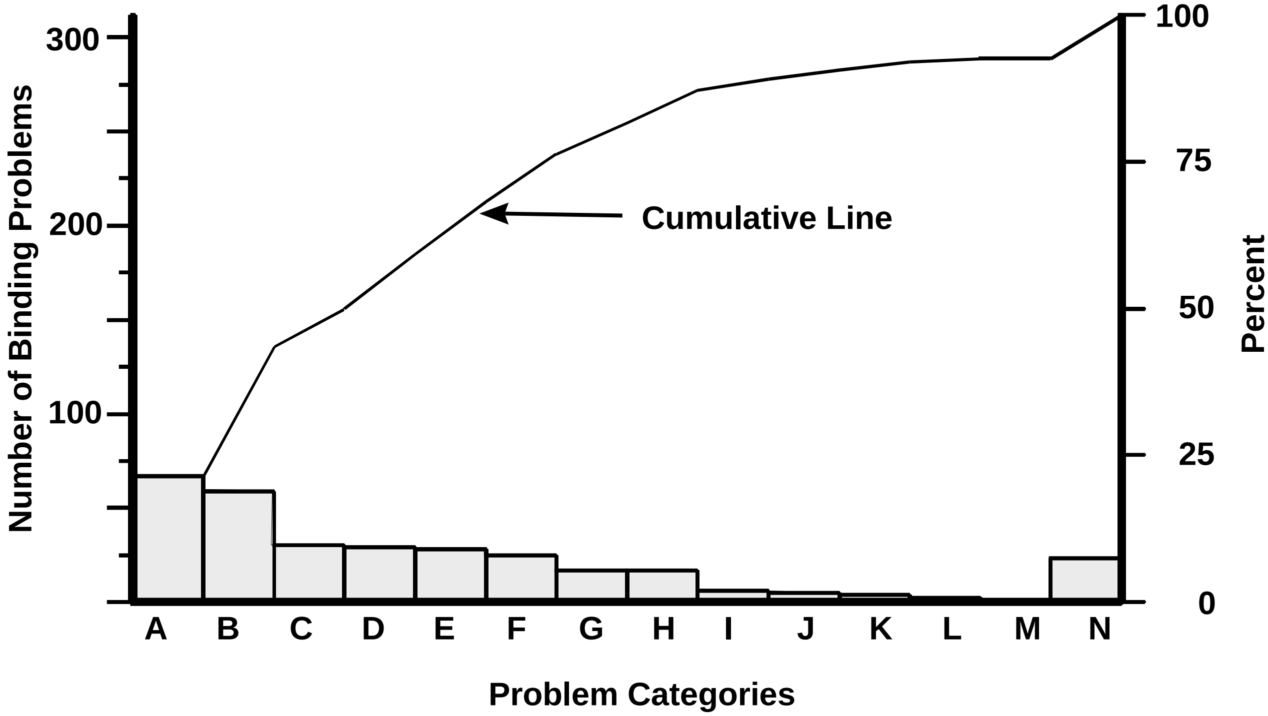
Pareto diagrams are used to:

- **Analyze a problem from a new perspective**
- **Focus attention on problems in priority order**
- **Compare data changes during different time periods**
- **Provide a basis for the construction of a cumulative line**

"First things first" is the thought behind the Pareto diagram. Our attention is focused on problems in priority order. The simple process of arranging data may suggest something of importance that would otherwise have gone unnoticed. Selecting classifications, tabulating data, ordering data, and constructing a Pareto diagram have proved to be useful tools in problem investigation.

Typical Pareto Diagram

The defects for a book product are shown in Pareto form below:



A. Emulsion - glue 67
B. Grease/oil/dirt 59
C. Hot melt - glue 30
D. Sewing thread 29
E. Gilding defects 28
F. End sheet problems 25
G. Case damage - area I 17
H. Square variation 17
I. Head bands 6
J. Case damage - unknown 5
K. Case damage - area II 4
L. Upside down books 2
M. Torn pages 0
N. All others 23

Figure 7.16 A Typical Pareto Diagram

Note that the "all others" category is placed last. Cumulative lines are convenient for answering such questions as, "What defect classes constitute 70% of all defects?"

The Pareto method assumes there will be segregation of the significant few from the trivial many. In many cases, the Pareto diagram is constructed based upon the number of event occurrences. However, criticality (or potential safety or economic loss) factors might result in a different Pareto alignment.

Scatter Diagrams

A scatter diagram is a graphic display of many data points which represent the relationship between two different variables. It is also referred to as a correlation chart. For example, temperature changes cause contraction or expansion of many materials. Both time and temperature in a kiln will affect the retained moisture in wood. Examples of such relationships on the job are abundant. Knowledge of the nature of these relationships can often provide a clue to the solution of a problem. Scatter diagrams can help determine if a relationship exists and how to control the effect of the relationship on the process.

In most cases, there is an independent variable and a dependent variable. By tradition, the dependent variable is represented by the vertical axis and the independent variable is represented by the horizontal axis.

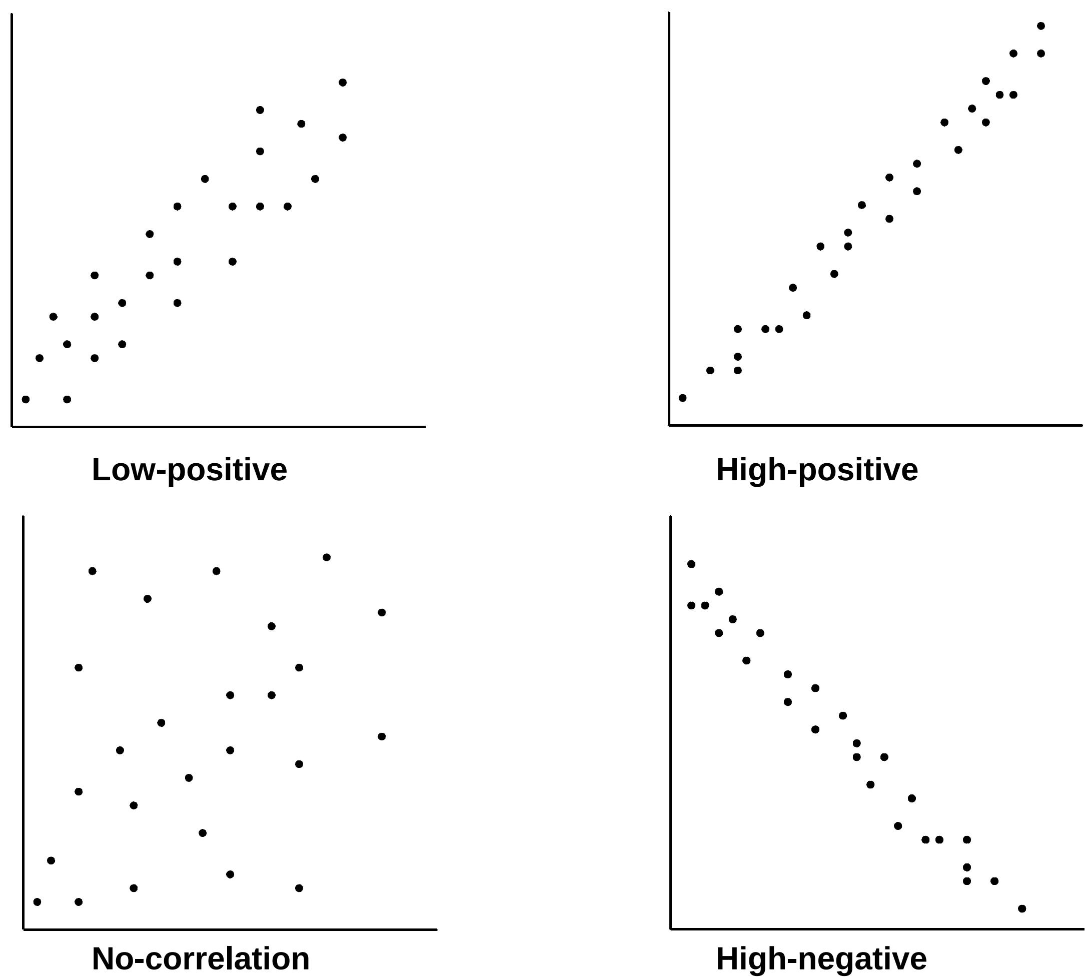


Figure 7.17 Scatter Diagram Examples

Scatter Diagrams (Continued)

The ability to meet specifications in many processes is dependent upon controlling two interacting variables. Therefore, it is important to be able to control the affect one variable has on another. For instance, if the amount of heat applied to plastic liners affects their durability, then control limits must be set to consistently apply the right amount of heat. Through the use of scatter diagrams, the proper temperature can be determined ensuring a quality product.

The dependent variable can be controlled if the relationship is understood. Correlation originates from the following:

- **A cause-effect relationship**
- **A relationship between one cause and another cause**
- **A relationship between one cause and two other causes**

Not all scatter diagrams reveal a linear relationship. The examples below definitely portray a relationship between the two variables, even though they do not necessarily produce a straight line. If a center line can be fitted to a scatter diagram, it will be possible to interpret it. To use scatter diagrams, one must be able to decide what factors will best control the process within the specifications.

As you may suspect, there is an entire domain of analysis to develop the algebraic equations which represent the "best fit" for the lines and curves. This subject can be explored to a greater extent by a study of experimental design and regression analysis. Often, a specialist may be necessary if a more in-depth analysis is needed.

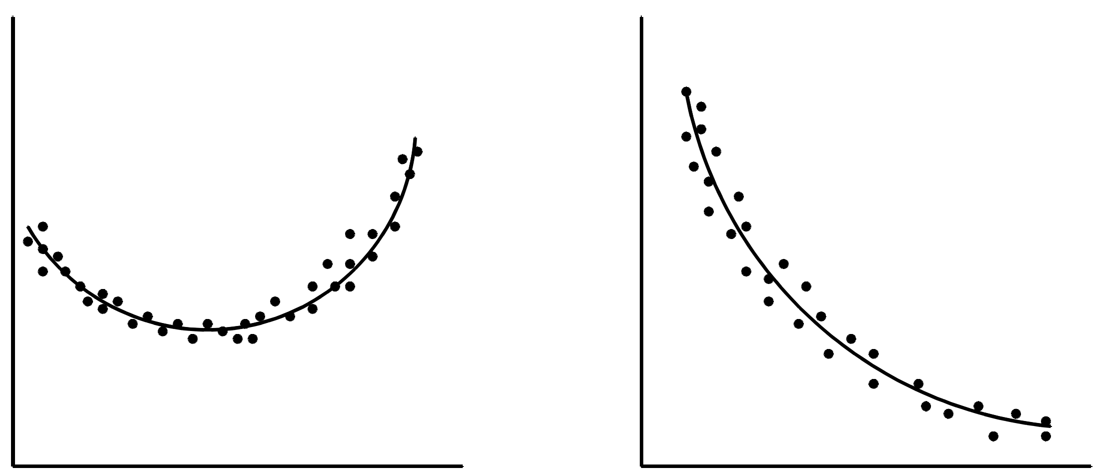


Figure 7.18 Examples of Non-linear Relationships

