U.S Army Corps of Engineers
Water Resources Support Center
Institute for Water Resources

APPLYING CONTINUOUS PROCESS IMPROVEMENT TOOLS IN THE CIVIL WORKS PROGRAM

by

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The enclosed text covers Total Quality Management (TQM) and statistical process control analysis in a detailed format. Many of the TQM support tools and technologies were developed by such men as Walter A. Shewhart, Joseph Juran, and Edwards W. Deming. While a number of TQM and process improvement proponents preach that statistical techniques need to be mastered by all levels of an organization or institution, this view is not widely held. Management needs to be familiar with such tools and techniques, as do their staffs or employees, but it is not practical nor reasonable for everyone in an organization to be fully cognizant of the details inherent in statistical techniques. Many do not simply have the skills to handle complex statistical analysis. Training each manager, supervisor, and employee is not always practical either and would be unnecessarily expensive.

In this context there are those in COE Districts, Divisions, and Washington level offices who are quite familiar with such complex tools and techniques. Economists, for example, typically have the specialized knowledge to conduct Shewhart control chart analysis, analyze process capability, and interpret intricate data structures which can be used by upper management to solve process control problems. In essence, Economists would serve to support management with the technical characteristics of instituting continuous process improvements.

In this capacity, economists can make a significant contribution and make a difference in the spread of TQM principles and ideas. Executives within the COE hierarchy can establish institutional goals, objectives, vision statements, tactical plans, etc. with the aid of their economist staff and continue to monitor the outcomes of decisions as mandated by continuous process control. Indices can be developed to this end.

While continuous process control is a natural tool for the economist, it has widespread applications Corps-wide. There are uses in nearly every COE office for statistical control techniques. Such tools can be employed to evaluate process inputs, ongoing processes, and COE outputs and outcomes. Customer satisfaction can be enhanced through the proper application of statistical tools as well.

Many COE elements and functions are not amenable to statistical analysis and process improvements due to government regulations. However, statistics may still be kept on these processes to monitor their effectiveness and to report to higher authority. Under the current administration many rules and regulations are being changed and this may open more processes to statistical analysis that cannot currently be influenced by such techniques.

In sum, statistical techniques can enhance the natural role of an economist in a support capacity for management in evaluating institutional and functional processes in the COE.

Given the above factors, the purpose of this document is to provide a fairly detailed description of TQM and to introduce the basic statistics necessary to understand and implement this type of program at any level of COE command. It will not describe the existing quality management structure within the COE--it assumes the reader is already familiar with it. While the document is highly statistical in content, it does not attempt to teach statistics and assumes the reader has already taken such training sometime in his or her past but needs a refresher. It is also not a document for TQM beginners. It is assumed that the reader has already had a one or two day seminar in TQM and has been exposed to some of the basic ideas and vocabulary surrounding the concept. The document was written as a functional user manual, reference, and implementation framework. There is enough information enclosed to provide the tools and techniques needed to fully implement TQM except perhaps for some fine details. It can serve as a guide for several years of TQM growth and development. It should be supplemented with periodic but continuous outside training in the form of seminars and workshops. The references in the bibliography are also very useful. The reader will likely find the material "intense" due to its technical character and will likely need to read the document two or three times before all the implications can be absorbed. Reinventing government is bringing with it a whole new understanding of what management is about. TQM is a powerful element in that understanding.

Perhaps as early as a million years ago homosapiens began to make crude tools fashioned on uniform designs. Flat, round stones became sharp ended wedges and were used as axes. Arrowheads were either elongated, cylindrical stone ground to a point or jagged shims chipped to a point. Utensils also took crude forms. The one thing these implements had in common was their respective reproducible shape. Axes, arrowheads, grinding stones, pottery, etc. all looked similar. This reproducibility of shape, form, and function may have been the first attempts at TQM. Not much changed until about 5,000 years ago when Egyptians started mass producing bow and arrowpoints with interchangeable parts.

By the Industrial Revolution in the 1750's the idea of reproducible piece parts came into general use. People realized that life could be made a little easier and more abundant if only things could be manufactured so that parts of more complex items could be substituted for one another. Just a few hundred years earlier the fashioning of things was done by craftsmen with each manufactured item being unique. One sword was not like another, wheels of equal dimensions were not the same, and spare parts were unheard of. The notion of tolerances was coming of its own. It was not fully understood that reproducible exactness was a quality concept until 1840 when "Go, No-go" tolerances were instituted as part of the manufacturing process [Shewhart, 1986]. A piece either fitted like another (go) or it did not (no-go) and was discarded as waste or re-worked. Technology and needs were such that exactness was not terribly critical but became more and more necessary. The problem of minimizing defective parts became important near the turn of the century. It was in 1924 that the first quality control chart was constructed [Shewhart, 1986]. The need for quality control became vital during this era because the cost involved from non-standardized production was a considerable constraint to mass production. With standardization, rejected parts were minimized and inspections were minimized as well. This gave birth to the use of statistics and process capability analysis that slowly grew.

The use of statistics and sampling for manufacturing first took-off in post WWII Japan where the concepts of special and common causes of variation took root. These ideas were introduced to the Japanese by two men who were part of the post war reconstruction effort - Dr. Edward Deming and Dr. Joseph Juran. These men knew the importance of uniformity in production, special causes of production variation, and common causes of process problems. Unfortunately American management rejected these statistical approaches to manufacturing, after all we beat the Axis Powers. Who else knew how to compete and produce better than we.

As world markets opened up throughout 1960's and 1970's, cost and quality competition grew more intense.

American management began to listen. We were on the verge of loosing the throne.

Although the statistics behind TQM/TAQ are covered extensively, it is assumed that the reader has had a course in basic statistical concepts. The important concepts within the framework of statistics that are needed to understand this text include: measures of central tendency, measures of variability, distributions, sampling, estimation and hypotheses testing. These are reviewed in the first half of the material. They are concepts central to the understanding of the construction of Shewhart control charts, and how to use them. They are also vital to understanding process capability analysis.

The basic flow of text material is that of introducing theory and principles followed by examples. The material builds and comes together in the form of a Shewhart Control Chart and process capability evaluation. All calculations are presented in a step-by-step format. Once the reader covers the material it may be used as a guide to future charting and process capability analysis.

It should also be understood that there is not one universally accepted form for TQM/TAQ. The most widely adopted structure is presented but variations are possible within the basic framework.

The works of Deming, Juran, and Shewhart form the underlying framework for this text. These visionaries did not coin the acronym TQM but it has been tied to their research and findings. Phrases such as "constancy of purpose", "common cause", and "special cause" will remain the legacy of Dr. Deming. Walter Shewhart used the term "assignable cause" where Deming uses "special causes" of product variation. Whatever the phrase one chooses to adopt the concepts are the same and the consequences of their work are powerful and profound.

Dr. Deming's "14 Points for Organizational Transformation" and "Seven Deadly Diseases" permeate TQM. These concepts blend well with the new found notion of employee empowerment and job owner-ship. They also support the rediscovery of the importance of the "customer" and "service" - critical ingredients which appear to have gone by the way-side over the last twenty to thirty years. If the reader wishes to by-pass the statistical development of TQM tools, then only pages 1-12, 45-52, 60-103 and 111-148 need to be read. Deming's "14 Points" are an integral part of this text and are central, critical elements in any TQM or TAQ program.

The concepts and ideas covered in this material coincide with Vice President Al Gore's report entitled "From Red Tape to Results, Creating A Government That Works Better and Costs Less: Report of the National Performance Review". The principles behind "Reinventing Government" by David Osborne and Ted Gaebler are also embedded within the framework of this text. The techniques applied herein are those expressed in the documents mentioned. Empowerment, outcomes vs outputs, problem prevention, decentralized authority, efficiency vs effectiveness, accountability, customer emphasis, etc. are topics covered in the following chapters.

This document is reflective of TQM principles in a generic sense and does not represent the TQM/TAQ structure adopted by the Galveston District. It is a framework document which can be used as a guide for others to use in developing their own variation of TQM/TAQ. The tools and quantitative techniques, however, are almost universally part of any TQM/TAQ operation.

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The objective of this text is to show TQM participants how to develop, interpret and apply Shewhart control charts to diagnose district systems process output problems and attain higher production and service efficiency through a change in management cultural behavior. A parallel purpose is to provide a management structure as a mechanism for implementing TQM.

The most important idea which management must realize is that TQM is a technical system of employing statistical methods to analyze processes and execute reforms [Shoop, 1993]. Most failures in attempting to implement TQM emanate from good intentions which fell short of their target because management did not have the appropriate statistical knowledge or tools to pin-point and fix problems. It is not enough that QMB's, PAT Staff and Facilitators know the appropriate statistical tools and techniques. The Executive Steering Committee members, Branch and Division chiefs must also be keenly aware of what is involved. If this new ethos is not ingrained in the highest levels of management, then any effort by staff personnel to employ quality improvements will not lead to the necessary threshold transformation. The record proves this time after time.

1. Why Change To TQM

The reasons for implementing TQM are becoming more evident every day. A recent article in "USA Today" (dated 23 March 1993) contained the headline [Healey, March 23, 1993].

"U.S. Carmakers hit Pothole! Reliability"

The news article provided a summary of a survey taken by "Consumer Reports" (March 31) of American attitudes about U.S. and Japanese made automobiles they recently purchased. The article said:

> "U.S. workmanship is not to blame for the Big Three showing. Some Japanese models are U.S.- built, Honda Accord, Nissan Sentra, Toyota Pick-up."

This and similar articles are symptomatic of management practices which have been successfully employed for many years but became outdated during the 1950's and 60's. Table 1 (following page) summarizes the important reasons why TQM is needed.

The items listed in Table 1 are extremely important. Each makes a statement larger than its apparent content. Each will be discussed in turn and their collective importance will become more apparent as this text progresses.

Cost reductions are more important today than ever. The difference between cost reductions in the traditional management framework and the TQM framework lies in how costs are cut and how cost cutting decisions are made. Traditionally, cost reductions meant workers were laid off or other resources were reduced; often less expensive resource inputs were substituted or higher quality ones. The results were clear -- a loss of sales and market share. In the

TABLE 1 WHY CHANGE TO TQM?
Costs are reduced.
Quality improves.
Output increases.
There are major reductions in waste, rework and internal review.
Knowledge of the system improves.
The multiplier or domino effect of defects is reduced. (i.e., problem passed on - used by others, etc. to create even more problems).
There is an empowerment impact.
Employees are generally happier. (Control, higher quality products and services, less blame, etc.)

TQM format, cost reductions are obtained by cutting back on the subsidized production of waste associated with non-uniform output, the scrap that results from the production of products and services due to poor system process quality control.

TQM systems process capability improvements result in quality gains through a constant commitment on the part of management to reducing common causes of product and service output variation. It is the inconsistency of uniformity in the traditional philosophy which adversely impacts quality. The exact same item produced through mass production can vary so much from one item to the next that a substantial fraction must be discarded because their characteristics (size, color, dimensions, service performance, etc.) vary enough to portray them as different items in fact. Quality in this context will be defined later in this text.

Output increases often follow cost reductions and quality improvements. Products and services delivered to customers which cost less than those of competitors and have higher quality will market themselves. Witness the dramatic growth in Japanese products and services in the world market. They ingrained TQM philosophy in their systems processes in the 1950's and 60's; it is quite evident today in their automobile production, appliances, computers and computer chips, cameras, and so forth.

The TQM management framework also results in major reductions in waste, scrap, rework, and internal review or inspections. Continued emphasis on the constancy of purpose [Deming, 1989] in reducing product and service variability results in improved efficiency in the systems process output. Once constancy of purpose becomes an indigenous part of corporate ethos there is a marked reduction in waste and a vastly diminished need for the testing and monitoring of product or service output. The system becomes customer monitored with very little need for a quality control effort. In the private sector of our economy this means less cost in testing and quality control; in the government sector this means less review, rework, and reduced time delays. In both cases, product and service returns are dramatically reduced because "customers" are satisfied. Employees can often be heard saying in a sigh "We don't have time to do it right the first time, but plenty of time to do it over". Such irony is often heard in business using the traditional approach to modern day management but is not heard in TQM work environments.

Through quality control tools such as flowcharts, histograms, Pareto diagrams, control charts, and a few others, knowledge of the systems process improves for both management and the employee. In a TQM environment employees have considerably more latitude in identifying and solving production and service problems. These quality control tools will be described in more detail later.

The multiplier or domino effect is best visualized in Figure 1. Note how an error at the beginning of a systems process can rapidly multiply throughout the system. The error is compounded by the length of time which passes before it is discovered. Overhead costs amplify the problem further (by a factor of 2.8 to 3.0).

The diagram shows how inter and intra office specialization and dependencies can lead to an error being passed through the system from one branch to another and between divisions. This simple diagram

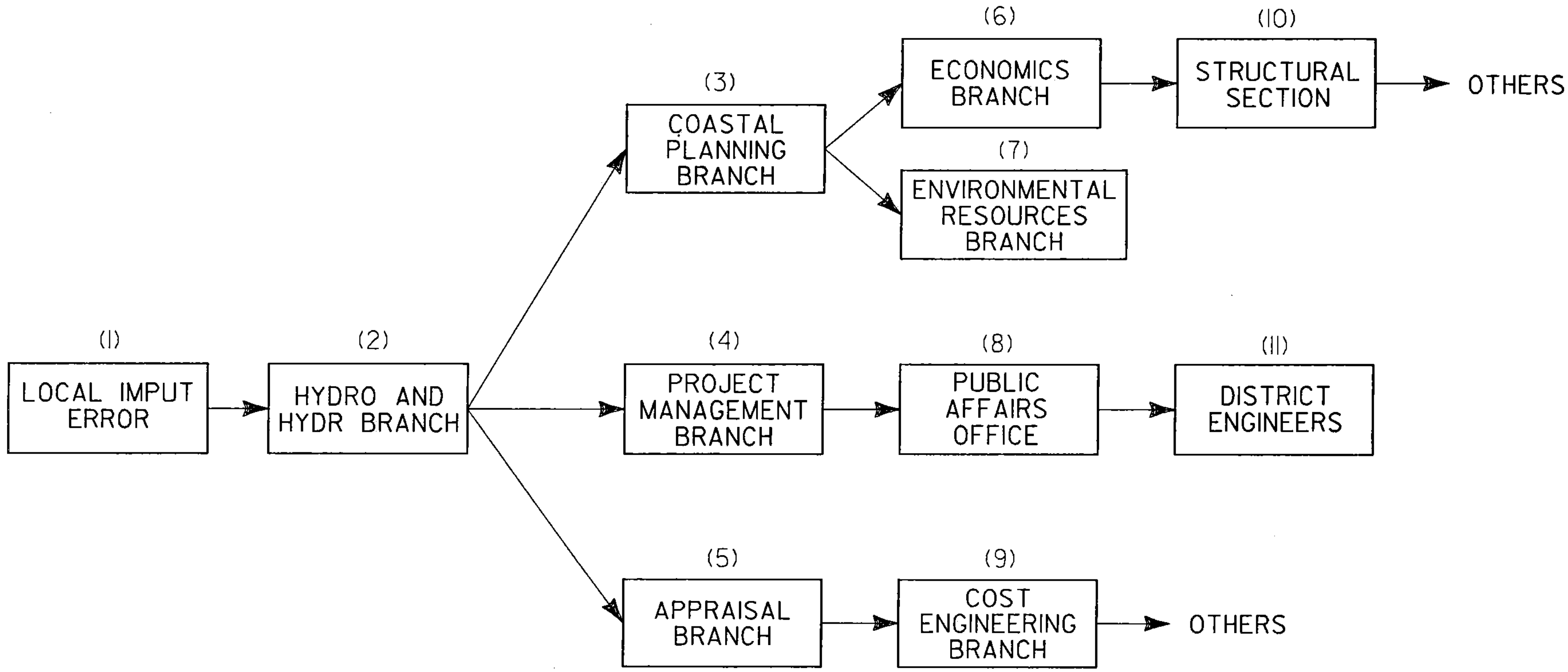

Figure 1
The Multiplier Effect of Errors

shows the effect of only one error. What would happen if additional errors are initiated at the any other level and subsequently passed on. It should be clear why systems process control needs TQM.

Empowerment of the employee has a "zapping" effect on attitude and behavior [Bynam, 1988]. Employees have a say in how things are done, have control over "their" work, feel like they are part of the process (own their job), and take pride in accomplishments. This gives employees "wanted" responsibility, energizes the work environment and vastly improves communication.

In the past, management tended to set artificial or mandated specification limits on quality, and quotas on output. When employees did not meet the limits or quotas, management placed blame for the problem squarely on the shoulders of employees. The problem, however, rested with the production or service system which was management's responsibility - not the employee's [Deming, 1989]. Common cause problems are management's problems by definition of what management does.

TQM also empowers the employee. Empowerment of the employee has two positive aspects. One, it has been demonstrated that empowerment is a strong motivating factor. Secondly, employees are an integral part of the process and often know where the problems are and how to correct them.

The end product of all the above is a more motivated and happier work force, higher quality products and services, efficiency gains, a more cost effective systems process control, and satisfied clients and customers that return again and again.

Table 2 contains some important definitions and descriptions with which the reader should acquaint himself/herself with before proceeding with the text. The definition of a process resembles similar definitions which can be found in many textbooks on the subject of management and production. Most such definitions focus on a process as it relates to the production of tangible items; with little focus on services. The enclosed definition is meant to be all encompassing (products and services) as typified by the use of the word output.

The word "system" is also comprehensive and implies the output associated with a product system or a service system. The definition is also flexible enough to be used to express general systems, sub-systems or multiple systems.

Quality is an interesting concept. Most people know it when they see it, but it is often evasive because of its subjectivity. One person's idea of quality is not the same as another's. The same is true across cultural lines and international boundaries. The definition in Table 2 deals with the subjectivity problem to a large extent. This definition is curious, though. A quality product or service may satisfy a customer beyond expectation and still be of poor quality to a purist.

The customer Is King (Queen)! This is true in the private sector of the country, and in the public and quasi-public sectors. COE customers are very diverse, crossing almost every discipline, culture, and national border. The COE is not only a servant to those outside its authority but is also a client to itself. The inter-connectivity of district elements (Divisions, Branches, etc.) and the COE Chain of Command (OCE, Divisions,

TABLE 2 FUNCTIONAL DEFINITIONS AND DESCRIPTIONS	
Process:	The factors of endowment (people, equipment, materials, methods, and environment) that produce a given product or service.
System:	A configuration of things or processes so inter-connected as to behave as one.
Quality:	The characteristics or attributes of a service or product that make it attractive or valuable to a knowledgeable customer.
	"Quality is meeting customer needs and expectations consistently and efficiently" [Turner, 1993].
Customer:	Customers include:
	● Federal Agencies and Offices
	● Local Governments
	● State Governments
	● The Public
	● Project Sponsors
	● Other offices within the District
	● Other COE offices along the Chain of Command (OCE, Divisions, WLR, etc.)
	● The Executive, Legislative and Judicial Branches of Government.
Empowerment:	The granting of trust and limited employee centered leadership and proprietorship over job duties and responsibilities.

WLRC, etc.) is extraordinary. The systems reliability structure is well established, but improvements in systems process output as depicted by TQM is needed. Is our systems process producing the quality our customers expect?

2. Traditional Management Approaches

The traditional approach to manufacturing or producing a product or service is to depend on multiple inspections or reviews to audit the final article or service and screen out items not meeting established expectations or criteria. This approach relies on checking or reviewing after the fact, i.e., detecting problems by examining post-production data. This is wasteful or inefficient because it allows labor, equipment, materials, and other resources to be consumed and looking for the problems, errors, or inaccuracies in mid-stream. We are, actually subsidizing defects by allowing them to happen in the first place. The results are reflected in the cost of doing business, higher customer prices, lower output and efficiency, considerable waste, and dissatisfied clients and customers.

To avoid these problems, a better scheme would be to adopt a method of prevention. Prevention is a pro-active approach. A preventative strategy is the theme of statistical process control.

There are many direct and indirect costs inherent in the use of the "cost of detection" approach to management; that is, allowing the problem or defect to occur in the first place. Rosander, [1989], provides a comprehensive discussion on the costs involved with traditional management approaches which is summarized below. There are internal, external, and prevention cost failures. Table 3 (Page 8) describes some of the more important costs.

Internal cost failures include waste (the net loss of labor and material), re-analysis (the cost of correcting defects), review (the cost of another review cycle), and downtime (the cost to redo rather than to go on to the next or new task). These should look familiar to most COE members. Those who have written reconnaissance, feasibility, and permit reports know these as common place costs.

External failure costs include unhappy clients (loss of customer and our reputation), and allowances (cost of concessions made to re-capture customer). These are familiar failures.

Prevention cost failures are a third cost factor associated with the traditional detection method of management. Included are problem corrections (meetings, letters, memo's etc.), the establishment of new procedures (modify the process), more review (testing and checking), and an examination of alternatives (more unplanned activities).

Table 3 lists the three major cost factors accompanying traditional management practices. There are other amenity and externality type costs not discussed but the ones above constitute the vast majority of not adopting TQM principles.

3. What Is A Process Control System

We have seen the difficulties associated with traditional management techniques. They adversely impact the process. The TQM approach rectifies many of the shortcomings of the traditional system.

TABLE 3
COST OF DETECTION [1/]
(Traditional Approach)

(Allowing The Problem Or Defect
To Occur In The First Place)

Several Kinds of Costs Incurred

- ❑ Internal Failure Cost:

  Waste - The net loss in labor and material.
  Re-analysis - The cost of correcting defects.
  Review - The cost of another review cycle.
  Downtime - The cost to redo rather than to go on to the next, new task.

- ❑ External Failure Costs:

  Unhappy Clients - Loss of customer, reputation.
  Allowances - Cost of concessions made to re-capture customer.

- ❑ Prevention Cost Failures:

  Problem Correction - Meetings, memo's etc.
  Establish New Procedures - Modify the process.
  More Review - Testing and checking (non value added work).
  Examination of Alternatives - More unplanned activities.

1/ Roseland, A.C.. The Quest For Quality In Services. N.Y. Quality Press, 1989.

Before describing this in detail a definition of a process control system is needed. A process control system in a TQM context can be defined as:

An approach to product or service output processes which involves the analysis of the interdependence between cause and effects and the adoption of management control practices which reduce or eliminate system disfunction.

Specifically, process control is a diagnostic process which systematically detects, identifies and eliminates problems or defects in a product or service output system. When we talk about output in the COE we are including the production of tangible products (reports, designs, plans, etc.) and services (dredging, permits, floodplain management information, etc.) Table 4 provides a more comprehensive list. The principles governing output are the same for a public, semi-public, or a private entity. They are also the same for production in hard core manufacturing, i.e., automobiles, steel, chemicals, etc., as they are for services, i.e., banking, insurance, real estate, lock operations, recreation, etc.

The next several sections introduce the statistical concepts needed to fully understand TQM in a Deming context. This statistical presentation should be viewed as a review. For a more detailed analysis, consult a text (see references) for details. Following this, the concepts will be put to use in a couple of examples.

**TABLE 4
PRODUCTS AND SERVICES PERFORMED
BY THE GALVESTON DISTRICT, COE**

- ❑ Reports of all kinds (information)
- ❑ Planning
- ❑ Dredging
- ❑ Flood Control
- ❑ Water Supply
- ❑ Recreation
- ❑ Flood Plain Management Guidance
- ❑ Emergency Services
- ❑ Lock Operations
- ❑ Flood Gate Operations
- ❑ Navigation Aids
- ❑ Erosion Control
- ❑ Storm Damage Assessments
- ❑ Coastal Storm Damage Protection
- ❑ Permits
- ❑ Appraisals
- ❑ Mapping
- ❑ Design
- ❑ Cost Estimates
- ❑ Many others
- ❑ Construction
- ❑ Project Maintenance

Table 5 presents raw or unorganized sample data which shows permit processing lead time for 39 permits of a fictitious Regulatory Branch over a one year period. Note that report completion time ranges from a low of 60 days to a high of 118 days. The mean time was 95.9 days. From the way the data is presented not much more can be said about the information in the table. If however, the data were separated into 7 groups of equal size, considerable more information can be obtained from this ungrouped data. Table 6 Column (1) organizes the same information into groups of similar size or value, i.e., 51-60, 61-70, etc. These 7 groups are called "class intervals" and in the case of our permit data each class interval is 9 days in length. Seven class intervals were convenient in this case for analytical purposes. An analyst can have as many class intervals as desired and they can be of any width depending upon the amount and type of information or data that is available. Column (2) of the table shows a count or tally of the number of report completion times falling into each class interval as read from the unorganized data in Table 5. Notice how more information has been abstracted from the raw data when it is organized into class intervals.

Column (3) sums the tallies of Column (2) to reveal how often or frequently each class interval of report completion times occur. It can now be said that 15 reports (38.5 percent) are completed within 91-100 days. Eight reports (20.5 percent) are completed within 81-90 days and similarly, another 8 reports are completed within 101-110 days, and so-on. The tallies show how report completion times seem to cluster around 91-100 days and thin-out as one moves away from this central tendency. The information in Table 6 is called a frequency distribution which is simply a table that organizes data into classes. It shows the number of observations from a series of data that fall into each class interval. Column (3) also presents the percentage of total report completion times that fall into each class interval. Note that class intervals should not overlap, i.e., 51-60, 60-70, 70-80, etc. They must be clearly separated into discrete intervals, i.e., 51-60, 61-70, etc.

Data from a frequency distribution can be used to develop a histogram. A histogram is a graphical plot of data derived from the frequency distribution. More properly defined [Levin, 1987] a histogram is "a graph of a data set composed of a series of rectangles, each proportional in width to the range of values in a class and proportional in height to the number of items falling into the class or the fraction of items in the class".

Figure 2 illustrates the construction of a histogram using the data from Table 6. The class interval 51-60 days occurs once and is plotted as 1 on the vertical axis. The same goes for the class interval 61-70. Class interval 71-80 occurs twice and is plotted on the vertical axis as 2. Reports completed on the class interval of completion times ranging from 81-90 have a frequency of 8 and so-on. Figure 3 shows the completed rectangular construction of the histogram with a smooth

TABLE 5
DATA FOR CONSTRUCTING A FREQUENCY DISTRIBUTION AND HISTOGRAM

Permit Number	(1) Number of Days
1	60
2	71
3	81
4	130
5	81
6	77
7	81
8	90
9	101
10	90
11	103
12	110
13	107
14	103
15	78
16	100
17	90
18	90
19	109
20	110
21	120
22	108
23	90
24	111
25	118
26	91

TABLE 5
DATA FOR CONSTRUCTING A FREQUENCY DISTRIBUTION AND HISTOGRAM

27	91
28	93
29	94
30	95
31	99
32	99
33	98
34	97
35	92
36	100
37	100
38	91
39	92
Total	3741

TABLE 6 DEVELOPMENT OF A FREQUENCY DISTRIBUTION			
Class Intervals of the Number of Days Needed To Complete A Class Interval of Report Permit Application	Tallies		Number of Times Each Completion Was Observed (Days) (Source Table 5)
51-60	1	1	2.6
61-70	1	1	2.6
71-80	11	2	5.1
81-90	1111 111	8	20.5
91-100	1111 1111 1111	15	38.5
101-110	1111 111	8	20.5
111-120	111	3	7.7
121-130	1	1	2.6 1/
		39	100.1

1/ Does not total to 100% due to rounding.

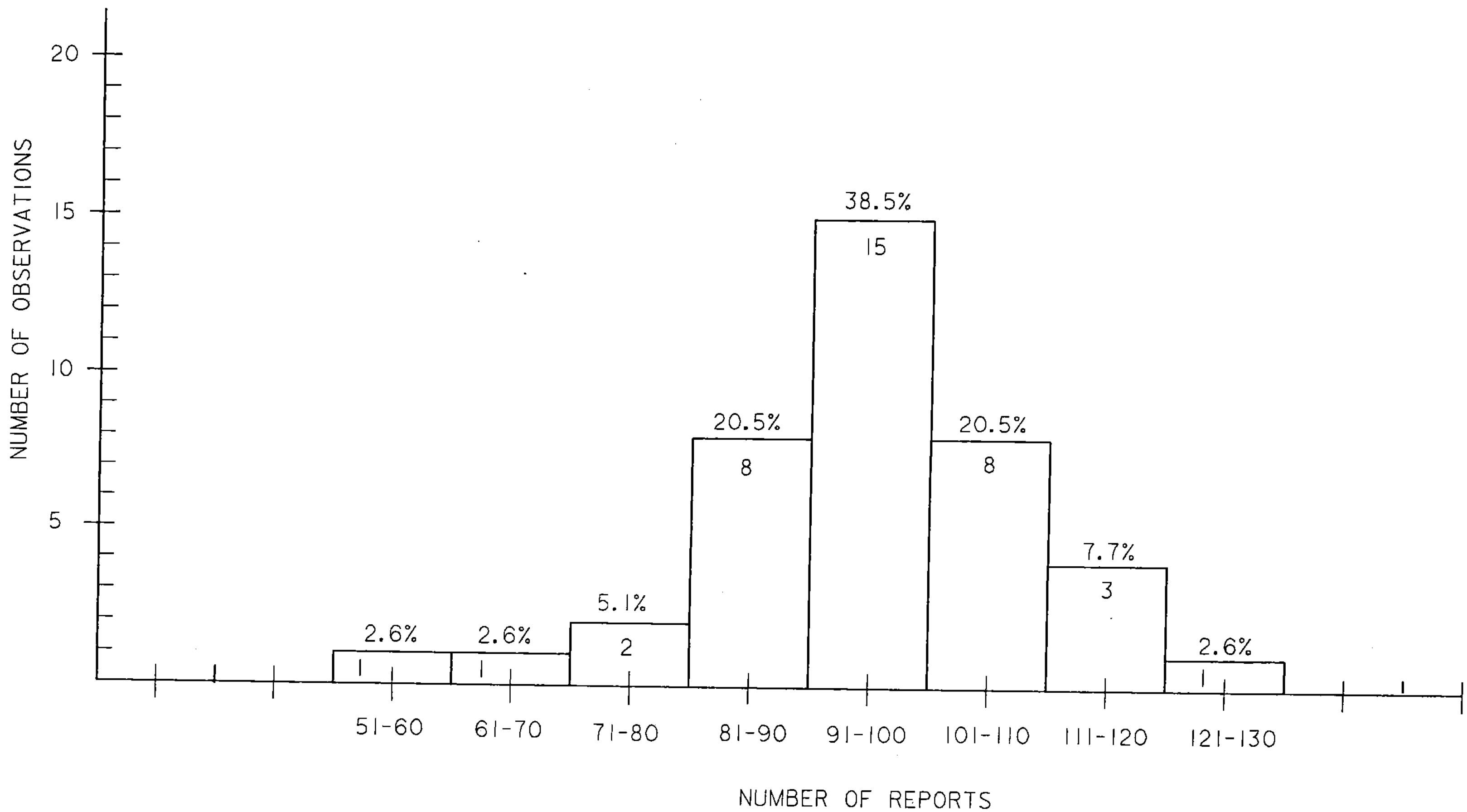

Figure 2
Construction of Class Intervals for the Development of a Frequency Distribution

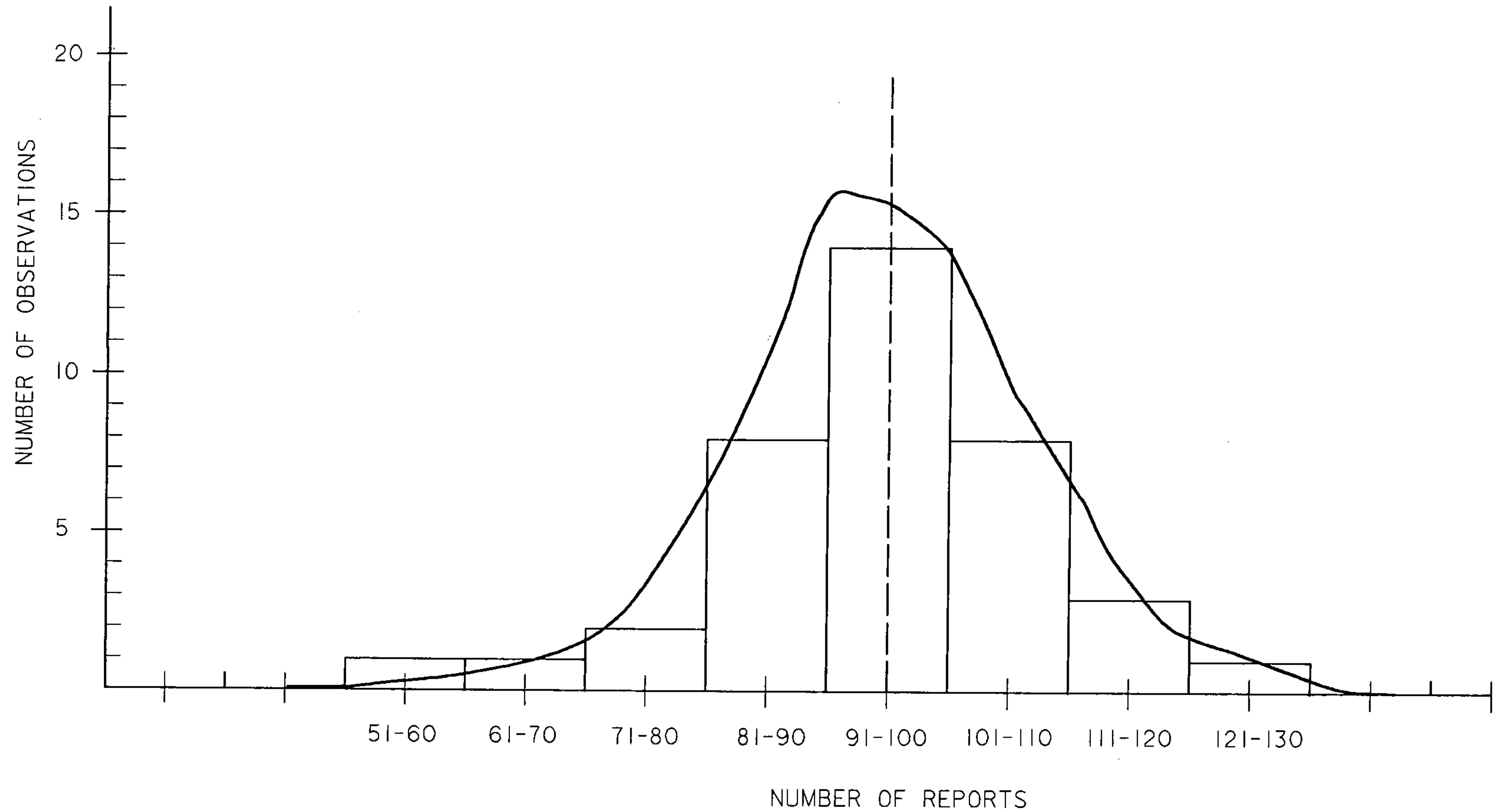

Figure 3
Construction of a Frequency Polygon

curve connecting the rectangles. Notice how the information plotted in Figure 3 clusters around the center of the bell shaped curved and thins out as one goes left or right of the graph's center (dotted line). The notions of how data spread around a central tendency will become very important as this text progresses.

III - INTRODUCTION TO THE CONCEPTS OF CENTRAL TENDENCY AND THE ANALYSIS OF VARIANCE

1. Central Tendency

Most measured data have a tendency to cluster or congregate about some central value, and this central value is frequently used as a way of summarizing data or information to describe the general pattern of this data or information. Often this central tendency is referred to by the term "average". An average is a word which actually consists of three distinct forms of central tendency. These forms are called the mean, the mode, and the median.

When most people use the term average they are actually referring to the mean of some set or group of numbers. The mean is the sum of all the numerical values making up the data divided by the number of data points in the set of data. The mathematical expression for this is:

Equation (1)

$$\bar{X} = \frac{X1 + X2 + \ldots + Xn}{N} = \frac{\Sigma X}{N}$$

where $\bar{X}$ is read "X bar" and "n" is the number of data points.

The mode, by definition, is the most commonly observed value in a series of numerical values. The mode has no mathematical expression to describe it.

The median is the third measure of central tendency or "average". It is a measure of central tendency that occupies the middle position in an array of numbers which are ranked in either ascending or descending order. The median has the following mathematical expression to describe it:

Equation (2)

Median = the $\left(\frac{n+1}{2}\right)$ th item in a data array

where "n" is the number of data points.

The mean, mode, and median are presented next by way of example.

Suppose a regulatory branch keeps a record of how long it takes to complete a permit action from the time a request is received until the final product is sent out of the district. The data in Table 5 is recreated in Table 7 and represents a sample of work in our fictitious regulatory branch over some period of time.

The mean of the data in Table 7 is the sum of all the numbers in Column (2) of the table divided by the total number of values. This turns out to be 3741/39 = 95.9. It is calculated by use of Equation (1). The 95.9 represents the mean number of days it takes to complete a permit action.

Column (2) of Table 7 shows how many times each number in Column (1) is observed among the 39 permit actions. The most frequently counted completion time is 90 days. This is, therefore, the mode.

The median completion time for a report is 95 days. It is calculated by use of

Equation (2). The data is found in Column (3) of Table 7 (see asterisk). Column (3) is Column (1) ranked in ascending order. The middle most value is 95 days.

As the reader has by now observed, there is nothing mysterious about the notion of central tendency. Central tendency is a natural phenomenon and is observable in annual rainfall patterns, wave heights on the oceans, urban water consumption patterns throughout a year, age distribution in a population, etc. When data are plotted in the form of a frequency distribution they usually tend to cluster near some central value, with fewer data points on either side the further one goes from the center towards the tails.

A histogram may be viewed as a bar chart of a frequency distribution. Figure 4 shows a histogram of the data on permit application approval. The data for the histogram comes from Table 7. Note that the histogram of the data shows a central tendency of data to cluster around the averages. Also notice that as one moves from the central tendency in either direction the data "thins out". A "bell shaped" curve results when the centers of the bars are connected with a smooth line. This bell shaped curve is called a probability distribution. This name is appropriate because the area under any part of the curve (in this case the bars) represents the probability of the events happening as shown on the horizontal axis. For example, completion times of between 51-60 days represents 1 out of 39 or 2.6 percent of all report completion times. Hence the probability of a new report being completed within 51-60 days is 0.026 or 2.6 percent.

2. Measures Of Dispersion

The "standard deviation" provides for a common measure of dispersion of data. It could be for a sample of data or an entire population of data. When the standard deviation is of a whole population (all data for a particular item) it is symbolized by (σ). Levin, [1987], defines the standard deviation of a population as "the square root of the sum of the squared differences between each data point and the mean of all data points in the population, divided by the total number of data points". The expression for the standard deviation of a population is:

$$\sigma = \sqrt{\frac{\Sigma f(x - \mu)}{N}}$$

where σ (pronounced sigma) is the population standard deviation, N is the total number of data points in the population, and X is each data point, and μ (pronounced "mu") is the mean of the entire population.

The "standard deviation" of a sample of the population (as compared to the entire population) is the square root of the sum of the squared differences between each data point and the mean of the observations in the sample, divided by the number of data points in the sample minus 1. It is symbolized by an s. This can be mathematically expressed as:

$$s = \sqrt{\frac{\Sigma f(x - \bar{x})^2}{N - 1}}$$

where $\bar{X}$ (pronounced X bar) is the sample mean, n is the total number of data points sampled, and X is each data point.

TABLE 7
EXAMPLES OF FINDING THE MEAN, MODE, AND MEDIAN

Permit Number	Number of Days	Mode	Median
1	60	1	60
2	71	1	71
3	81	3	77
4	130	1	78
5	81	1	81
6	77	1	81
7	81	3	81
8	90	5	90
9	101	1	90
10	90	5	90
11	103	2	90
12	110	2	90
13	107	1	91
14	103	2	91
15	78	1	91
16	100	3	92
17	90	5	92
18	90	5	93
19	109	1	94
20	110	2	95*
21	120	1	97
22	108	1	98
23	90	1	99
24	111	1	99
25	118	1	100
26	91	3	100
27	91	3	110

TABLE 7
EXAMPLES OF FINDING THE MEAN, MODE, AND MEDIAN

Permit Number	Number of Days	Mode	Median
28	93	1	101
29	94	1	103
30	95	1	103
31	99	2	107
32	99	2	108
33	98	1	109
34	97	1	110
35	92	2	110
36	100	3	111
37	100	3	118
38	91	3	120
39	92	2	130
Total	3,741		

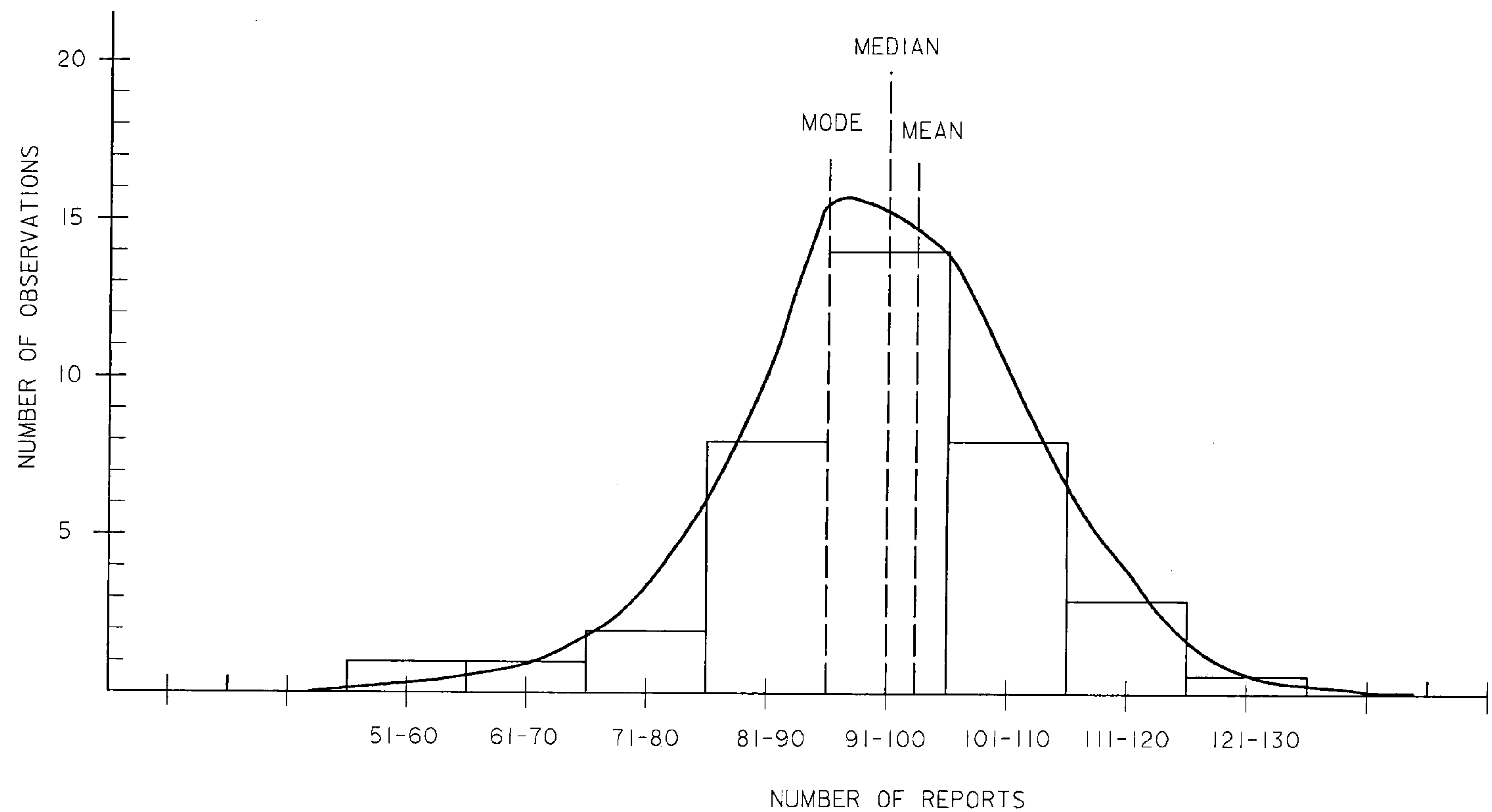

Figure 4
Dispersion of Data Around the Central Tendency

Minus 1 in the above expression is an adjustment made for degrees of freedom. Degrees of freedom is defined to be "the number of variables, minus the number of independent linear restrictions placed on them" [Meek, et al, 1987].

The sample standard deviation for a population can be evaluated whenever the population is relatively small and/or data collection funds are plentiful, i.e., to collect all permit report costs since 1960 would be expensive. A sample is used because it is less costly to obtain, and if the sample is properly collected (randomly chosen), and the sample size adequate (discussed later) then it is reflective of the very population itself.

Using the data on Table 6 we can compute the standard deviation as indicated in Table 8a. For our regulatory problem the standard deviation is 13.614 using a random sample and 13.438 using the entire population. These are very close results.

Note that in this case the population and sample standard deviation are very close to one another. It is important to realize that as sample size increases, population and sample standard deviations approach the same value. For example, if we use the first 10 numbers of Table 8a as a sample and view all the data in the table as the population we will get a completely different standard deviation. The sample standard deviation (first 10 data points) is 21.578. The population standard deviation is 13.614. If we use the first 15 numbers in Table 8a as a sample, the sample standard deviation becomes 18.719. As can be seen as the sample size increases, the standard deviation more closely approximates the population standard deviation. Table 8b shows this relationship.

In some cases, the work we do in the COE may require a sample to determine standard deviation. In other cases the population is small enough that all of the data can be used to determine the standard deviation. For the remainder of this text, the sample standard deviation will be assumed because much of the data used to evaluate process capability parameters in COE work will be sample oriented.

The standard deviation is a particularly valuable measure of dispersion because of its association with the mean in the bellshaped or normal distribution. The standard deviation can be used along with the mean to indicate the relative proportions of the data in a distribution that lie within a particular distance from the mean.

Figure 5 shows a "normal" distribution. The "normal" distribution has unique characteristics that separate it from other distributions. The figure shows that 68.3% of all data which make up the distribution must fall within ± 1 standard deviation of the mean. About 95.4% of all data must fall within ± 2 standard deviations of the mean. Finally, about 99.7% of all data must fall within ± 3 standard deviations of the mean. The total area under this curve is 100% as would be expected. The curve represents 100% of the data. These relationships are very powerful. The relationships that exist between the mean and the standard deviation in a normal distribution may also be used for analysis purposes with distributions that are nearly normal. In our regulatory process example the following determinations can be made:

68.3% level $= \bar{X} \pm 1s = 95.9 \pm 1(13.61) = 95.9 \pm 13.61$
95.4% level $= \bar{X} \pm 2s = 95.9 \pm 2(13.61) = 95.9 \pm 27.22$
99.7% level $= \bar{X} \pm 3s = 95.9 \pm 3(13.61) = 95.9 \pm 40.83$

68.3%	level	;	82.89	to	109.51	;	25/39	=	64.1%
95.4%	level	;	68.68	to	123.12	;	27/39	=	94.9
99.7%	level	;	55.07	to	136.73	;	39/39	=	100.0

TABLE 8a
EVALUATION OF VARIANCE

No.	X	X - X̄	$(X-\bar{X})^2$
1	60	60 - 95.9 = -35.9	1288.81
2	71	71 - 95.9 = -24.9	620.01
3	81	81 - 95.9 = -14.9	222.01
4	130	130 - 95.9 = 34.1	1162.81
5	81	81 - 95.9 = -14.9	222.01
6	77	77 - 95.9 = -18.9	357.21
7	81	81 - 95.9 = -14.9	222.01
8	90	90 - 95.9 = -5.9	34.81
9	101	101 - 95.9 = -5.1	26.01
10	90	90 - 95.9 = -5.9	34.81
11	103	103 - 95.9 = 7.1	50.41
12	110	110 - 95.9 = 14.1	198.81
13	107	107 - 95.9 = 11.1	123.21
14	103	103 - 95.9 = 7.1	50.41
15	78	78 - 95.9 = -17.1	292.41
16	100	100 - 95.9 = 4.1	16.81
17	90	90 - 95.9 = -5.9	34.81
18	90	90 - 95.9 = -5.9	34.81
19	109	109 - 95.9 = 13.1	171.61
20	110	110 - 95.9 = 14.1	198.81
21	120	120 - 95.9 = 24.1	580.81
22	108	108 - 95.9 = 12.1	146.41
23	90	90 - 95.9 = -5.9	34.81
24	111	111 - 95.9 = 16.0	256.00
25	118	118 - 95.9 = 22.1	488.41
26	91	91 - 95.9 = -4.9	24.01
27	91	91 - 95.9 = -4.9	24.01

TABLE 8a
EVALUATION OF VARIANCE

No.	X	$X - \bar{X}$	$(X-\bar{X})^2$
28	93	93 - 95.9 = -2.9	8.41
29	94	94 - 95.9 = -1.9	3.61
30	95	95 - 95.9 = -0.9	0.81
31	99	99 - 95.9 = 3.1	9.61
32	99	99 - 95.9 = 3.1	9.61
33	98	98 - 95.9 = 2.1	4.41
34	97	97 - 95.9 = 1.1	1.21
35	92	92 - 95.9 = -3.9	15.21
36	100	100 - 95.9 = 4.1	16.81
37	100	100 - 95.9 = 4.1	16.81
38	91	91 - 95.9 = -4.9	24.01
39	92	92 - 95.9 = -3.9	15.21
		= 7042.78	

Standard Deviation: s = 13.614 (random sample)
σ = 13.438 (entire population)

TABLE 8b
SAMPLE SIZE AND STANDARD DEVIATION

Sample Size	Standard Deviation	Comments
10	21.578	
15	18.719	
20	16.800	
25	16.918	(Extreme mean impact)
30	15.458	
35	14.317	
39	13.438	Entire Population

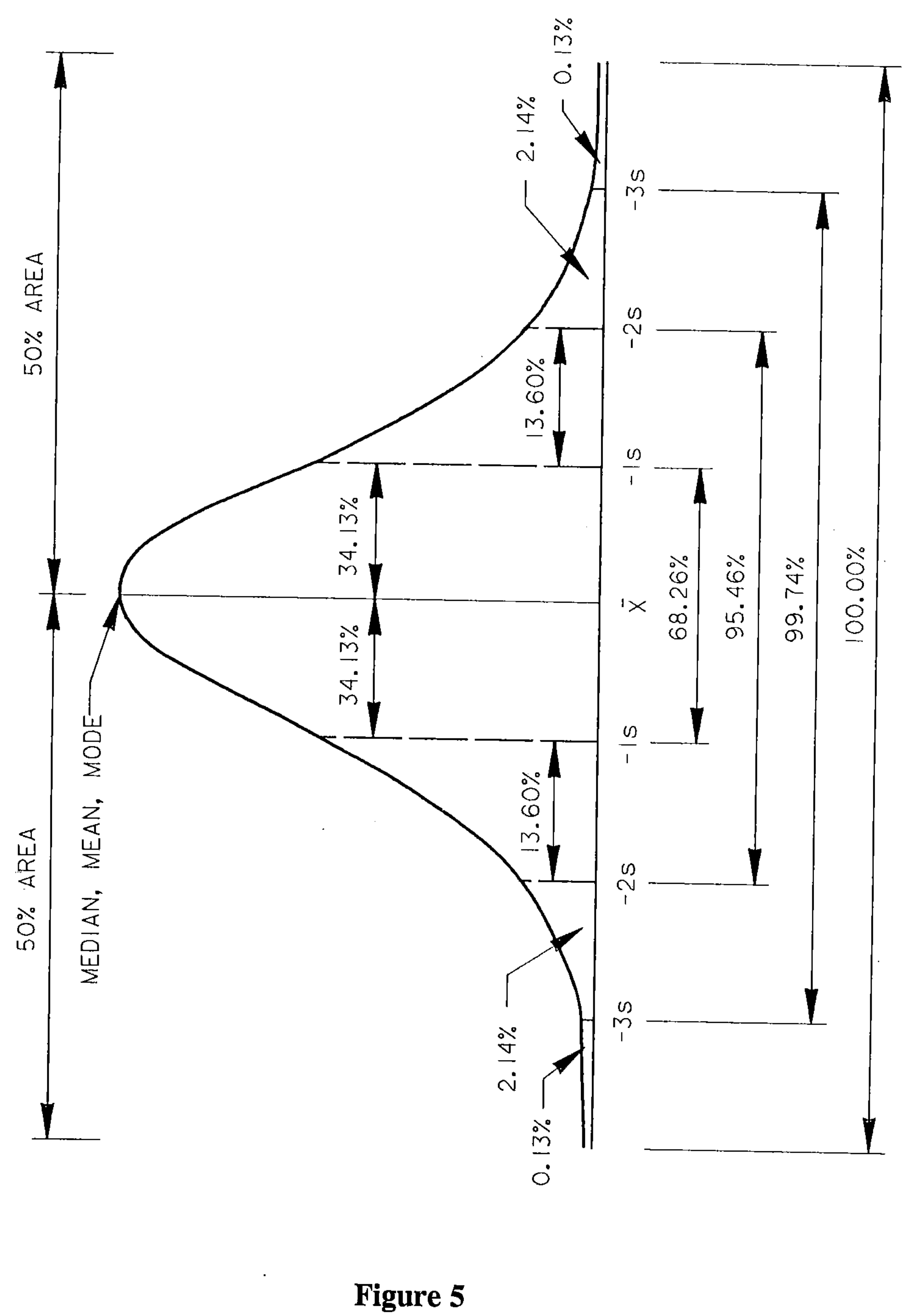

Figure 5
The Normal Distribution

It can be reasonably concluded that our data very closely approximates a normal curve. The differences are as follows:

Standard Actual Distribution	Theoretical Deviations Distribution	Difference
1	68.3%	64.1%
	+4.2%	
2	95.4	94.9
	+0.5	
3	95.7	100.0
	-0.3	

The range is the simplest and crudest measure of dispersion and is the difference between the highest (V_H) and lowest (V_L) value in an array of numbers. The equation for the range is: Equation (5)$R = V_H - V_L$

Although a very simple indicator it can be very useful, as we will see later. The range for our regulatory data is:

$$130 - 60 = 70 \text{ days}$$

3. Other Distributions

The normal distribution has some outstanding properties but not all distributions are normal. Figures 6 and 7 show other shapes and configurations that a distribution can take. Note in Figure 6 how the dispersion of data can be highly localized or concentrated about the mean as in curve (1). Curve (2) is normal as discussed. Curve (3) has a high level of dispersion - the data scatter widely from the mean.

The curves in Figure 6 and 7 are not unusual and should not be taken lightly. More will be said about these curves later.

4. Statistical Inference

Earlier in this text the concept of a normal or bell curve was introduced. One of the major characteristics of this curve is its symmetrical shape. Both halves have the same shape and contain the same area or number of data points. The mean, median, and mode are the same value and all are located at the peak of the curve. Figure 5 depicted these qualities. In our permit report application we discovered that our bell curve very closely approximated a normal curve. Recall that the normal curve shows that 68.26% of the observations will likely fall within the range of the mean, plus or minus one standard deviation, 95.46% within plus or minus two standard deviation's, and 99.74% within plus or minus three standard deviations as will be demonstrated below. The percentage of the population that falls within any distance from the mean or within any particular range can be determined.

Figure 8 will aid in demonstrating this principle. This figure is similar to that of Figure 4, with the exception that the standard deviation values for the permit report completion times are shown with the class intervals and class midpoints on the horizontal axis. There is an equation which aids in the calculation of the areas under the curve. These areas are important because they allow for determination of the probabilities that any new report will be completed; and in evaluating confidence levels of predicting report completion times. This equation is:

Equation (6) $$Z = (X\text{-mean})/s$$

where Z is the deviation of X from the mean measured in standard deviations, X is any report completion time on the X axis, the mean is as before and, "s" is the sample standard deviation.

SAME MEAN, INCREASING VARIANCE

WHEN THE STANDARD DEVIATION DECREASES, THE NORMAL DISTRIBUTION BECOMES MORE PEAKED. WHEN THE STANDARD DEVIATION INCREASES, THE NORMAL DISTRIBUTION FLATTENS AND SPREADS OUT.

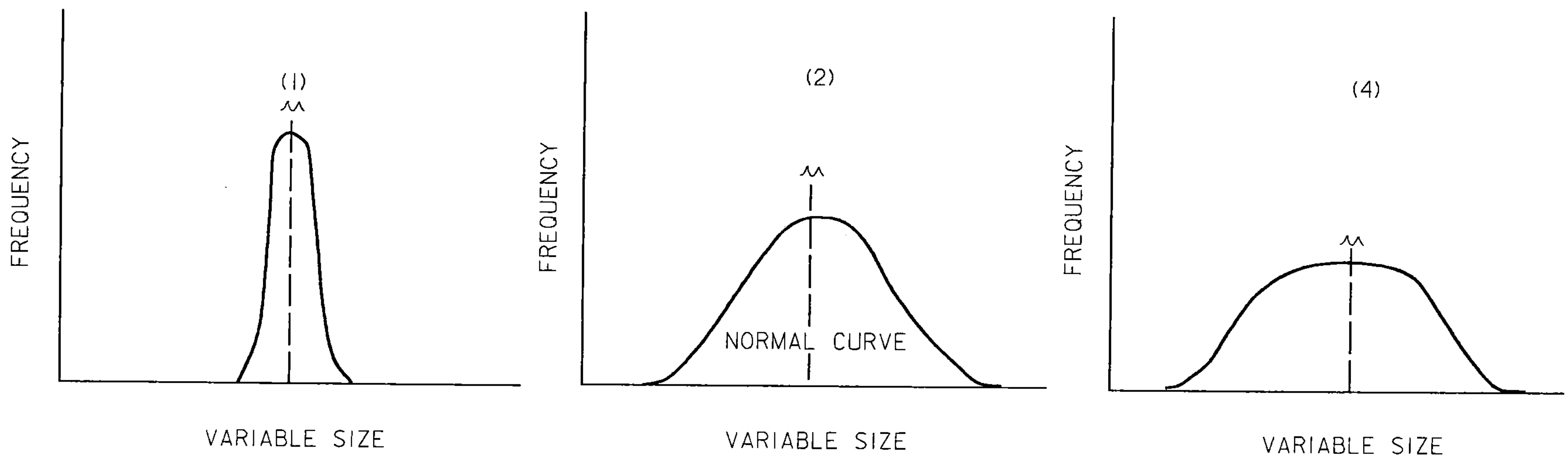

Figure 6
Variability or Spread of a Distribution

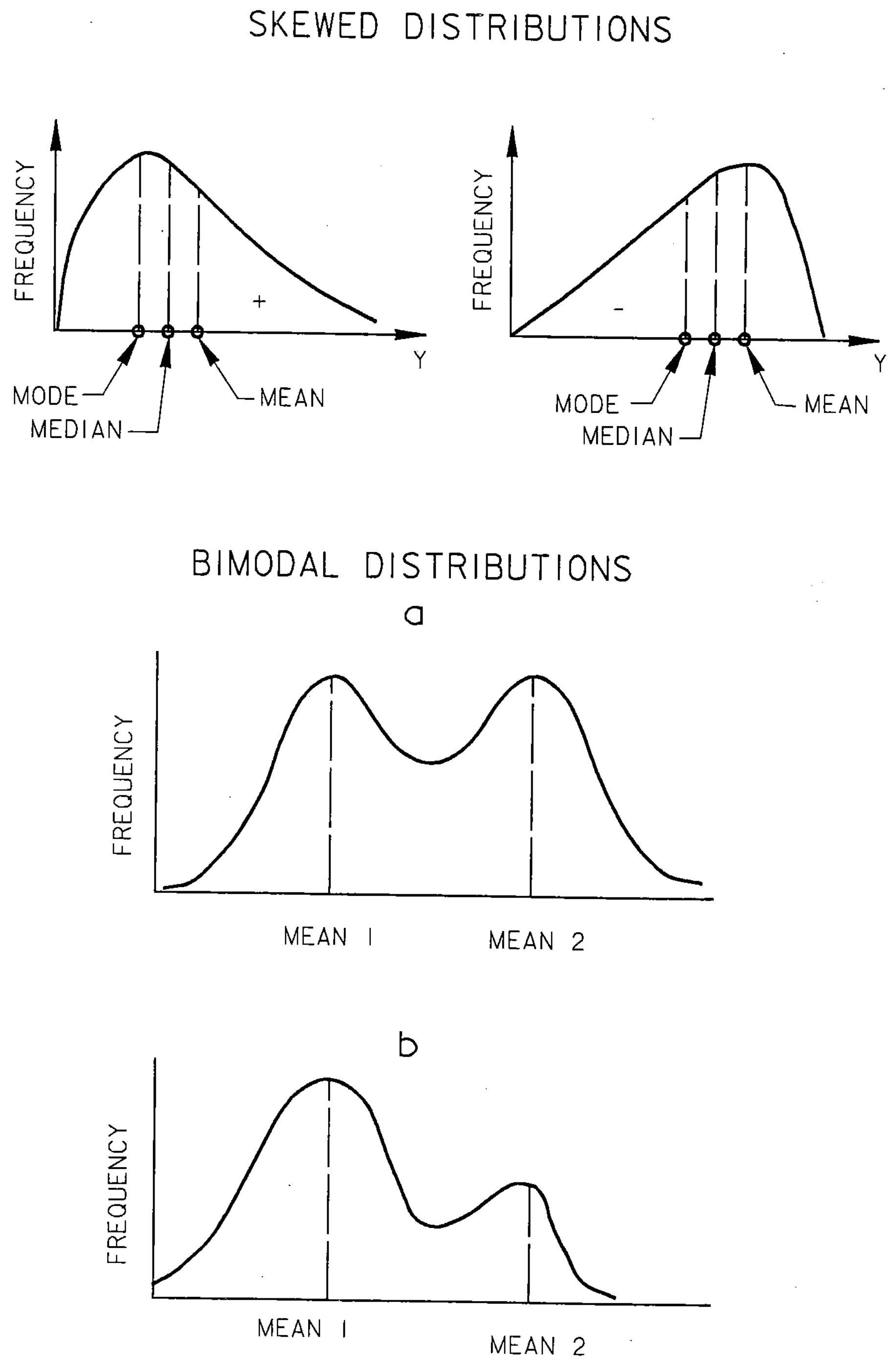

Figure 7
Shapes of Distributions

The value of Z, once calculated, is read from a table of areas under the normal curve as shown in Table 9. An example will serve to help explain the permit report completion facts (mean = 95.9, s = 13.61).

The probability of a report being completed between 95.9 and 109.5 days is:

$$Z = (X\text{-Mean})/S = (109.5 - 95.9)/13.61 = 0.999$$

Looking up 0.999 on Table 9 yields a value of .3389 or 33.89%. Thus the chance that any new, incoming report will be completed within 95.9 to 109.5 days is 33.89%. Since the curve in Figure 8 is symmetrical, the probability of a new report being completed between 85.5 and 109.5 days is: 2 X 33.89% or 67.8%. Given that the probability under the normal curve must equal to 1.00 (100% of all events) by definition, the chance of getting a report done between 55.5 and 109.5 days is: 50.0% (left half of the curve) + 33.89% (that portion of area between 95.5 and 109.5) which equals 83.89%. Similarly, the chance of getting a report done between 109.5 and 125.5 days is: 1.00 - 83.89% = 16.1 %. As is apparent, determining the chances of getting a permit report completed between any area of the curve can be calculated once the curves for the mean and standard deviation are known for any population or population sample.

Another example will help clarify the analysis. Suppose we wish to know what percent of permit reports are completed within 65.5 and 75.5 days. The calculations are as follows:

$$Z = (75.5 - 95.5)/13.61 = -1.470$$

(The minus sign is ignored, this means the area is to the left of the mean). The value of 1.470 in Table 9 shows that 42.92% of reports are completed within 75.5 days. In like manner:

$$Z = (65.5\text{-}95.5)/13.61 = -2.204$$

(The minus sign is ignored, this means the area is to the left of the mean). The value of 2.204 in Table 9 shows that 48.61% of reports are completed within 65.5 days. Thus the percentage of reports completed within 65.5 and 75.5 days is 48.61% - 42.92% = 5.69%.

We need to stop and reflect upon what all this means. First the curve itself was formed by the data indigenous to some permit section management process. Completion times vary because employees vary in skill and capability, the work environment and management planning skills vary, and the complexity of reports differ. Variation in completion times are thus due to many factors. Secondly, once a historic record is established such that a sample size will allow for the construction of a frequency curve, future completion times are relatively predictable as shown above, as long as the "system" continues to function as it has in the past. Thirdly, the frequency distribution or bell curve establishes "process capability" or shows what the permit process is capable of doing, i.e., permits are completed with a range of from 51 to 130 days, the mean process time is 95.5 days, the variability of report completion is 13.61 days (standard deviation), most reports (mode) are completed in 90 days and half the reports (median) are completed in less than 95 days and half need more than 95 days. The reader should reflect on all of this before proceeding; it is the backbone of performance improvement measurement and is vital to understanding the information in the next few chapters.

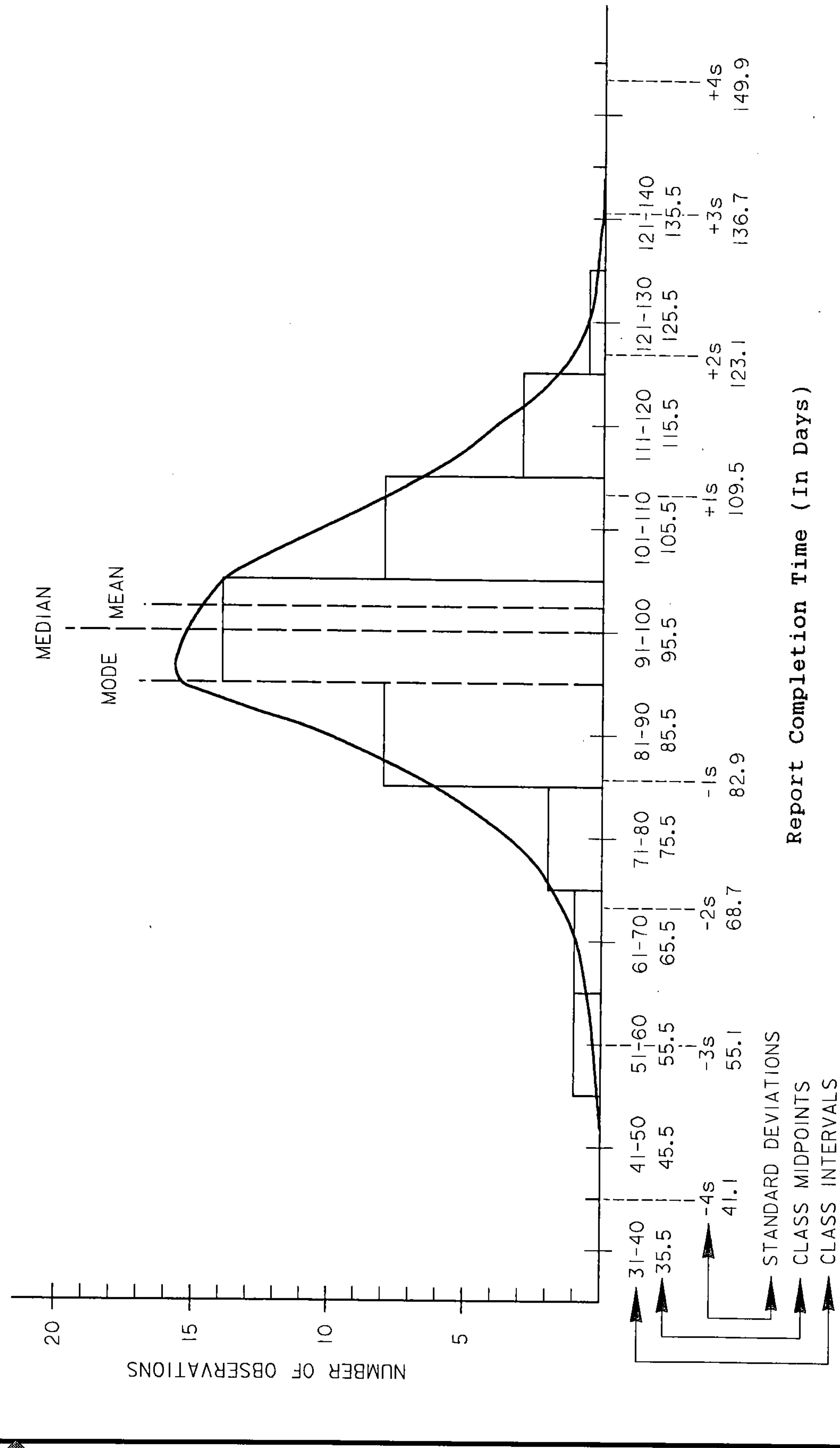

Figure 8
Dispersion of Data Around
The Central Tendency

TABLE 9
Areas under the Normal Curve[1]

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.0000	.0040	.0080	.0120	.0160	.0199	.0239	.0279	.0319	0.036
0.1	.0398	.0438	.0478	.0517	.0557	.0596	.0636	.0675	.0714	.0753
0.2	.0793	.0832	.0871	.0910	.0948	.0987	.1026	.1064	.1103	.1141
0.3	.1179	.1217	.1255	.1293	.1331	.1368	.1406	.1443	.1480	.1517
0.4	.1554	.1591	.1628	.1664	.1700	.1736	.1772	.1808	.1844	.1879
0.5	.1915	.1950	.1985	.2019	.2054	.2088	.2123	.2157	.2190	.2224
0.6	.2257	.2291	.2324	.2357	.2389	.2422	.2454	.2486	.2517	.2549
0.7	.2580	.2611	.2642	.2673	.2704	.2734	.2764	.2794	.2823	.2852
0.8	.2881	.2910	.2939	.2967	.2995	.3023	.3051	.3078	.3106	.3133
0.9	.3159	.3186	.3212	.3238	.3264	.3289	.3315	.3340	.3365	.3389
1.0	.3413	.3483	.3461	.3485	.3508	.3531	.3554	.3577	.3599	.3621
1.1	.3643	.3665	.3686	.3708	.3729	.3749	.3770	.3790	.3810	.3830
1.2	.3849	.3869	.3888	.3907	.3925	.3944	.3962	.3980	.3992	.4015
1.3	.4032	.4049	.4066	.4082	.4099	.4115	.4131	.4147	.4162	.4177
1.4	.4192	.4207	.4222	.4236	.4251	.4265	.4279	.4292	.4306	.4319
1.5	.4332	.4345	.4357	.4370	.4382	.4394	.4406	.4418	.4429	.4441
1.6	.4452	.4463	.4474	.4484	.4495	.4505	.4515	.4525	.4535	.4545
1.7	.4554	.4564	.4573	.4582	.4591	.4599	.4608	.4616	.4625	.4633
1.8	.4641	.4649	.4656	.4664	.4671	.4678	.4686	.4693	.4699	.4706
1.9	.4713	.4719	.4726	.4732	.4738	.4744	.4750	.4756	.4761	.4767
2.0	.4772	.4778	.4783	.4788	.4793	.4798	.4803	.4808	.4812	.4817
2.1	.4821	.4826	.4830	.4834	.4838	.4842	.4846	.4850	.4854	.4857
2.2	.4861	.4864	.4868	.4871	.4875	.4878	.4881	.4884	.4887	.4490
2.3	.4893	.4896	.4898	.4901	.4904	.4906	.4909	.4911	.4913	.4916
2.4	.4918	.4920	.4922	.4925	.4927	.4929	.4931	.4932	.4934	.4936
2.5	.4938	.4940	.4941	.4943	.4945	.4946	.4948	.4949	.4951	.4952
2.6	.4953	.4955	.4956	.4957	.4959	.4960	.4961	.4962	.4963	.4964
2.7	.4965	.4966	.4967	.4968	.4969	.4971	.4972	.4973	.4974	.4974
2.8	.4974	.4975	.4976	.4977	.4977	.4978	.4979	.4979	.4980	.4981
2.9	.4981	.4982	.4982	.4983	.4984	.4984	.4985	.4985	.4986	.4986
3.0	.4987	.4987	.4987	.4988	.4988	.4989	.4989	.4989	.4990	.4990

[1] Levin, Richard R., Statistics for Management. N.J.: Prentice-Hall. 1976

We have seen that the mean is a very useful statistic in connection with the analysis of raw data in and of itself, in determining the standard deviation, and in calculating the Z score. However, because these other statistics are dependent on the accuracy of the estimated mean (remember the estimated mean is a representative of the true, population mean), some measure of confidence about the reliability of the mean needs to be established. There is an expression which can be used to determine a specific sample size that will result in a given level of confidence in the estimated mean. This expression is:

Equation (7)

$$n = (z^2s^2)/e^2$$

where n equals sample size required, Z is the Z statistic developed earlier, s is the sample standard deviation, and e is the desired maximum difference (error) in the mean.

Let us use our permit report data to illustrate the usefulness of the above equation. Suppose we want to be 95% confident of our mean value of 95.9. To be 95% confident our Z score must be 1.96 (Table 9), (2.4750 X 2 = 0.95 or 95%). We also feel that our maximum error in the mean be no more than 5 reports. Using these numbers, the sample size we need is:

$n(95\%) = (1.96)^2(13.614)^2/(5)^2 = 28.5\ (29)$ rounded

Since we have a sample size of 39, already, we have more than satisfied our requirements. If we wanted to be more confident, say 98%, we use a Z score of 2.33 to get a required sample size of:

$$n(98\%) = (2.33)^2(13.614)^2/(5)^2 = 40.2(40)$$

Our sample size of 39 more closely resembles the sample size needed for a 98% level of confidence.

The 95% confidence limits are saying that we are 95% confident that our mean value, 95.9, lies between 90.0 and 100.9. Remember, our mean value was taken as representing an estimate of the mean of a population. We took a sample - we did not use the entire population to find the mean. If we had used the entire population that mean would be 95.9 (we viewed our data set of 39 as a sample of many previous years not sampled).

The readers should also note that equation 7 can be turned around to solve for e, s, n, or Z-score. For example, if we had Z-score equal to 1.96, the standard deviation of 13.614 and a sample size of 29, we could solve for e as follows:

Equation (8)

$$e^2 = (z^2s^2)/n$$

$e^2 = (z^2s^2)/n = (1.96)^2(13.614)^2/39 = 18.3$ or $e = 4.96$; an answer comparable to our e of 5.0 above.

1. <u>The Sampling Process</u>

On several occasions reference had been made to the concept of sampling. More details about sampling are being introduced here to familiarize the reader with the broad array of sampling techniques needed for TQM analysis.

Levin, [1987], has described sampling as "an orderly approach to selecting a few data points (a sample) from an entire set of data (a population) in order to obtain information about the population". In simple random sampling, one selects samples by procedures that allow each sample point to have an even chance or likelihood of being selected and each data point in the entire population to have an even chance of being chosen as part of the sample. This process eliminates bias and allows for the sample to more fairly represent the true population.

a. <u>Random Sampling</u>

The easiest method to select a random sample is to use a table of random numbers such as that found in Table 10 [Levin, 1987]. Tables of random number are common in textbooks on statistics and are usually generated by computer program process designed to guarantee randomness. The individual numbers range from 0 to 9 each with the same probability of being selected within any row or column.

As an illustration, let us use Table 7 data and our random number table, Table 10. If we assign each permit with a number as we did in Table 7, we can use the random number table (Table 10) to derive a random sample. For example, let us use Column 2 and let the first two digits in Table 10 represent the number of Column 1 in Table 7. If the two digits are larger than the population of 39 then the first digit in column two can be used. The first random number in Table 10 is 20; permit number 20 (Table 7) took 110 days. The second number in Column 2 is 72 (greater than 39) where the random number 7 is used; permit number 7 on Table 7 is 81 days. The third number in Column 2 of Table 10 is 34; permit number 34 in Table 7 is 97 days, and so on. Table 11 shows the results of choosing ten such random numbers as a sample. The sample mean of all the numbers is 93.5 which is close to our real population mean of 95.9.

What sample size did I need to be 95% confident that my sample mean was between 90.9 and 100.9?

$$n\,(95\%) = (1.96)^2(13.614)^2/(5)^2 = 28$$

Since my sample size was only 10 I cannot be 95% certain that the mean fell into the 90.9 and 100.9 range. I can be 75.4% certain, however;

$$z^2 = (10)(5)^2/(13.614)^2 = 1.349,$$
$$z = 1.161 = 75.4\%$$

Even though our sample mean of 93.5 was very close to our actual population mean of 95.9, I can only be 75.4% certain that this population size of 10 will give me a mean between 90.9 and 100.9.

In any event, the reader can see how random sampling is conducted and how sample size, confidence levels, z-scores, the standard deviation, mean and error are related.

There are three other sampling techniques which will be briefly mentioned.

Table 10
A Table of Random Numbers [1]

1581922396	2068577984	8262130892	837456049	4637567488
0928105582	7295088579	9586111652	7055508767	6472382934
4112077556	3440672486	1882412963	0684012006	0933147914
7457477468	5435810788	9670852913	1291265730	4890031305
0099520858	3090908872	2039593181	5973470495	9776135501
7245174840	2275698645	8416549348	4676463101	2229367983
6749420382	4832630032	5670984959	5432114610	2966095680
5503161011	7413686599	1198757695	0414294470	0140121598
7164238934	7666127259	5263097712	5133648980	4011966963
3593969525	0272759769	0385998136	9999089966	7544056852
4192054466	0700014629	5169439659	8408705169	1074373131
9697426117	6488888550	4031652526	8123543276	0917534537
2007950579	9564268448	3457416988	1531027886	7016633739
4584768758	2389278610	3859431781	3646768456	4141314518
3840145867	9120831830	7228567652	1267173884	4020651657
0190453442	4800088084	1165628559	5407921254	3768932478
6766554338	5585265145	5089052204	9780623691	2195448096
631516284	9172824179	5544814339	0016943666	3828538786
3908771938	4035554324	0840126299	4942059208	1475623997
5570024586	9324732596	1186563397	4425143189	3216653251
1999997185	0135968938	7678931194	1351031403	6002561840
7864375912	8383232768	1892857070	2323673751	3188881718
7065492027	6349104233	3382569662	4579426926	1513082455
0654683246	4765104877	8149224168	5468631609	6474393896
7830555058	5255147182	3519287786	2481675649	8907598697

1 Levin, Richard R., Statistics For Management. N.J.: Prentice-Hall. 1976

TABLE 11 DEVELOPING A RANDOM SAMPLE		
Trial Number	Randomly Chosen Permit Number	Random Report Completion Time
1	20	110
2	7	81
3	34	97
4	5	81
5	30	95
6	22	108
7	4	130
8	7	81
9	7	81
10	2	71
		10)935 93.5

They include systematic sampling, stratified sampling, and cluster sampling. They all try to approximate simple random sampling and are used for their precision, economy, or physical ease.

b. Systematic Sampling

When conducting systematic sampling, data are selected from a population at regular or periodic intervals. An example might include; choosing every 10th report, on every 5th day, on every 3rd project. This approach differs from simple random sampling in that each data point has an equal chance of being chosen but each sample does not have an equal chance at being chosen. There is a tendency to introduce bias if the procedure by which the process being sampled is not consistent over time.

c. Stratified Sampling

When doing stratified sampling the population is separated into groups or strata which are homogeneous in some characteristics. In stratified sampling we select at random from each set of circumstances a predetermined number of observations in proportion to strata size, or we select an equal number of observations from each stratum and give weight to the final results in proportion to the stratum's share of the total population. This relative approach insures that every observation in the population has a chance of being drawn. This type of sampling is very useful when it is necessary to divide the population into strata, i.e., by age, size, length or some other characteristic.

Stratified sampling is employed when each strata has minimum variation within itself but there is wide intergroup differences, i.e., a poll of 15-17 year olds versus a poll of 60-65 year olds concerning political attitudes.

d. Cluster Sampling

Cluster sampling is conducted when there exists considerable number of mutually exclusive groups each with relative few items. In cluster sampling the population is divided into groups or clusters and then select a random sample is selected from each cluster. It is assumed that each cluster is descriptive of the population itself. It is a money saving technique.

There is an important connection between sample size and the standard error of the mean. If the sample size is ample (n is greater than 30) the sampling distribution mirrors the normal distribution even if the population is not normally distributed. It should be noted that as n increases, the standard error of the mean decreases. As sample size increases, we have more data on which to evaluate the population mean, and therefore the likely difference between the actual value of the mean and the sample decreases. This is illustrated in Figure 9.

In summary, sampling is done because to examine the entire population of data for each variable (all permit reports, all errors in all reports, all annual leave for all employees, etc.) is either too costly, too time consuming or next to impossible. Secondly, a correctly conducted sampling produces very accurate results making 100% sampling unnecessary. Large samples do not necessarily produce more accurate results. There are many different types of sampling but the four most commonly used include simple random sampling, systematic, stratified sampling, and cluster sampling. Each has its advantages and its disadvantages.

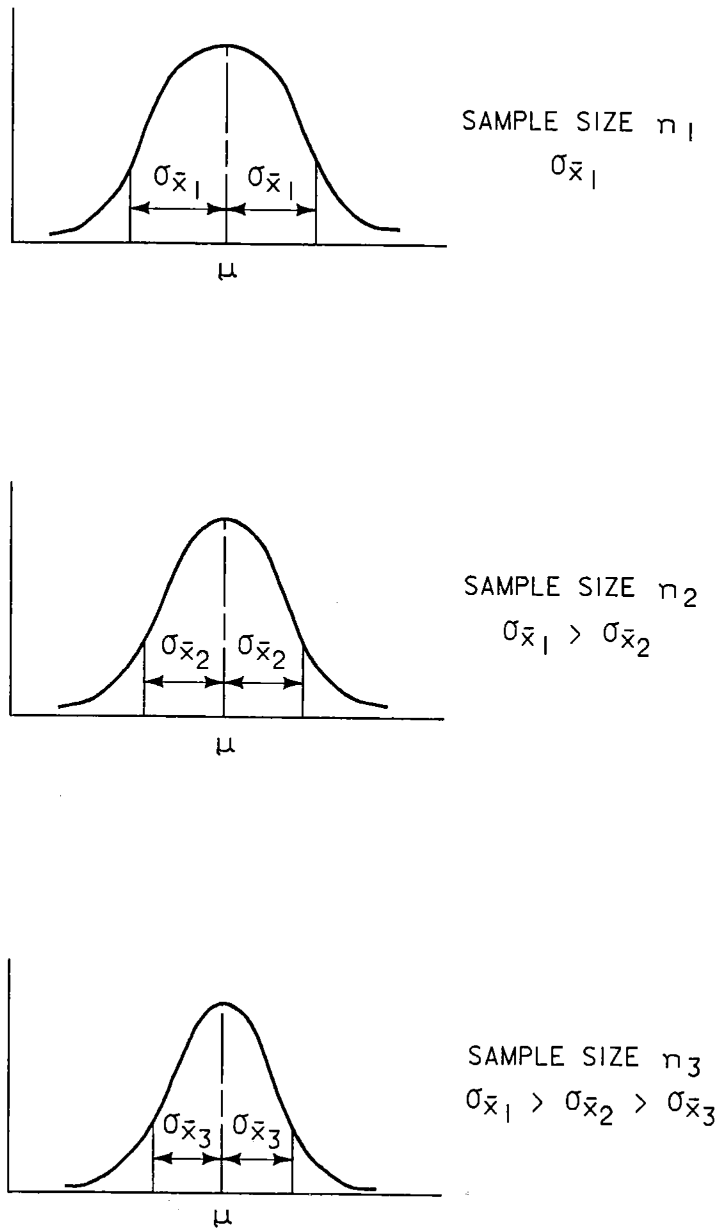

Figure 9
The Relationship Between the Population Size and the Standard Error of the Mean

An excellent discussion of process variation and statistical quality control can be found in an AT&T publication [AT&T, 1956] from which much of the following information is based.

When data are collected relating to the measurement properties for any problem, production, situation or process (products and services) these data usually display random variation. Instead of the same datum measurement being observed each time, the measurement (of the same thing) varies. When plotted on graph paper one would observe an up and down or nonuniform saw tooth character. Similarly, any series of numbers from a process will produce a zig-zag or fluctuating pattern. There is no known product, service, item or process which does not produce or show measurement variation over time. This seemingly trivial observation is extraordinarily important.

Measured random variations are caused by a large number of reasons: differences in materials, equipment, the local environment, human skills, management practices, etc. Many of these differences are small but are the chief driving force behind fluctuations which are natural or normal. On occasion, however, there will be a significant or unusual difference more profound than all other differences combined. These are not random process variations. Such significant differences may be observed when equipment breaks down, employees receive new training, management changes hands, an experienced worker takes over where an inexperienced worker left off, etc. These large signatures or causes produce a fluctuation pattern which is unusually large or aberration; they are abnormal, but they are not random.

Evidence indicates that there is a clear cut and measurable difference between the natural and the unnatural fluctuations. These differences can be detected and subsequently analyzed by existing statistical tools such as the frequency distribution.

Once it is determined that a fluctuation is unnatural (say greater than 3s) its cause can be determined. Thus, causes can be isolated and studied for any process, whether it be a production process, a service output process or a manufacturing process.

Fluctuations were observed long ago in the manufacturing of carriage wheels, metal parts, and banking services. When one documents the measurement differences between the same part manufactured in the same way within the same process the measurements tend to cluster around a central value with some degree of scatter on either side of the central value. This is the typical pattern of a frequency distribution discussed earlier. If the cause system is constant, the frequency distribution approaches some distribution function; a mathematically predictable behavior. A consistent or repeated pattern is formed and is made up of a large number of fluctuations - some larger or smaller than others -shifting within the bounds of the fluctuation pattern itself (bell shaped curve) when there are no unusual, significant, or abnormal causes at work.

The fluctuation patterns in normal production and service operations have statistical limits. If that pattern is normal or natural its fluctuations will fit within the confines of these limits as stated earlier. If a pattern is, however, unnatural, its fluctuations will exceed these limits. When statistical limits are added to a fluctuating pattern the results are referred to as a control chart. These statistical limits are 3 standard deviations. Any pattern of data in a control chart which fluctuates outside of these 3 standard deviations from the mean or which show non random (unnatural) points, it is said to be indicative of a process which is "out of control". Three standard deviations is a generally accepted criteria but more will be said about this later in the text.

The control chart, in sum, is a group of fluctuating, random patterns representing a process bounded within statistical limits. The control chart is the back bone of statistical process control and capability analysis mentioned earlier.

The notion of control involves taking action with the intent of achieving a desired end; a means - ends relationship. The prime purpose in statistical process control is to detect and eliminate the unnatural fluctuations and reduce the variation in natural, normal fluctuations to foster uniformity of quality. In other words product or service quality needs to be reproducible within limits. Note that when a significant cause is discovered and removed, this changes the control limits by narrowing them, leaving behind more typical cause variation fluctuating in a narrower range. The process of detecting, identifying and eliminating causes may be a long run process. Initial rapid elimination may occur, but the longer term or more complex causes may take time. Remember, the idea of a state of statistical control serves as a basis for describing and reaching the goal of uniformity and achieving the functional capability of a process capable of reaching this goal. In the following paragraphs the data for permit reports will be used for a step-by-step control chart construction. More will be said later with regard to the concepts of special and common causes of variation.

The objective of statistical process control is to eliminate special causes of variation and then to monitor the process for shifts in process averages and variances over time. This goes a long way toward improvement in product and service quality.

There are two types of control charts. One for analyzing variable characteristics (anything which can be measured) and one for attributes (where something is produced or serviced which either passes a test or fails it). In this text we will be dealing chiefly with variable control charts because they fit in the COE process better than attributes charts and provide considerably more information.

As discussed earlier every item, service, or process varies in some characteristic. These variations may be due to human resource capabilities, environmental factors, management practices, etc. There are two major types of variation that are important and distinct to process capability analysis. They are, <u>common cause variation</u> and <u>special cause variation</u>.

Common cause variation is the collective effect of many or all individual causes of variation that are indigenous to the process of producing a good or service that cannot be removed without management action. Studies have shown that common cause variation is 85% management related [Deming, 1982]. Each of the many causes of variation that compose the total may exhibit vastly different distributions, but in combination, they are approximately normal. Consequently whenever we have common cause variation we can assume that the process population distribution of the variable being measured is nearly normal. Table 12 lists a few attributes of common cause variation in the COE. This list should be studied as a means of building a sensitivity to the characteristics of common cause variation. In order to correct common cause variation that is the heart of a nonuniform production system, corrective action is required. Common cause variations are the process errors over which employees have no control, i.e., for the COE this could represent changes in regulations, priority changes, equipment breakdown, congressional requests, among others.

Special cause variation emanates from individual sources of variation that may be statistically identified and removed from the production and service process. When adequate statistical evidence is presented, employees are best at identifying a special cause of variation and are paramount in eliminating the cause. Such causes include incomplete or improper training of a new employee, a piece of equipment not properly functioning, an incorrect procedure or technique, etc. These problems represent approximately 15% of process variation [Deming, 1982]. Tables 13 and 14 list a few items of potential common or special variation.

The keys to determining whether a cause is special or common is to first detect it, isolate it, then eliminate it. These factors fall under the topic of control charts which are closely allied to common and special cause analysis.

TABLE 12
COMMON AND SPECIAL CAUSE ATTRIBUTES [1/]

Special Causes Associated with things which are:	Common Causes Associated with things which are:
Unnatural	Normal
Disturbed	Natural
Unstable	Stable
Non-homogeneous	Undisturbed
Mixed	Homogeneous
Erratic	Coming from a single distribution
Abnormal	Not changing
Shifting	Steady
Unpredictable	Predictable
Inconsistent	Same
Out-of-the-ordinary	Consistent
Different	Statistically constant
Important	Non-significant
Significant	

1/ AT&T, Statistical Quality Control Handbook (Indiana: AT&T Technologies, Inc. Sec. Ed. 1958).

TABLE 13
HOW WOULD YOU RATE EACH:
SPECIAL VS COMMON

- ❑ Plan formulation changes
- ❑ Changes in regulations
- ❑ Equipment breakdown
- ❑ Lack of training
- ❑ Too many meetings
- ❑ Meetings too long
- ❑ Non-acceptance of new ideas
- ❑ Too many jobs/tasks per person
- ❑ Lack of secretarial assistance
- ❑ Communication problems
- ❑ Quantitative errors
- ❑ Grammatical errors
- ❑ Lack of data or information
- ❑ General office disturbance
- ❑ Policy or operational differences between Division, Branches, etc.
- ❑ Unfunded tasks
- ❑ Micro management approaches
- ❑ Other

TABLE 14
HOW WOULD YOU RATE EACH:
SPECIAL VS COMMON

- ❑ Major unscheduled tasks
- ❑ Flash fires, crises events
- ❑ Employment freezes
- ❑ Priority changes
- ❑ Hurricanes
- ❑ Loss of funding/budget cuts
- ❑ Reorganization
- ❑ TQM
- ❑ Long term illness of key employees/supervisors
- ❑ Changes in management, supervision or leadership
- ❑ Major policy directions
- ❑ Congressional requests
- ❑ People leaving (promotions, other jobs, etc.)
- ❑ Other

When variable data are evaluated, the data are graphed over time on a mean chart and a range chart. For each sample data, the mean and standard deviation are most often used for plotting. However, the range may substitute for the standard deviation because of the ease of its determination without much loss in the validity of the final results.

The initial step in developing a control chart is the assembling of a sample size. Sample sizes or subgroups may be as low as 2 but more typically are 5 or any number between. A sample may be collected weekly, monthly, or annually depending upon the circumstances. At least 20 samples are deemed a viable size. For each sample the mean $\bar{X}$ and the range, R are calculated, then the mean of the individual sample means are calculated as a good proxy of the process mean. The expression for this is:

Equation (9)

$$\bar{\bar{X}} = \Sigma \overline{X_j} / k$$

where k is the number of subgroups or samples ($\bar{\bar{X}}$ = X-double bar or the average of the averages).

Following this, the average range of the subgroups are calculated:

Equation (10)

$$\bar{R} = \Sigma R_j / k$$

where k is the number of subgroups or samples as before.

From these equations, a control chart can be constructed which yields a significant amount of information about the process under investigation.

Given earlier discussions, we can expect the process to be normally distributed, or nearly so, if the driving causes of variation are common. The distribution of sample sizes themselves are also expected to be normal even if small sample sizes (2 through 5) are used.

One of the functions of using the mean chart is to detect a change in the production or service process mean. The use of a chart for this purpose is basically a hypothesis test. Meek, Taylor, Dunning and Klafehn [1987] describe in clear terms the purpose of variable control charts which is summarized in the following paragraphs. If a sample value is drawn from a process operation such that its mean is larger or smaller than the overall process mean, then it is likely that the process mean has changed position. When we conclude that the process mean has shifted, which actually has not, we are making what is called a Type I error. Alternatively, when we conclude that the process mean has not shifted, when in fact it has, we are making what is called a Type II error. Usually, the calculated control limits are set at plus or minus three standard deviations (3s) from the mean to limit the chance of making a Type I error. From a table of standard normal distribution Z-scores, we can ascertain that the probability that process mean has shifted when in actuality it has not, is 0.003 (3 standard deviations). Figure 10 illustrates these

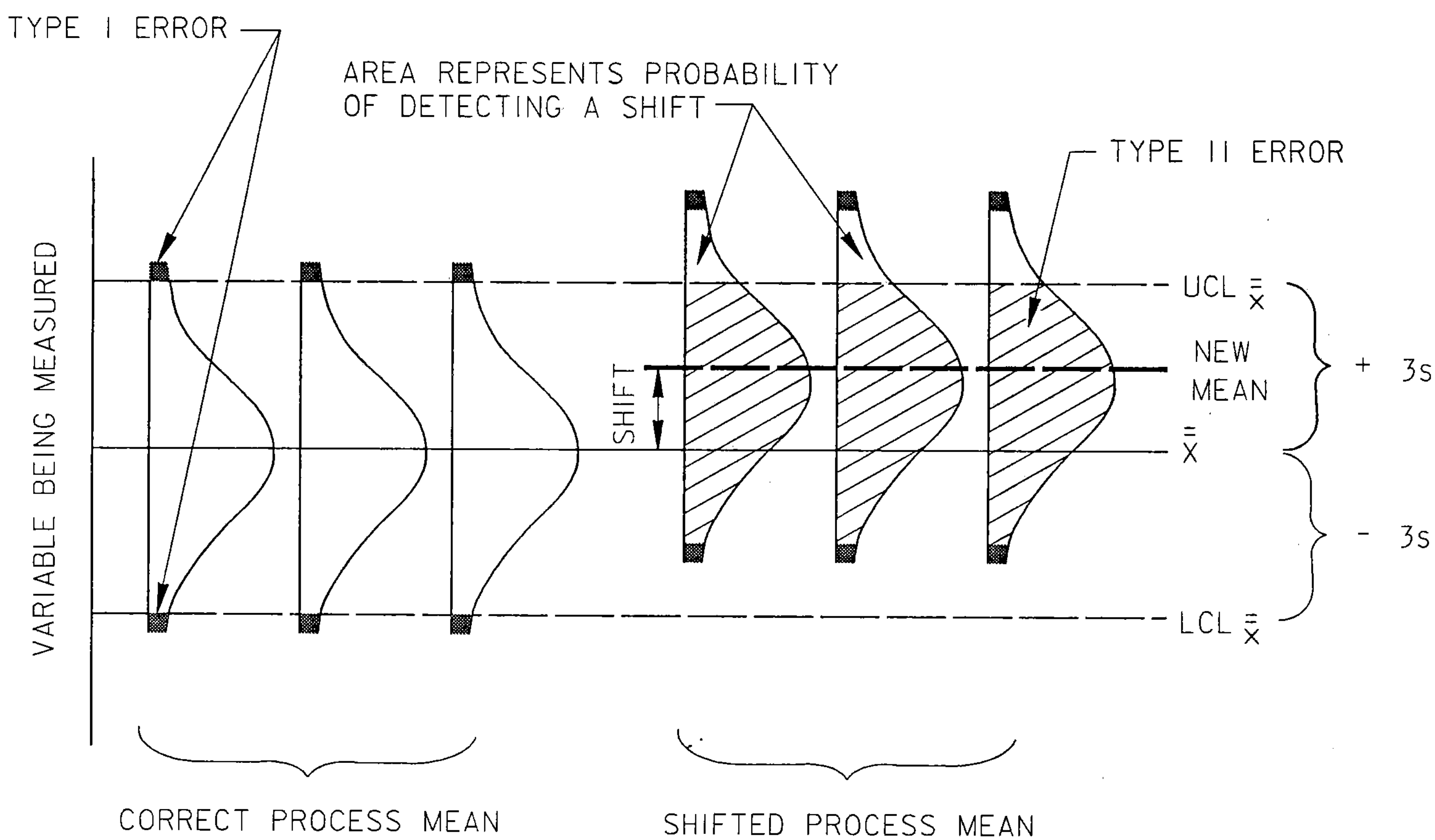

Figure 10
Example of Shift in Process Mean

principles. Three standard deviations are used because studies have shown that this criteria is the most economically efficient standard to use when testing Type I and Type II errors [Shewhart, 1986].

It is the conclusions of hypothesis testing that determines the three standard deviation control limits (3s). Studies conducted in the past have demonstrated that these limits are the most economically efficient criteria when balancing the cost and benefits of detection and problem identification against the consequences of eliminating a special cause.

1. Basic Equations

We can look at quality control from the confidence interval for $\bar{X}$. The upper and lower control limits are positioned at a distance of three standard deviations from the average sample mean by the expression [Meek, et al, 1986]:

Equation (11)

$$UCL_{\bar{X}} = \bar{\bar{x}} - A_2\bar{R}$$

Averages (X bar chart)

Equation (12)

$$LCL_{\bar{X}} = \bar{\bar{x}} - A_2\bar{R}$$

where UCL_X and LCL_X are the upper and lower control chart limits, $\bar{X}$ is the process mean A_2 is a sample size adjustment factor and $\bar{R}$ is the mean process range, and:

Equation (13)

$$UCL_{\bar{R}} = D_4\bar{R}$$

Ranges (for R charts)

Equation (14)

$$LCL_{\bar{R}} = D_3\bar{R}$$

where $UCL_{\bar{R}}$ and $LCL_{\bar{R}}$ are the upper and lower control chart limits, $\bar{R}$ is the mean process range, and D_3 and D_4 are sample size adjustment factors. Table 15 shows the value needed for sample size adjustment multipliers.

The range chart R is used in conjunction with an $\bar{X}$ chart to audit the variability process. Variability changes are just as undesirable as changes in the process mean. The range chart is not only used to audit process fluctuation but aids in identifying ways to decrease process variability. One of the functions of statistical process control is to reduce the variation around the desired or target process mean.

An interesting spinoff use for control charts aside from monitoring shifts in process mean and in process fluctuations is the diagnosis of cause and effect. Charting aids in detecting a problem and a long with other business monitoring tools, can go along way in specifying cause and effects relationships. Simply put, more is learned about the process.

Figure 11 illustrates the setup needed to analyze the behavior of the process mean and examine range activity.

2. Rational Subgroup Selection

The choice as to how many values make up a subgroup is as much an art as a science. Generally this choice is dependent upon the behavior of the phenomenon being chartered [AT&T, 1958]. If the raw data appears to fluctuate widely, one would want to choose a subgroup size around 4 or 5 to

TABLE 15
ADJUSTMENT FACTORS 1/

Subgroup Size	A_2	D_2	D_3	D_4
2	1.88	1.13	*	3.27
3	1.02	1.69	*	2.57
4	0.73	2.06	*	2.28
5	0.58	2.33	*	2.11
6	0.48	2.53	*	2.00
7	0.42	2.20	0.08	1.92
8	0.37	2.85	0.14	1.86
9	0.34	2.97	0.18	1.82
10	0.31	3.08	0.22	1.78

1/ Wayne W. Daniel and James C. Terrell., Business Statistics For Management And Economics, 5th ed. Boston: Houghton and Mifflin. 1989.

help moderate the fluctuations. If the fluctuations appear dampened already, then a subgroup size of 2 or 3 may be more suitable. You do not want too large of a subgroup size as this would tend to disguise the magnitude of fluctuations to the point of hiding special causes. Alternatively, a sample size too small may lead to many things looking like special causes. Rational subgroups are usually chosen to make the variation within each subgroup as small as possible for the process (representing the variation from common causes) and so that any shifts in the process performance (i.e., special causes) can emerge as differences between subgroups [Shewhart, 1986]. There are rules of thumb for selecting subgroups.

They include:

- ❑ A subgroup should be selected in such a way as to allow for opportunities in variations to show up. Consequently subgroup size should be small (2 to 5 measurements is suitable).

- ❑ Subgroup size must remain constant for all subgroups.

- ❑ Should be taken (sampled) frequently enough to show variations in the process under investigation - give the process time to show change - fluctuations.

- ❑ The number of subgroups must be sufficient to allow process variation to show-up. From a statistical point, 25 or more subgroups containing about 100 or more measurements give a good test for stability and show variance.

Recall what was discussed earlier in the text, that the samples of 2-5 are used to find a mean ($\bar{X}$). These subgroup means are then used to find the mean of the means ($\bar{\bar{x}}$). The mean of the sampling distribution of means is equal to the population mean. We also find the mean of the ranges $\bar{R}$ (which is our substitute for the standard deviation) approximates the mean of the population range distribution.

An example of how to develop a control chart will aid considerably in understanding what has been introduced earlier. Table 5 has been reconstructed as Table 16 for the purposes of control chart development. Column (1) shows a subgroup number. Each subgroup number consists of three sequential numbers from Table 5 as shown in Column (2). The numbers in Column (2) represent the values used to form that particular subgroup. In this case the subgroup size is three numbers. Remember a subgroup can consist of between 2 and 5 numbers. Remember also a subgroup serves two purposes; one is to dampen oscillation and the other is to serve as a "sample" of a larger set of data. Column (3) represents the sum of the values in each group. The values in parenthesis in Column (4) are rounded numbers. As can be seen at the bottom of Column (4), $\bar{\bar{x}}$ (see equation 9) is calculated as 95.9 days; this is the mean of the means. Column (5) shows the range R of each subgroup. As before the range is the difference between the highest and lowest value in a group. The mean of the ranges ($\bar{R}$) is calculated as 17.9.

The data in Table 16 is transferred to Figure 12. Figure 12 is a standard form constructed for the purpose of graphing a control chart and showing all the information pertinent to the development of the chart. It is a complete record in-and-of itself. Note that the data is located in the bottom left of the chart. The raw data are shown, the mean $\bar{X}$ of each subgroup is presented and the range R within each subgroup is also shown.

Figure 13 shows a Scatter Diagram of both the mean day completion values ($\bar{X}$) and range values. Note the scattering of data points. Under "NOTES" we show the basic calculations for finding $\bar{\bar{x}}$ and $\bar{R}$ as per equations 8 and 9. Figure 14 shows a Run Chart which is nothing more than a Scatter Diagram with the points connected. The fluctuations in report completion times becomes apparent. These fluctuations are the ones discussed earlier and consist of special and common cause forces at work in the system. They show the process is producing variation in report output times in terms of mean completion times ($\bar{\bar{x}}$) and in the range ($\bar{R}$) of completion times.

Figure 15 shows the placement of process mean report completion time ($\bar{\bar{x}}$) and mean range fluctuation ($\bar{R}$). It is now possible to compare movement, variances, or fluctuations on the basis of a frame of reference.

Figure 16 is the grand finale. Using Equations 11 through 14 we have calculated the lower and upper control limits for the process mean $\bar{\bar{x}}$, and the mean process range $\bar{R}$. The equations are repeated below with values inserted so that the reader can trace how the graphed data were calculated. The equations are:

The location of the Process Mean $\bar{\bar{x}}$

$UCL = \bar{\bar{x}} + A_2\bar{R}$	$LCL = \bar{\bar{x}} - A_2\bar{R}$
$= 95.9 + (1.02)(17.9)$	$= 95.9 - (1.02)(17.9)$
$= 114.2$	$= 77.6$

The location of the Process Range $\bar{R}$

$UCL = D_4\bar{R}$	$LCL = D_3\bar{R}$
$= (2.57)(17.9)$	$= 0(17.9)$
$= 46$	$= 0$

TABLE 16
ANALYSIS OF SUBGROUP DATA

(1) Subgroup Number	(2) Values Used In Subgroup (No. of days)	(3) Sum of Subgroup (No. of days) $\bar{\bar{x}}$	(4) Mean of Subgroup	(5) Range of the Subgroup (R)
1	60+71+81	212	70.7 (71)	21
2	130+81+77	288	96.0 (96)	53
3	81+90+101	272	90.7 (91)	20
4	90+103+110	303	101.0 (101)	13
5	107+103+78	288	96.0 (96)	29
6	100+90+90	280	93.3 (93)	10
7	109+110+120	339	113.0 (113)	11
8	108+90+111	309	103.0 (103)	21
9	118+91+91	300	100.0 (100)	28
10	93+94+95	282	94.0 (94)	2
11	99+99+98	296	98.7 (99)	1
12	97+92+100	289	96.3 (96)	8
13	100+91+92	283	94.3 (94)	9
			13 | 1247.2	| 233
			$\bar{\bar{x}}$ = 95.9	$\bar{R}$ = 17.9

SHEWHART CONTROL CHART

PROJECT NAME: ANALYSIS OF PERMIT REPORT COMPLETION TIME
DIVISION: CONSTRUCTION/OPERATIONS
BRANCH: CO-R
SECTION: CO-RR

DATE: 10 JUNE 1993

COMMENTS: USE $\bar{X}$ AND $\bar{R}$ CHARTS TO EVALUATE PROCESS CAPABILITY [SUBGROUP SIZE = 3]

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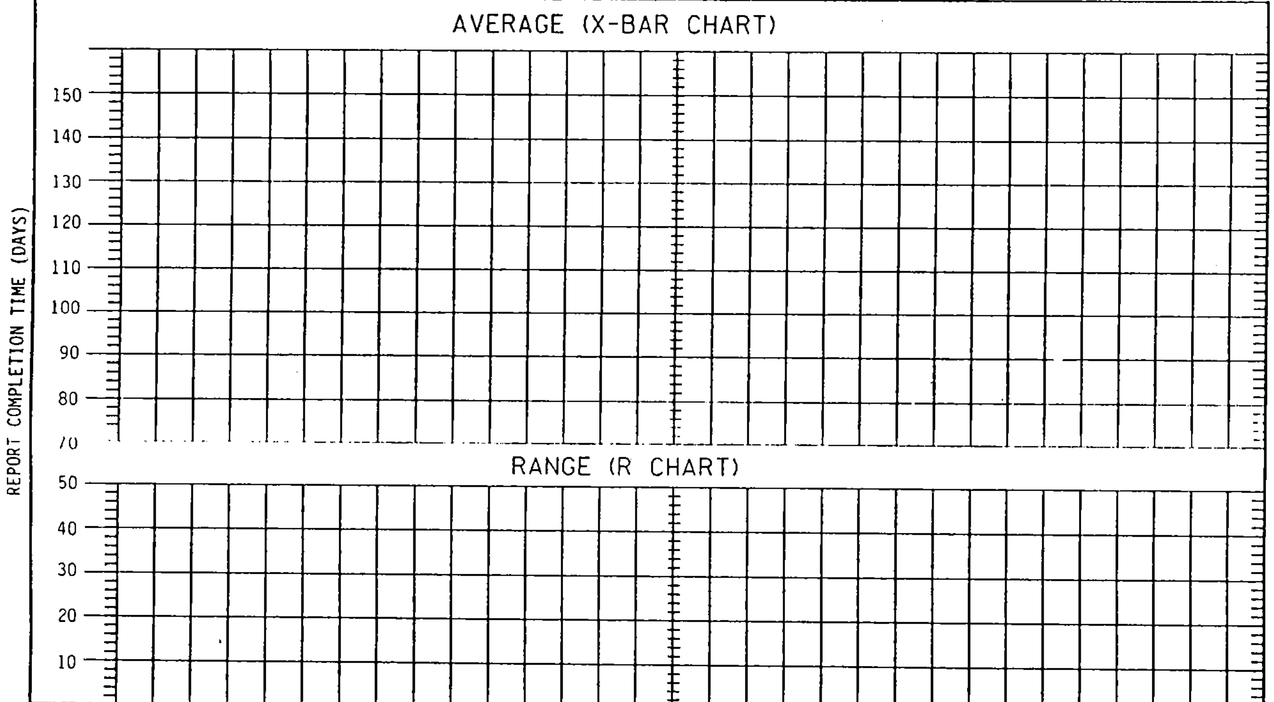
RECORDING RAW DATA



DATE / DAY	1	2	3	4	5	6	7	8	9	10	11	12	13
ATTRIBUTE 1	60	130	81	90	107	100	109	108	118	93	99	97	100
2	71	81	90	103	103	90	110	90	91	94	99	92	91
3	81	77	101	110	78	90	120	111	91	95	98	100	92
4	--	--	--	--	--	--	--	--	--	--	--	--	--
5	--	--	--	--	--	--	--	--	--	--	--	--	--
SUM	212	288	272	303	288	280	339	309	300	282	296	289	283
X-BAR	71	96	91	101	96	93	113	103	100	94	99	96	94
RANGE	21	53	20	20	29	10	11	21	27	2	1	8	9

STEPS 1 AND 2

$\bar{\bar{X}} = \sum \bar{X}/N = 1247/13 = 95.9$

$\bar{R} = \sum R/N = 232/13 = 17.9$

TABLE OF X AND R CONTROL FACTORS

SUBGROUP SAMPLE SIZE (n)	X CHART FACTORS FOR CONTROL LIMITS (A_2)	R CHART FACTORS FOR CONTROL LIMITS (D_3)	(D_4)
2	1.88	0	3.27
3	1.02	0	2.57
4	.73	0	2.28
5	.58	0	2.11
6	.48	0	2.00
7	.42	.08	1.92
8	.37	.14	1.86
9	.34	.18	1.82
10	.31	.22	1.78

NOTES

Figure 12
Control Chart - Recording Raw Data

SHEWHART CONTROL CHART

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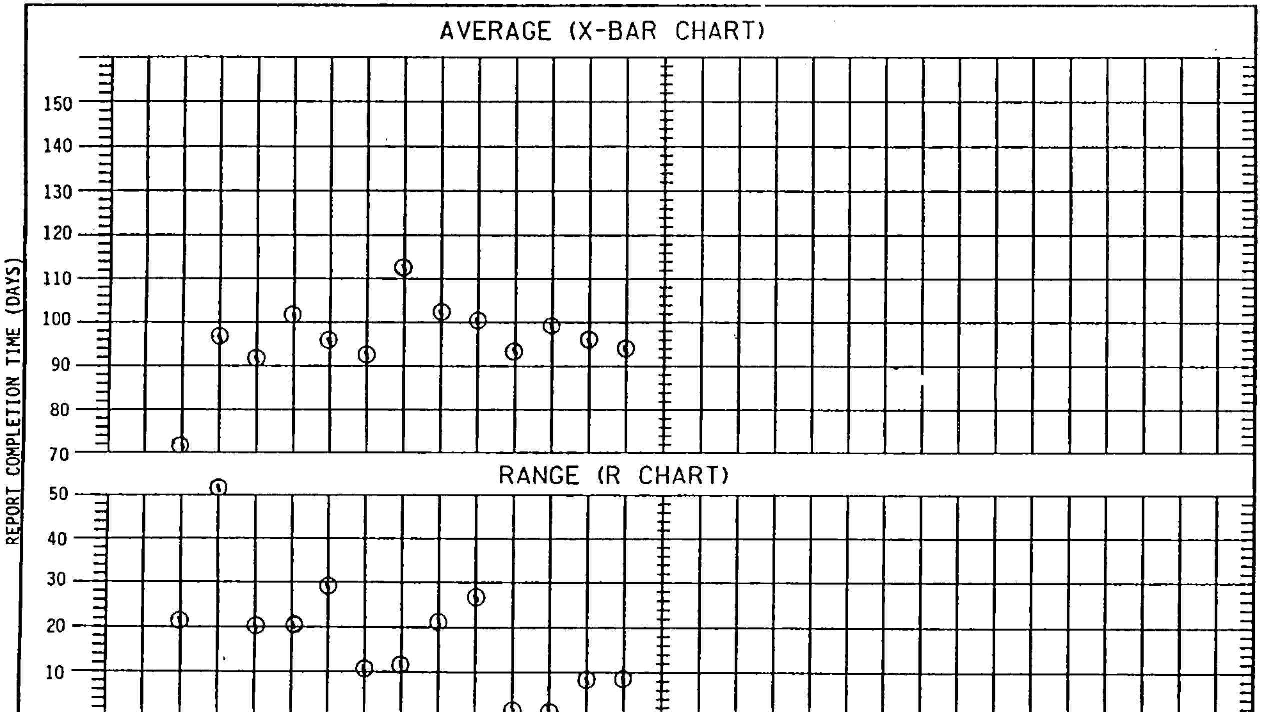
Team Galveston

PROJECT NAME: ANALYSIS OF PERMIT REPORT COMPLETION TIME   DATE: 10 JUNE 1993
DIVISION: CONSTRUCTION/OPERATIONS
BRANCH: CO-R
SECTION: CO-RR

COMMENTS: USE $\bar{X}$ AND $\bar{R}$ CHARTS TO EVALUATE PROCESS CAPABILITY (SUBGROUP SIZE = 3)

SCATTER PLOT



DATE / DAY	1	2	3	4	5	6	7	8	9	10	11	12	13
ATTRIBUTE 1	60	130	81	90	107	100	109	108	118	93	99	97	100
ATTRIBUTE 2	71	81	90	103	103	90	110	90	91	94	99	92	91
ATTRIBUTE 3	81	77	101	110	78	90	120	111	91	95	98	100	92
ATTRIBUTE 4	--	--	--	--	--	--	--	--	--	--	--	--	--
ATTRIBUTE 5	--	--	--	--	--	--	--	--	--	--	--	--	--
SUM	212	288	272	303	288	280	339	309	300	282	296	289	283
X-BAR	71	96	91	101	96	93	113	103	100	94	99	96	94
RANGE	21	53	20	20	29	10	11	21	27	2	1	8	*9

STEPS 1 AND 2

$\bar{\bar{X}} = \sum \bar{X}/N = 1247/13 = 95.9$

$\bar{R} = \sum R/N = 232/13 = 17.9$

TABLE OF X AND R CONTROL FACTORS

SUBGROUP SAMPLE SIZE (n)	X CHART FACTORS FOR CONTROL LIMITS (A_2)	R CHART FACTORS FOR CONTROL LIMITS (D_3)	(D_4)
2	1.88	0	3.27
3	1.02	0	2.57
4	.73	0	2.28
5	.58	0	2.11
6	.48	0	2.00
7	.42	.08	1.92
8	.37	.14	1.86
9	.34	.18	1.82
10	.31	.22	1.78

NOTES

Figure 13
Control Chart - Scatter Plot

SHEWHART CONTROL CHART

PROJECT NAME: ANALYSIS OF PERMIT REPORT COMPLETION TIME
DIVISION: CONSTRUCTION/OPERATIONS
BRANCH: CO-R
SECTION: CO-RR

DATE: 10 JUNE 1993

COMMENTS: USE $\bar{X}$ AND $\bar{R}$ CHARTS TO EVALUATE PROCESS CAPABILITY [SUBGROUP SIZE = 3]

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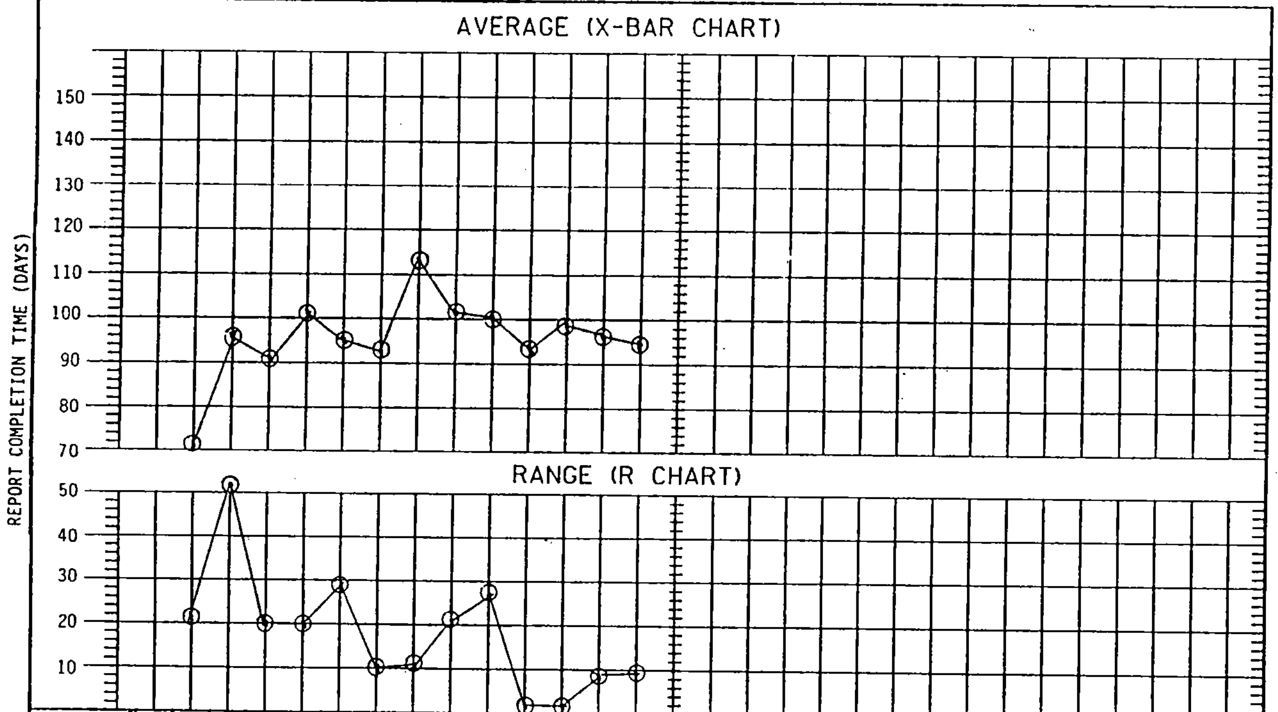
RUN CHART



DATE / DAY	1	2	3	4	5	6	7	8	9	10	11	12	13
ATTRIBUTE 1	60	130	81	90	107	100	109	108	118	93	99	97	100
2	71	81	90	103	103	90	110	90	91	94	99	92	91
3	81	77	101	110	78	90	120	111	91	95	98	100	92
4	--	--	--	--	--	--	--	--	--	--	--	--	--
5	--	--	--	--	--	--	--	--	--	--	--	--	--
SUM	212	288	272	303	288	280	339	309	300	282	296	289	283
X-BAR	71	96	91	101	96	93	113	103	100	94	99	96	94
RANGE	21	53	20	20	29	10	11	21	27	2	1	8	9

STEPS 1 AND 2

$\bar{\bar{x}} = \sum \bar{X}/N = 1247/13 = 95.9$

$\bar{R} = \sum \bar{R}/N = 232/13 = 17.9$

TABLE OF X AND R CONTROL FACTORS

SUBGROUP SAMPLE SIZE (n)	X CHART FACTORS FOR CONTROL LIMITS (A_2)	R CHART FACTORS FOR CONTROL LIMITS (D_3)	(D_4)
2	1.88	0	3.27
3	1.02	0	2.57
4	.73	0	2.28
5	.58	0	2.11
6	.48	0	2.00
7	.42	.08	1.92
8	.37	.14	1.86
9	.34	.18	1.82
10	.31	.22	1.78

NOTES

Figure 14
Control Chart - Run Chart

SHEWHART CONTROL CHART

PROJECT NAME: ANALYSIS OF PERMIT REPORT COMPLETION TIME
DIVISION: CONSTRUCTION/OPERATIONS
BRANCH: CO-R
SECTION: CO-RR

DATE: 10 JUNE 1993

COMMENTS: USE $\bar{\bar{X}}$ AND $\bar{R}$ CHARTS TO EVALUATE PROCESS CAPABILITY [SUBGROUP SIZE = 3]

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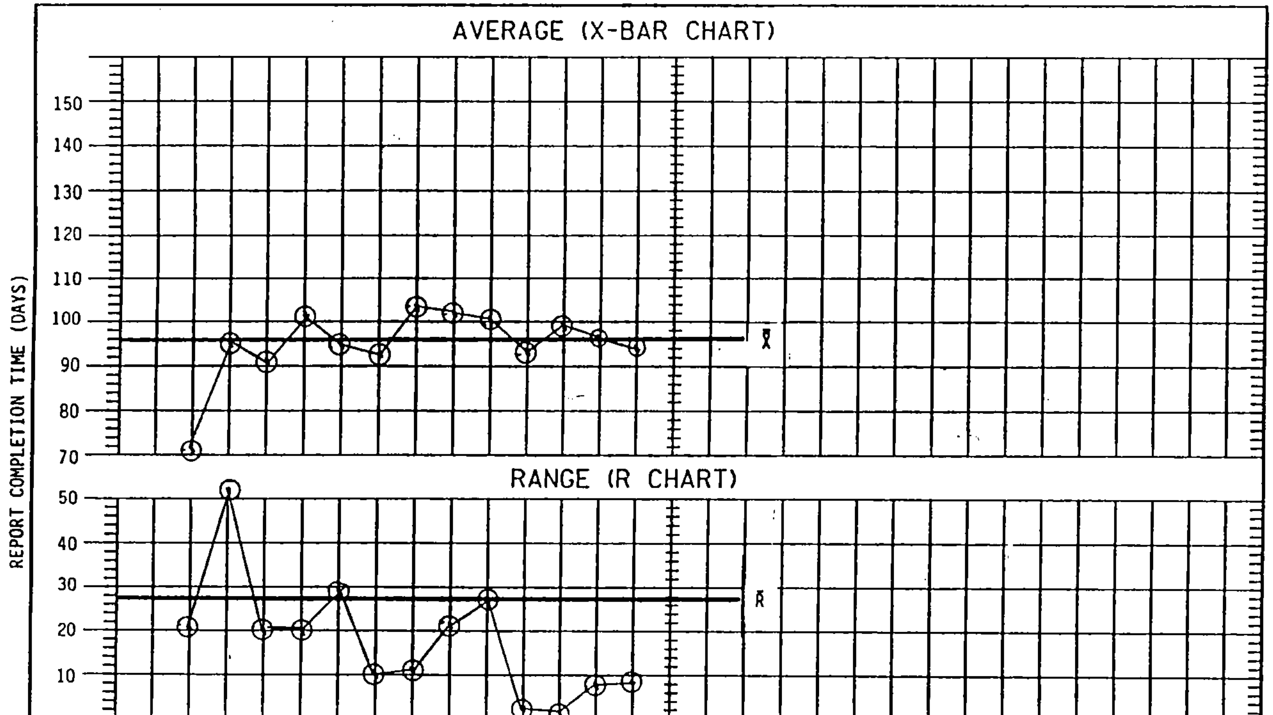
PLOTTING MEAN



DATE / DAY	1	2	3	4	5	6	7	8	9	10	11	12	13
ATTRIBUTE 1	60	130	81	90	107	100	109	108	118	93	99	97	100
2	71	81	90	103	103	90	110	90	91	94	99	92	91
3	81	77	101	110	78	90	120	111	91	95	98	100	92
4	--	--	--	--	--	--	--	--	--	--	--	--	--
5	--	--	--	--	--	--	--	--	--	--	--	--	--
SUM	212	288	272	303	288	280	339	309	300	282	296	289	283
X-BAR	71	96	91	101	96	93	113	103	100	94	99	96	94
RANGE	21	53	20	20	29	10	11	21	27	2	1	8	9

STEPS 1 AND 2

$\bar{\bar{X}} = \sum \bar{X}/N = 1247/13 = 95.9$

$\bar{R} = \sum R/N = 232/13 = 17.9$

TABLE OF X AND R CONTROL FACTORS

SUBGROUP SAMPLE SIZE (n)	X CHART FACTORS FOR CONTROL LIMITS (A_2)	R CHART FACTORS FOR CONTROL LIMITS (D_3)	(D_4)
2	1.88	0	3.27
3	1.02	0	2.57
4	.73	0	2.28
5	.58	0	2.11
6	.48	0	2.00
7	.42	.08	1.92
8	.37	.14	1.86
9	.34	.18	1.82
10	.31	.22	1.78

NOTES

Figure 15
Control Chart - Plotting Mean

SHEWHART CONTROL CHART

PROJECT NAME: ANALYSIS OF PERMIT REPORT COMPLETION TIME
DATE: 10 JUNE 1993
COMMENTS: USE $\bar{X}$ AND $\bar{R}$ CHARTS TO EVALUATE PROCESS CAPABILITY (SUBGROUP SIZE = 3)
DIVISION: CONSTRUCTION/OPERATIONS
BRANCH: CO-R
SECTION: CO-RR

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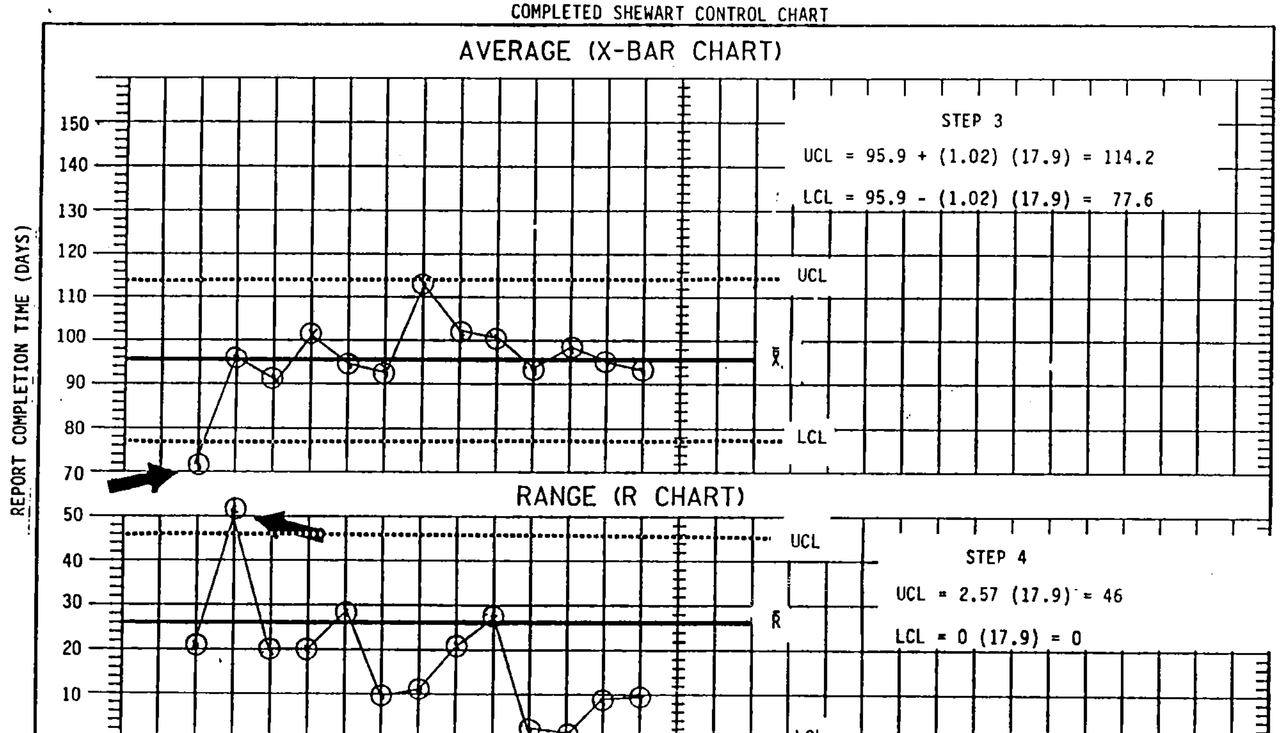
COMPLETED SHEWHART CONTROL CHART



DATE / DAY	1	2	3	4	5	6	7	8	9	10	11	12	13
ATTRIBUTE 1	60	130	81	90	107	100	109	108	118	93	99	97	100
2	71	81	90	103	103	90	110	90	91	94	99	92	91
3	81	77	101	110	78	90	120	111	91	95	98	100	92
4	--	--	--	--	--	--	--	--	--	--	--	--	--
5	--	--	--	--	--	--	--	--	--	--	--	--	--
SUM	212	288	272	303	288	280	339	309	300	282	296	289	283
X-BAR	71	96	91	101	96	93	113	103	100	94	99	96	94
RANGE	21	53	20	20	29	10	11	21	27	2	1	8	9

STEPS 1 AND 2

$\bar{\bar{X}} = \sum \bar{X}/N = 1247/13 = 95.9$

$\bar{R} = \sum R/N = 232/13 = 17.9$

TABLE OF X AND R CONTROL FACTORS

SUBGROUP SAMPLE SIZE (n)	X CHART FACTORS FOR CONTROL LIMITS (A_2)	R CHART FACTORS FOR CONTROL LIMITS (D_3)	(D_4)
2	1.88	0	3.27
3	1.02	0	2.57
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7	.42	.08	1.92
8	.37	.14	1.86
9	.34	.18	1.82
10	.31	.22	1.78

NOTES

Figure 16
Completed Shewhart Control Chart

Note the sample size adjustment factors are on the figures in the small box located in the upper right hand side of the graphs.

Observe that the points located outside the 3 standard deviation limits are denoted by the darkened arrows. These points represent an out of control event or process; they are special cause induced. The special causes are two independent events as indicated by their different subset spawning. Something caused the mean value to fluctuate so widely that the process mean at that point shifted by more than 3 standard deviations from the process mean $\bar{\bar{x}}$. Similarly, something in the range detection indicated that a special force caused the range to widen well beyond the normal process range; i.e., past 3 standard deviations. All other fluctuations stay within a 3 standard deviation criteria.

It should be noted that the shift in the $\bar{\bar{x}}$ for the special cause is a desirable one; the cause should be found because this point indicates a movement in the direction of decreasing report time completion. If the point had moved in the other direction, say to 130, the cause needs to be determined because this tended to move completion times upward - an undesirable affect.

The shift noted in the R chart is undesirable because whatever caused it may happen again resulting in adverse fluctuation (a wider spread) in the range of the production process.

1. Deciphering The Magic Behind The $\bar{X}$ And R Charts

In essence, there are two out of control, special cause related conditions. One is when $\bar{X}$ and R data fall outside their respective statistical limits of 3 standard deviations. The second occurs when a pattern emerges with data points within the 3 standard deviation limits, but data within the common cause range form a nonrandom scatter configuration. The basic types of special cause patterns are listed in Table 17 [AT&T, 1958]. Figure 17 illustrates what each special cause might look like if plotted on a graph. Note that these patterns detect a problem; it takes other tools (Pareto charts, cause-and-effect charts, etc.) to isolate and identify the problem. More will be said on these tools later. Each graph applies to both the $\bar{X}$ and R charts.

Figure 17A has been the major topic of concern covered in previous sections. Extreme events occurring during a production process (products or services) have resulted in special cause events, meaning the process is out of control. Two out of 17 points have exceeded the 3 standard deviation limit; one above the threshold and one below. This is an unstable process. The causes need to be determined and eliminated to bring the process into balance or into stability. The cause of such an event could be one or multiple and would depend upon what specific process is being investigated. There is a strong chance that it is a localized or work environment related problem and not a common cause.

Figure 17B represents an out of control condition which forms a trend line. This is an out of control process because the data points form a trend which is a pattern that is not random. By definition, a pattern is not random. Since the line is sloped upward, something in the process is getting worse over time. This could be due to a piece of equipment gradually wearing out resulting in the production of a poorer

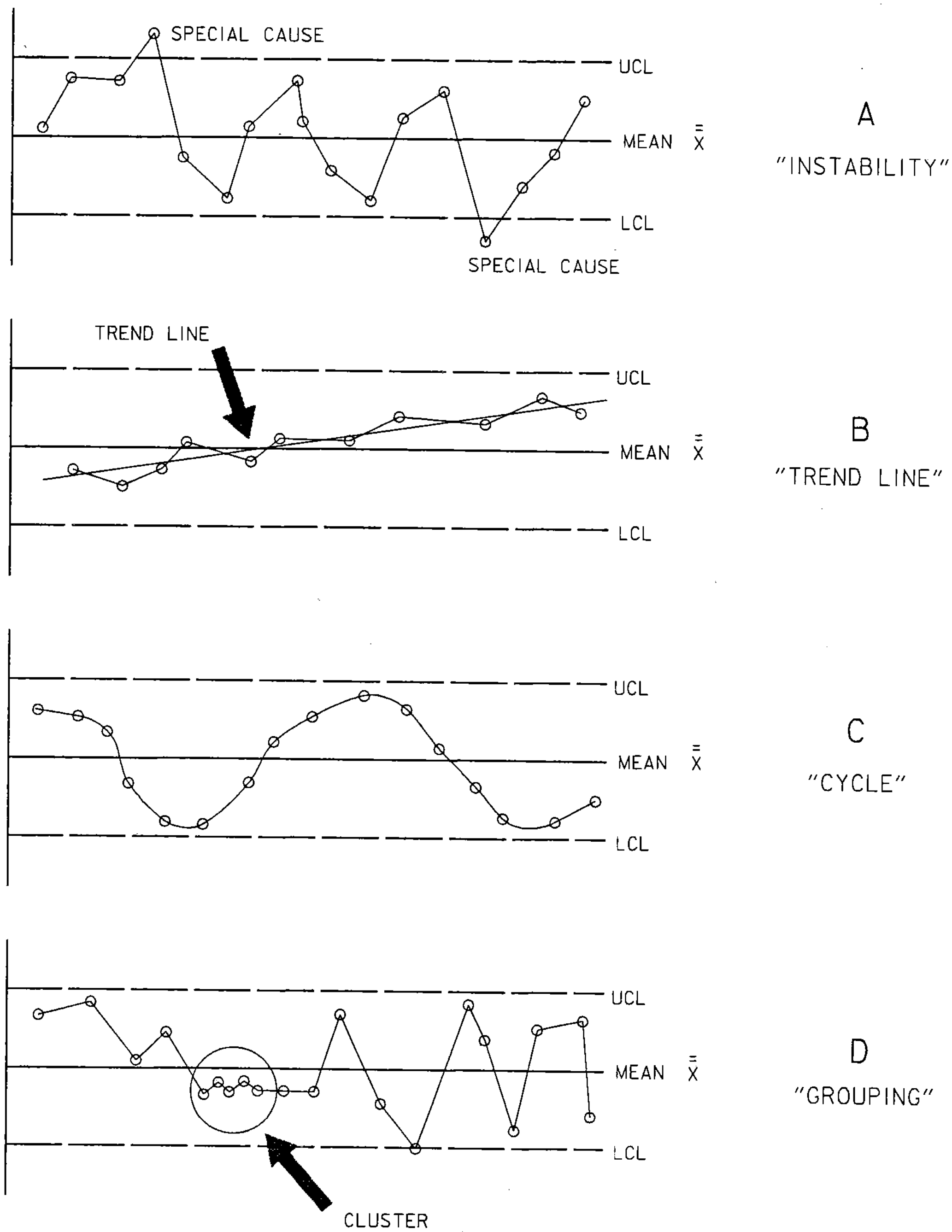


Figure 17
Out of Control Patterns for
X and R Charts

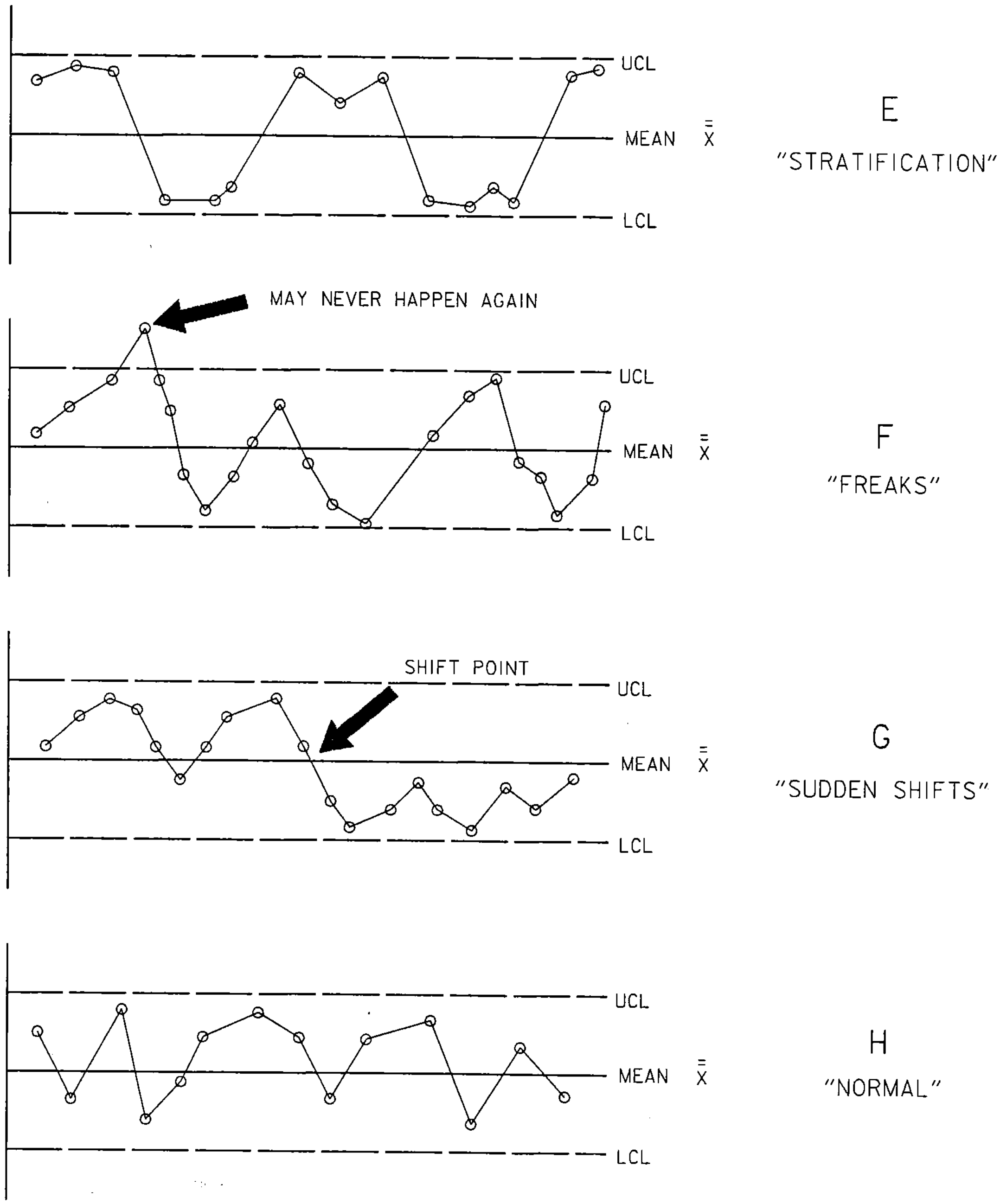


Figure 17
Out of Control Patterns (con't)

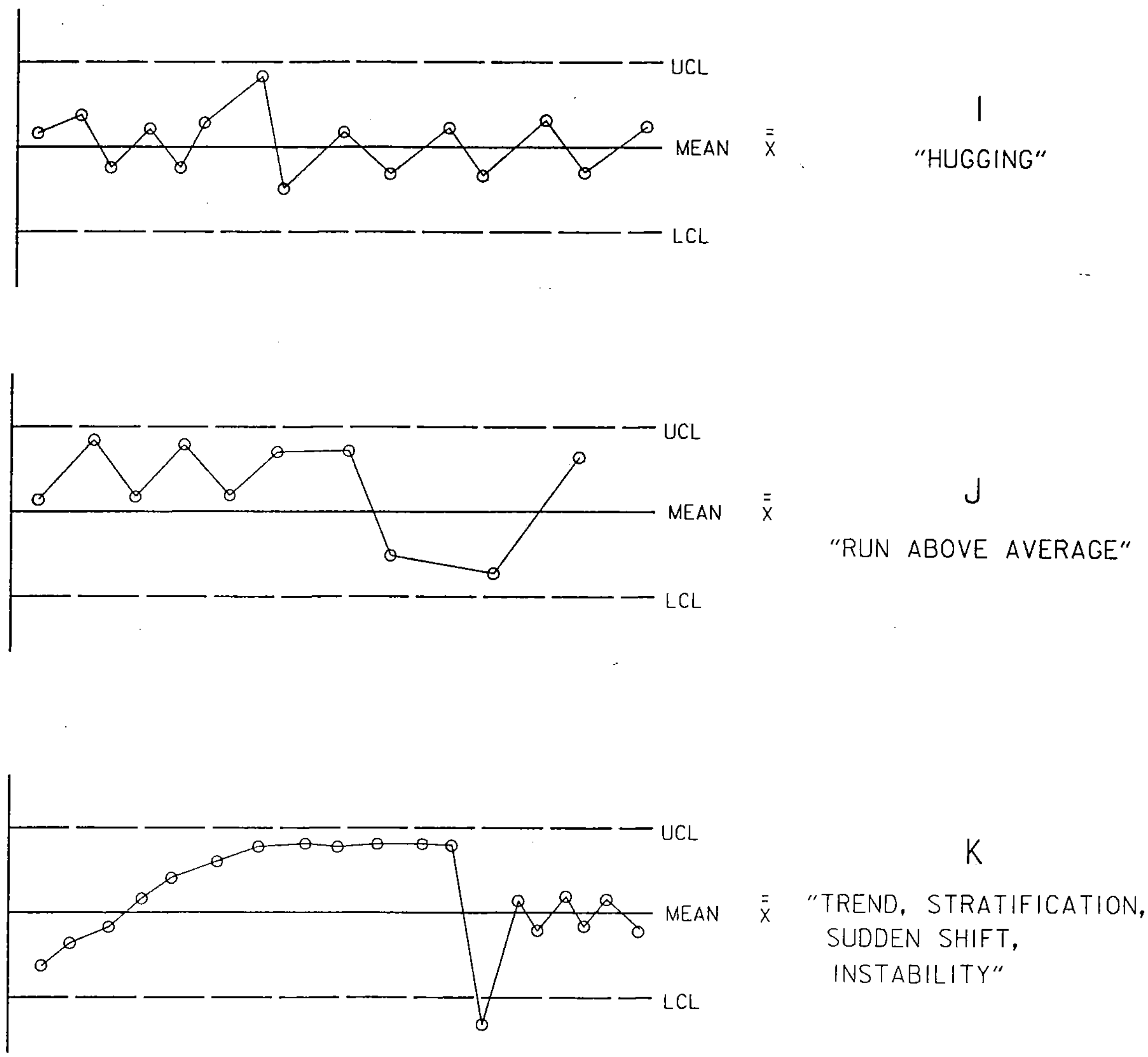


Figure 17
Out of Control Patterns (con't)

TABLE 17 TYPES OF OUT OF CONTROL OR SPECIAL CAUSE PATTERNS [1/]	
Instability	Freaks
Trends	Sudden Shifts
Cycles	Gradual Shifts
Grouping	Hugging
Stratification	Special Runs

1/ AT&T, Statistical Quality Control Handbook. (Indiana - AT&T Technologies, Inc. 2nd ed. 1958)

quality product. It could also represent poorer quality reports being produced by an employee whose work load has substantially increased or who has been given assignments which frequently change priority, both resulting in less time to do quality work. Again, the cause will be dependent upon what is being produced and what is being measured. There is no cookbook answer. A scatter plot, Pareto chart, flow chart or cause-and-effect diagram is needed to isolate the exact cause and effect relationship. Downward sloping trends also represent a condition of special causes. Note the trends in the $\bar{X}$ and R charts in Figure 16. We have identified another out of control problem.

Figure 17C shows an out of control process called a cycle. Again a pattern is formed which is not indicative of randomness. A situation like this could be caused by a budget cycle or simultaneous scheduling. Both of these occur when for example, a host of new project starts are all funded during the same timeframe and are expected to follow the same processes of intermediate reviews (IRC's, IPR's, etc.) and be completed at approximately the same time. This causes the "boom" and "bust" cycles illustrated in the graph. It could also be caused by contracting or inventory cycles. Despite the fact that all plotted points are within control limits, observation of such a pattern depict nonrandom, situations which are deleterious to the production process via the non uniformity and low quality which is often the byproduct.

Grouping is illustrated in Figure 17D. It, too constitutes an out of control production process. Once again the randomness criteria is broken. Grouping can be caused by temporary overcontrol by an individual with specific criteria. It may also emanate from over control by influential groups who have a specific target in mind such as in management by objective (MBO). The result is classified as a special cause. Micro management is often a culprit as well.

Stratification is shown in Figure 17E. It is exemplified by product and service outputs that take place at extremes; as shown, they cling to the upper and lower control limits. Stratification can occur due to rapidly changing priorities, changes in guidance, and as part of a moral issue, among others. Whatever the cause, there is a pattern not in line with common cause variation.

"Freaks" are nothing more than highly unusual events which have an extremely rare event occurrence. Such a case is shown in Figure 17F. This type of event is typified by a "bad day" or a "Peter Principle" happening. For example, ninety percent of an offices' computer are fraught with a virus on a day when a congressman needs some report coupled with an office flu taking out a third of the staff, garnished with five new flash fires and a discovery that some vital information needed that day was incorrect. There are plenty of reasons for a setback in schedules. This is a Freak. It is random or highly unusual and may never happen again but is nonetheless an out of control situation by any definition.

Sudden shifts in the process is depicted in Figure 17G. A sudden shift is also not in line with randomness because the process mean or range has dramatically shifted from normal to abnormal or from one form of abnormal to another. These shifts can be explained by changes in training, shifting work from an inexperienced to an experienced worker or vise versa. Also, changes in guidance, management, and "flash fires" may also result in sudden shifts in process performance.

Figure 17H shows no abnormalities. There are no trends, freaks, stratifications, etc. It is a normal process governed by the randomness of common cause forces. It was placed here to contrast previous special cause patterns. This is what we want to observe in a production or service process. All causes are common causes. It shows all special causes have been eliminated leaving only common causes to tend with.

Hugging is a pattern depicted in Figure 17I. It occurs when the points "hug" the centerline or one of the control limits. This pattern is typical of micro management techniques where fear and tight control govern the process. It stems from perceived or real threats if production standards exceed the upper or lower control limits. This is not a random process.

Runs are patterns where plot points stay in one position or another for periods of time as in Figure 17J. Such a pattern usually underscores an attempt by someone to follow a service or production process which is not in line with an average system process. Other reasons exist for this pattern, but as before, it is not typical of a common cause circumstance.

Finally the reader needs to be cognizant of multiple, out of control processes as shown in Figure 17K. This figure shows the simultaneous problems of trends, runs, hugging, instability and sudden shifts. Many forces are at work producing an out of control process. Some of these forces blend, and subsequently even disguise others. They must be separated and eliminated from the process.

When all of the special cause factors have been eliminated (and only then) we are ready to contend with common causes. Remember, special cause are responsible for 15 percent of system process problems. The remaining 85 percent are common causes which are chiefly in the realm of management.

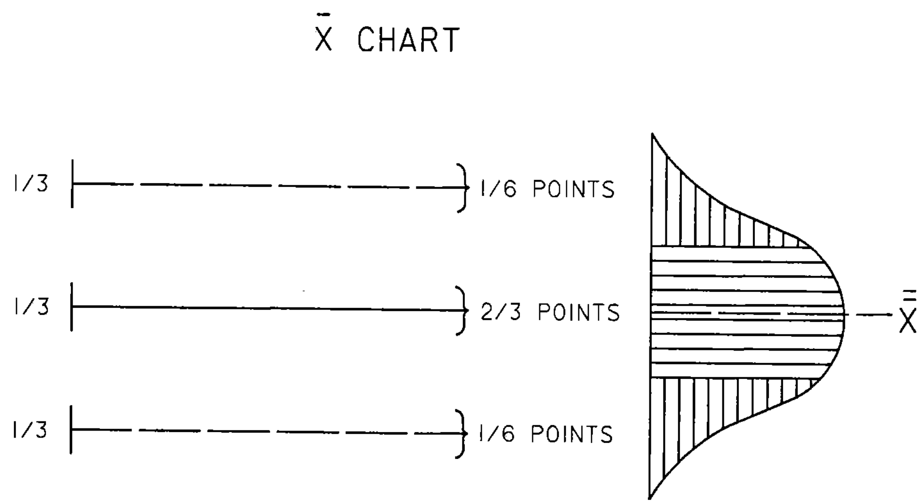
Previous material detailed a considerable amount of information concerning the structure and meaning of the $\bar{X}$ and R charts in monitoring product and service output quality and uniformity. There are a few simple rules and ideas which will allow for a relatively quick detection of problems as they appear in control charts. They include:

- ❑ A process is out of control if 7 points in a row fall below or above the center line ($\bar{X}$ or R).
- ❑ A process is out of control if 7 points in a row are each progressively lower or each progressively higher than the previous points.
- ❑ A process is out of control for any nonrandom process where it is easy to predict where the next point will be.
- ❑ A process is out of control where any nonrandom process is present.
- ❑ A process is out of control where any points lie outside control limits.

Figure 18 also brings to light a few concepts discussed in the text. Recall that about 68 percent of all data points must fall within one standard deviation of the mean for a process to be classified as normal. This is true for both $\bar{X}$ and R charts. Roughly translated, the middle third of a control chart frequency distribution should contain about 2/3 (67%) of all measurements and approximately 1/6 (16%) should fall into each remaining 1/3 tail of the curve. This rule of thumb helps guarantee normality and quickly identifies skewness in a process.

Figure 19 shows the pathway to continuous improvement in process capability. An explanation of the techniques starts with Period I where special causes are first discovered and then eliminated. These are identified by the arrows (instability condition and a trend; 7 points in a row) and can be assessed using Figure 17. Period II shows that all special causes have been identified and eliminated. Note that as we progressed from Period I to Period II, the variance of the system has decreased and the mean process declined from about 4.2 percent defects to about 2.2 percent defects. As common causes continue to be eliminated through action on the system, variance continues to decrease and the mean process defects continue to fall as exemplified by Period II. The manager or employee must continue to watch for new special causes even if the old system's special causes have been previously eliminated. The reason is that things change over time and new special causes not previously experienced may creep into the system.

An additional concept called a "breakthrough" [Turner, 1993], needs to be introduced. It is a single significant change or the sum of a number of incremental changes which cause a control chart to dramatically decline such as that shown in Figure 17K. A system or process discovery improvement may lead to such a change.



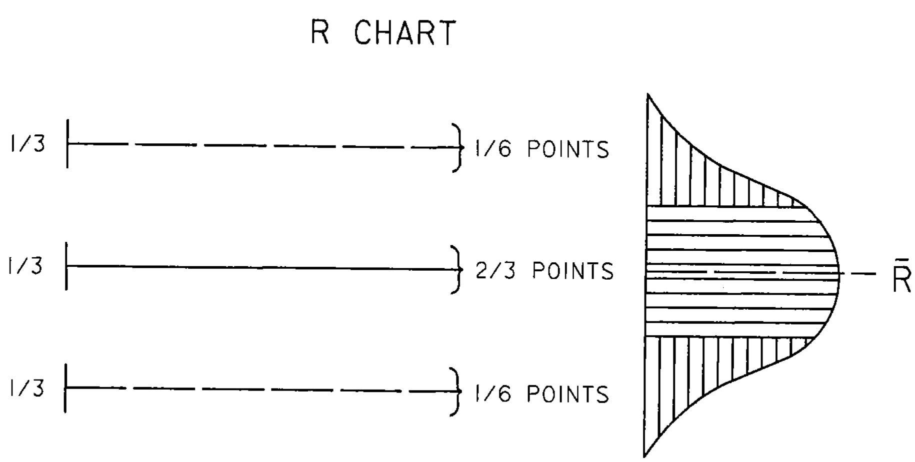


Figure 18
Symmetry in the Output Process

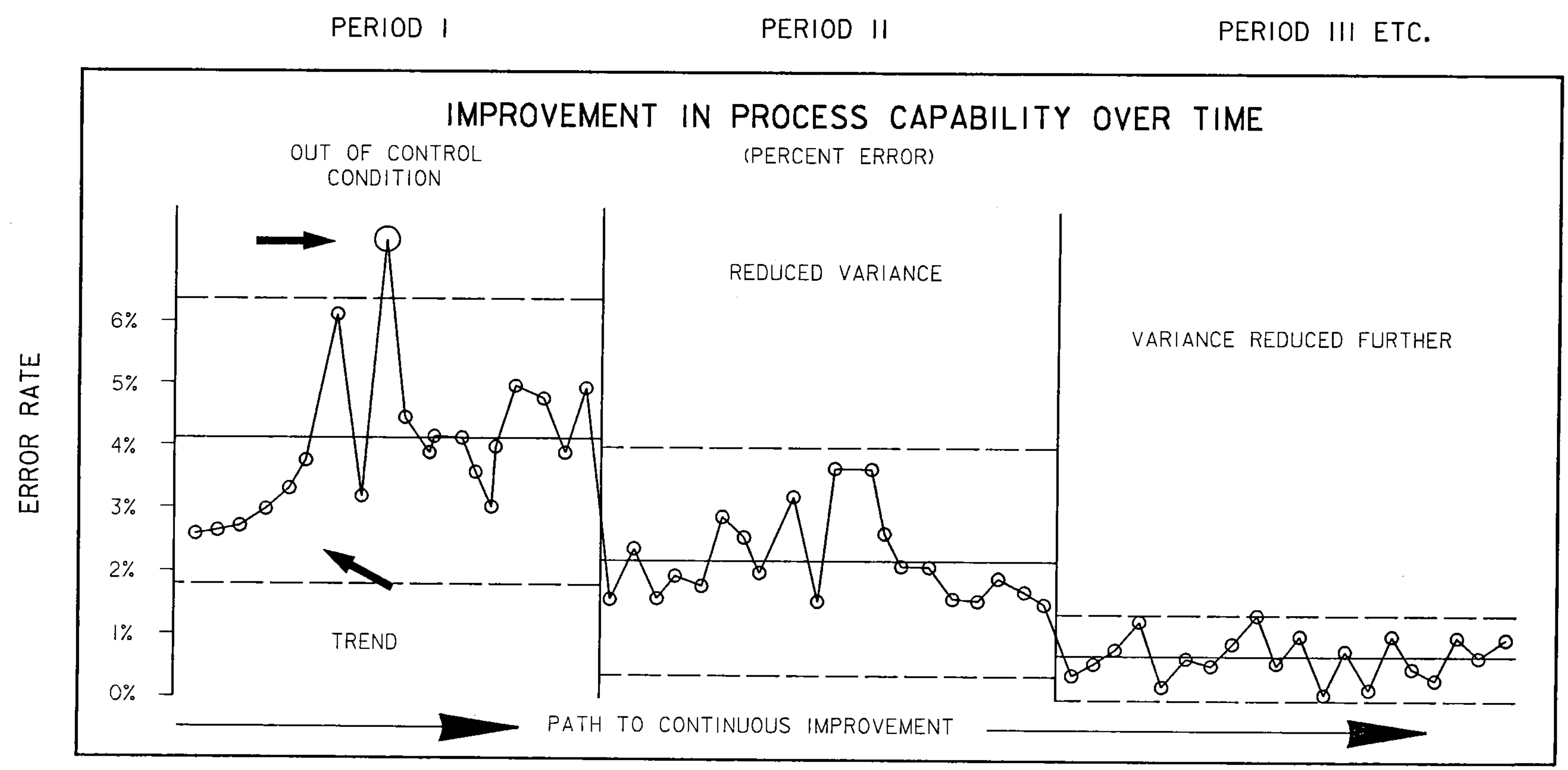


Figure 19
General Pattern of Progress,
Deming's "Consistency of Purpose"

SHEWHART CONTROL CHART

PROJECT NAME: UNSCHEDULED TASKS DATE: 28 FEB 93

DIVISION: PLANNING

BRANCH: ECONOMICS

SECTION: N/A

COMMENTS: CONTROL CHART OF THE AVERAGE NUMBER OF HOURS PER WEEK OFFICE SPENDS ON UNSCHEDULED WORK TASKS

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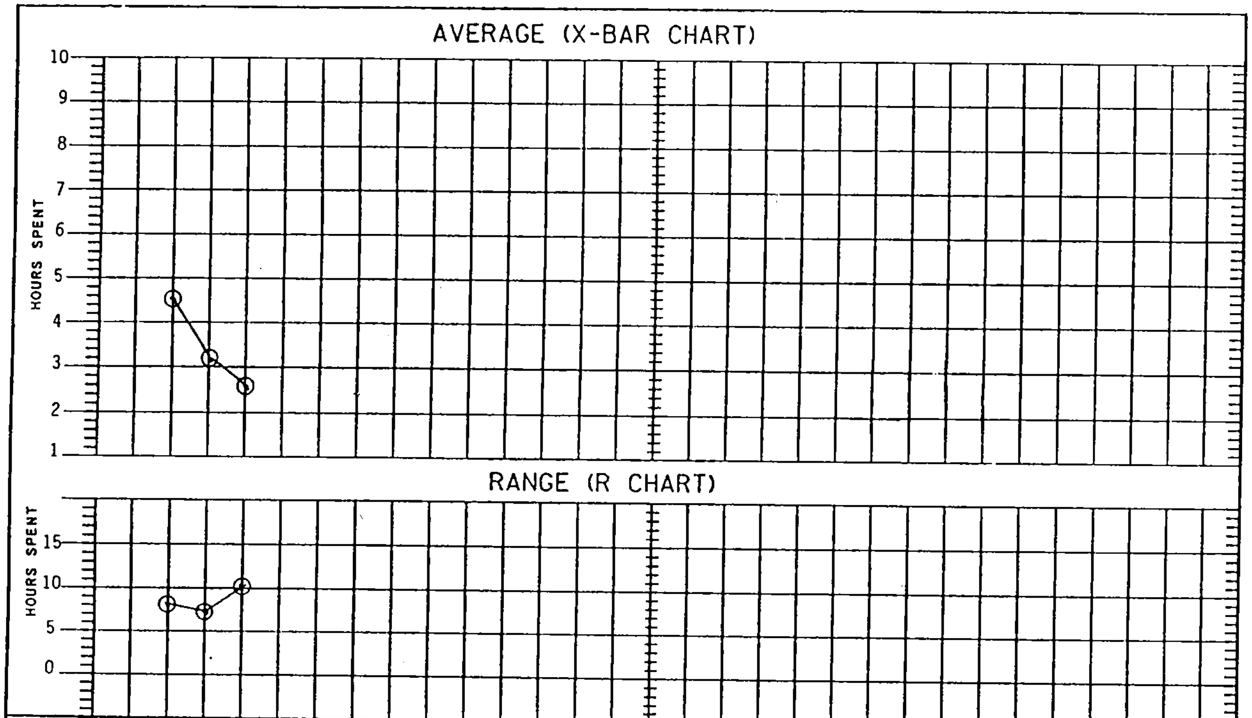

DATE / DAY	--	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
ATTRIBUTE 1	E1	8	3	0																	
2	E2	7	0	0																	
3	E3	5	7	3																	
4	E4	3	5	10																	
5	E5	0	1	0																	
SUM		23	16	13																	
X-BAR		4.6	3.2	2.6																	
RANGE		8	7	10																	

TABLE OF X AND R CONTROL FACTORS

SUBGROUP SAMPLE SIZE (n)	X CHART FACTORS FOR CONTROL LIMITS (A_2)	R CHART FACTORS FOR CONTROL LIMITS (D_3)	(D_4)
2	1.88	0	3.27
3	1.02	0	2.57
4	.73	0	2.28
5	.58	0	2.11
6	.48	0	2.00
7	.42	.08	1.92
8	.37	.14	1.86
9	.34	.18	1.82
10	.31	.22	1.78

NOTES

Figure 20
Shewhart Control Chart

SHEWHART CONTROL CHART

PROJECT NAME: UNSCHEDULED TASKS DATE: 28 FEB 93
DIVISION: PLANNING
BRANCH: ECONOMICS
SECTION: N/A

COMMENTS: CONTROL CHART OF THE AVERAGE NUMBER OF HOURS PER WEEK OFFICE SPENDS ON UNSCHEDULED WORK TASKS

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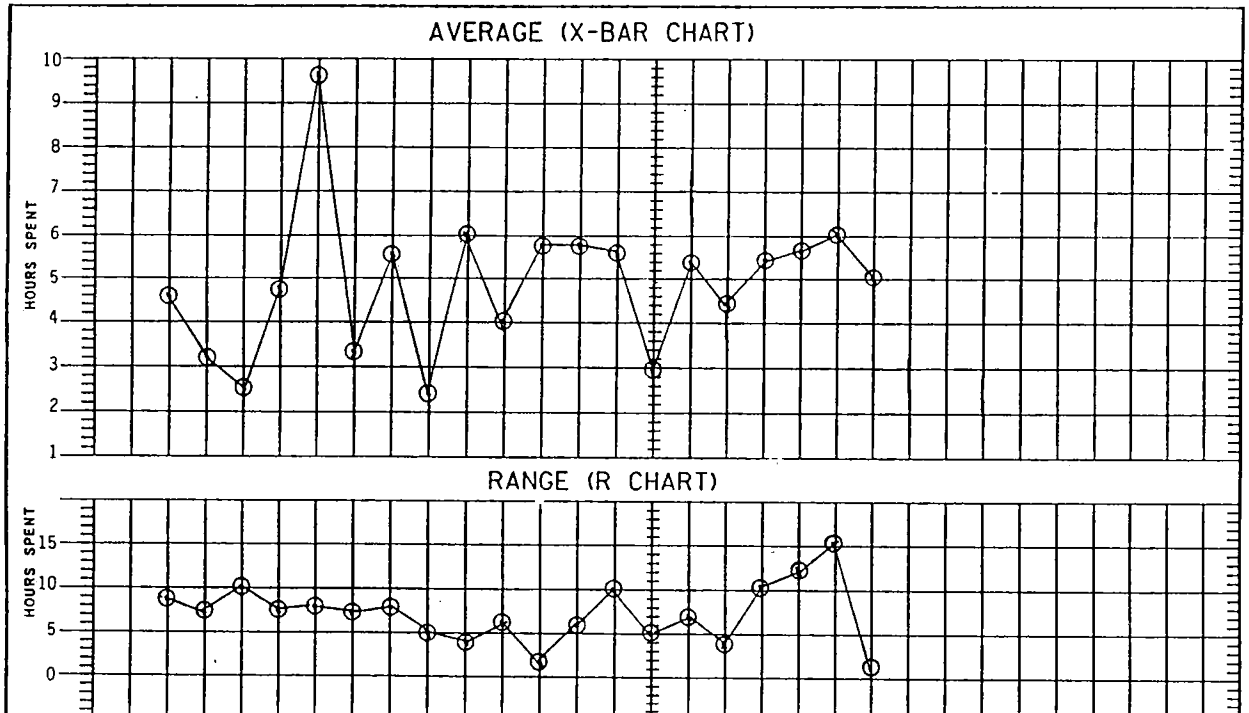

DATE / DAY	--	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
ATTRIBUTE 1	E1	8	3	0	1	10	4	6	1	4	2	7	6	0	5	4	5	0	0	15	5
2	E2	7	0	0	8	5	3	8	3	5	2	6	8	0	5	4	6	9	1	15	5
3	E3	5	7	3	6	10	1	7	1	6	8	6	8	10	5	10	6	10	10	0	6
4	E4	3	5	10	6	13	1	7	1	8	4	6	2	10	0	3	3	5	12	0	4
5	E5	0	1	0	3	10	8	0	6	7	4	4	5	8	0	6	2	3	5	0	5
SUM		23	16	13	24	48	17	28	12	30	20	29	29	28	15	27	22	27	28	30	25
X-BAR		4.6	3.2	2.6	4.8	9.6	3.4	5.6	2.4	6.0	4.0	5.8	5.8	5.6	3.0	5.4	4.4	5.4	5.6	6.0	5.0
RANGE		8	7	10	7	8	7	8	5	4	6	3	6	10	5	7	4	10	12	15	2

TABLE OF X AND R CONTROL FACTORS

SUBGROUP SAMPLE SIZE (n)	X CHART FACTORS FOR CONTROL LIMITS (A_2)	R CHART FACTORS FOR CONTROL LIMITS (D_3)	(D_4)
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NOTES

Figure 21
Shewhart Control Chart

SHEWHART CONTROL CHART

PROJECT NAME: UNSCHEDULED TASKS   DATE: 28 FEB 93
DIVISION: PLANNING
BRANCH: ECONOMICS
SECTION: N/A

COMMENTS: CONTROL CHART OF THE AVERAGE NUMBER OF HOURS PER WEEK OFFICE SPENDS ON UNSCHEDULED WORK TASKS

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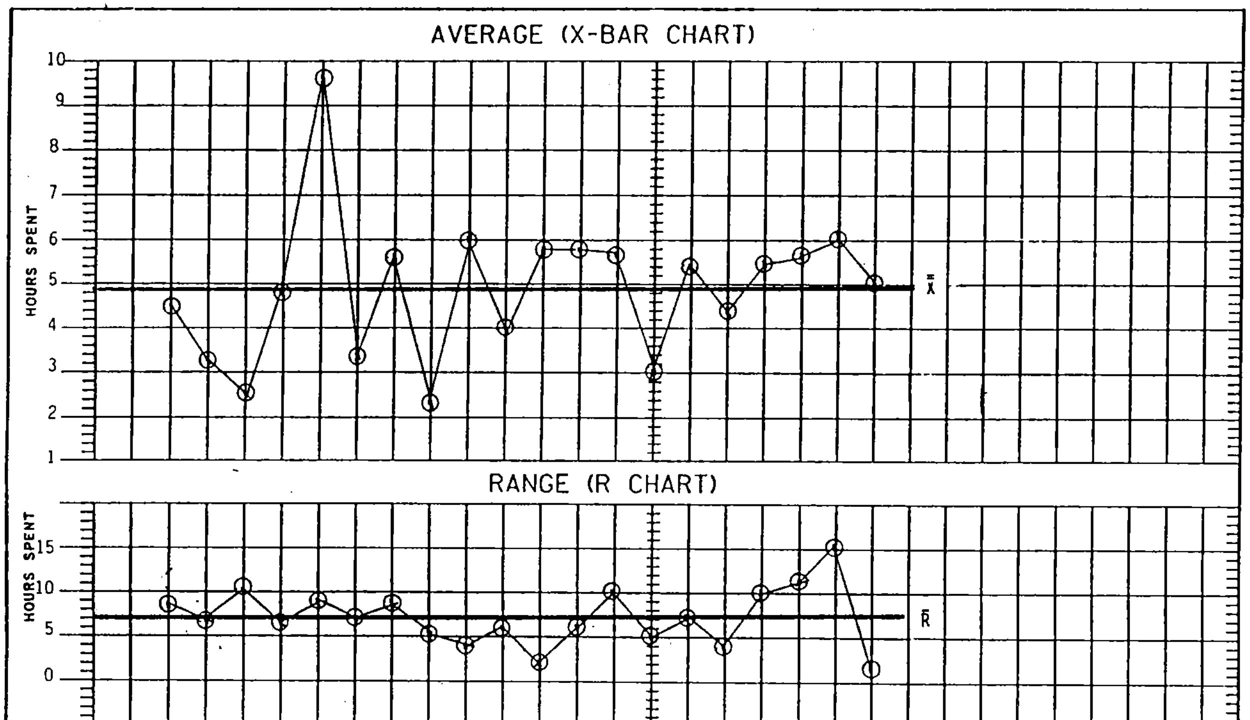

DATE / DAY	--	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
ATTRIBUTE 1	E1	8	3	0	1	10	4	6	1	4	2	7	6	0	5	4	5	0	0	15	5
2	E2	7	0	0	8	5	3	8	3	5	2	6	8	0	5	4	6	9	1	15	5
3	E3	5	7	3	6	10	1	7	1	6	8	6	8	10	5	10	6	10	10	0	6
4	E4	3	5	10	6	13	1	7	1	8	4	6	2	10	0	3	3	5	12	0	4
5	E5	0	1	0	3	10	8	0	6	7	4	4	5	8	0	6	2	3	5	0	5
SUM		23	16	13	24	48	17	28	12	30	20	29	29	28	15	27	22	27	28	30	25
X-BAR		4.6	3.2	2.6	4.8	9.6	3.4	5.6	2.4	6.0	4.0	5.8	5.8	5.6	3.0	5.4	4.4	5.4	5.6	6.0	5.0
RANGE		8	7	10	7	8	7	8	5	4	6	3	6	10	5	7	4	10	12	15	2

STEPS 1 AND 2

$\bar{\bar{X}} = \sum 98.2/20 = 4.9$

$\bar{R} = \sum 144/20 = 7.2$

TABLE OF X AND R CONTROL FACTORS

SUBGROUP SAMPLE SIZE (n)	X CHART FACTORS FOR CONTROL LIMITS (A_2)	R CHART FACTORS FOR CONTROL LIMITS (D_3)	(D_4)
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NOTES

Figure 22
Shewhart Control Chart

SHEWHART CONTROL CHART

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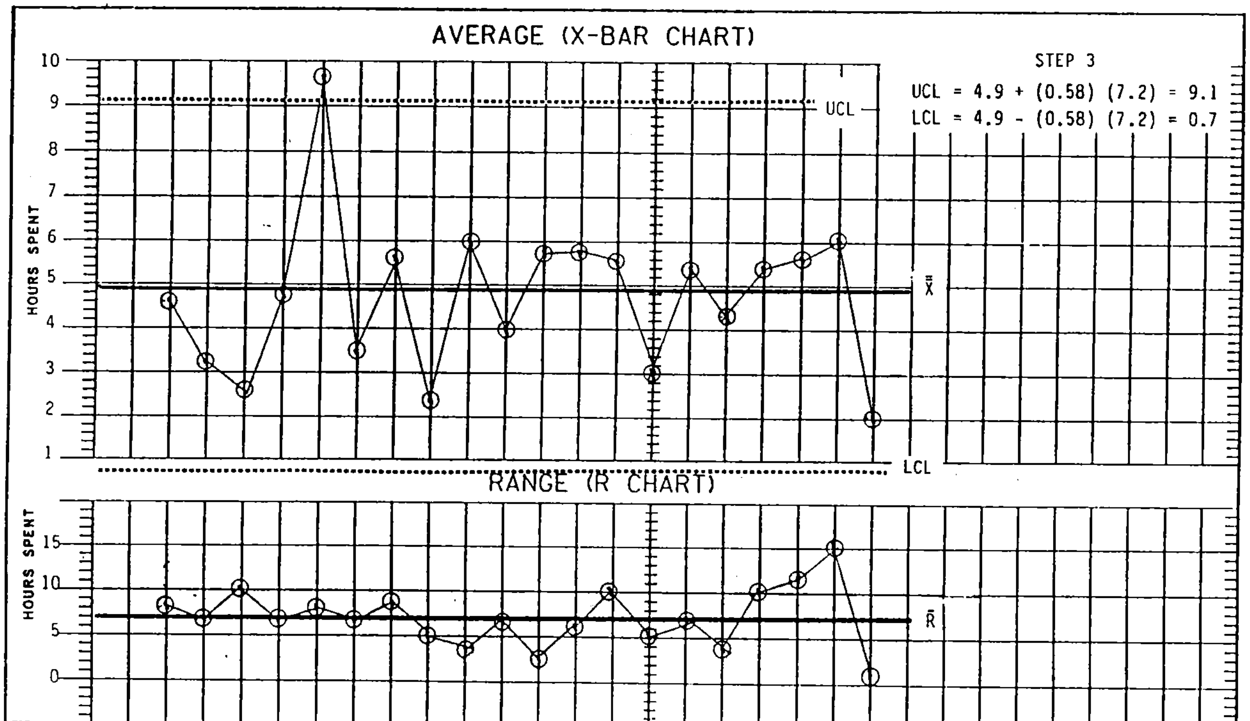
PROJECT NAME: UNSCHEDULED TASKS DATE: 28 FEB 93

DIVISION: PLANNING

BRANCH: ECONOMICS

SECTION: N/A

COMMENTS: CONTROL CHART OF THE AVERAGE NUMBER OF HOURS PER WEEK OFFICE SPENDS ON UNSCHEDULED WORK TASKS



DATE / DAY		--	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
ATTRIBUTE	1	E1	8	3	0	1	10	4	6	1	4	2	7	6	0	5	4	5	0	0	15	5
	2	E2	7	0	0	8	5	3	8	3	5	2	6	8	0	5	4	6	9	1	15	5
	3	E3	5	7	3	6	10	1	7	1	6	8	6	8	10	5	10	6	10	10	0	6
	4	E4	3	5	10	6	13	1	7	1	8	4	6	2	10	0	3	3	5	12	0	4
	5	E5	0	1	0	3	10	8	0	6	7	4	4	5	8	0	6	2	3	5	0	5
SUM			23	16	13	24	48	17	28	12	30	20	29	29	28	15	27	22	27	28	30	25
X-BAR			4.6	3.2	2.6	4.8	9.6	3.4	5.6	2.4	6.0	4.0	5.8	5.8	5.6	3.0	5.4	4.4	5.4	5.6	6.0	5.0
RANGE			8	7	10	7	8	7	8	5	4	6	3	6	10	5	7	4	10	12	15	2

STEPS 1 AND 2

$\bar{\bar{x}} = \sum 98.2/20 = 4.9$

$\bar{R} = \sum 144/20 = 7.2$

TABLE OF X AND R CONTROL FACTORS

SUBGROUP SAMPLE SIZE (n)	X CHART FACTORS FOR CONTROL LIMITS (A_2)	R CHART FACTORS FOR CONTROL LIMITS (D_3)	(D_4)
2	1.88	0	3.27
3	1.02	0	2.57
4	.73	0	2.28
5	.58	0	2.11
6	.48	0	2.00
7	.42	.08	1.92
8	.37	.14	1.86
9	.34	.18	1.82
10	.31	.22	1.78

NOTES

Figure 23
Shewhart Control Chart

SHEWHART CONTROL CHART

One Team,
One Purpose...
Dedicated to Excellence

Team Galveston

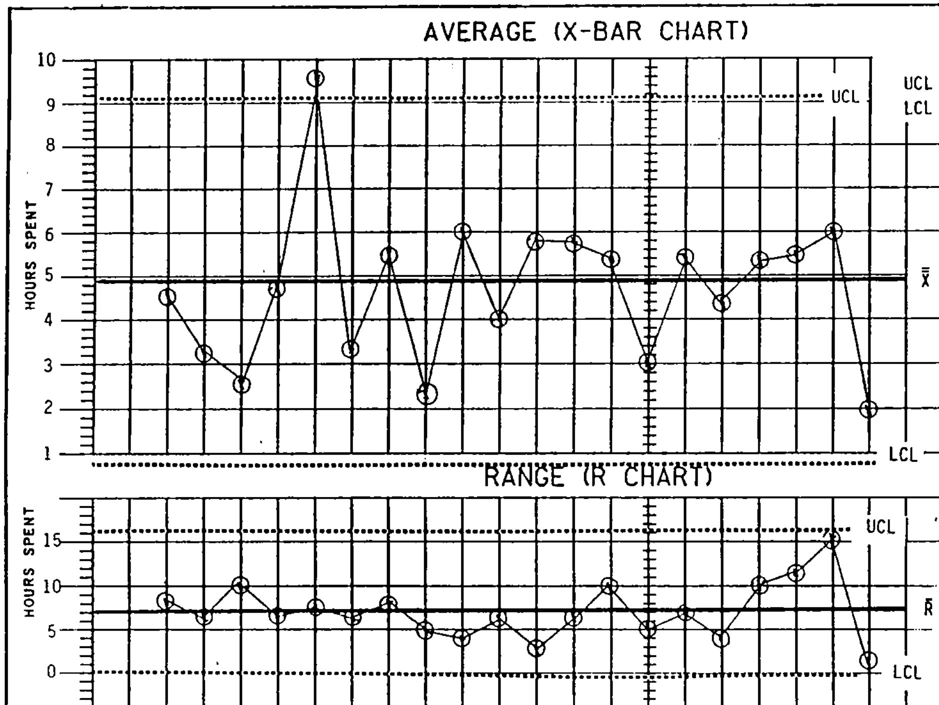
PROJECT NAME: UNSCHEDULED TASKS DATE: 28 FEB 93

DIVISION: PLANNING

BRANCH: ECONOMICS

SECTION: N/A

COMMENTS: CONTROL CHART OF THE AVERAGE NUMBER OF HOURS PER WEEK OFFICE SPENDS ON UNSCHEDULED WORK TASKS



STEP 3

UCL = 4.9 + (0.58) (7.2) = 9.1
LCL = 4.9 - (0.58) (7.2) = 0.7

$\bar{\bar{X}}$

STEP 4

UCL = 2.11 (7.2) = 15.2
LCL = 0 (7.2) = 0

$\bar{R}$

DATE / DAY	--	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
ATTRIBUTE 1	E1	8	3	0	1	10	4	6	1	4	2	7	6	0	5	4	5	0	0	15	5
2	E2	7	0	0	8	5	3	8	3	5	2	6	8	0	5	4	6	9	1	15	5
3	E3	5	7	3	6	10	1	7	1	6	8	6	8	10	5	10	6	10	10	0	6
4	E4	3	5	10	6	13	1	7	1	8	4	6	2	10	0	3	3	5	12	0	4
5	E5	0	1	0	3	10	8	0	6	7	4	4	5	8	0	6	2	3	5	0	5
SUM		23	16	13	24	48	17	28	12	30	20	29	29	28	15	27	22	27	28	30	25
X-BAR		4.6	3.2	2.6	4.8	9.6	3.4	5.6	2.4	6.0	4.0	5.8	5.8	5.6	3.0	5.4	4.4	5.4	5.6	6.0	5.0
RANGE		8	7	10	7	8	7	8	5	4	6	3	6	10	5	7	4	10	12	15	2

STEPS 1 AND 2

$\bar{\bar{X}} = \sum 98.2/20 = 4.9$

$\bar{R} = \sum 144/20 = 7.2$

TABLE OF X AND R CONTROL FACTORS

SUBGROUP SAMPLE SIZE (n)	X CHART FACTORS FOR CONTROL LIMITS (A_2)	R CHART FACTORS FOR CONTROL LIMITS (D_3)	(D_4)
2	1.88	0	3.27
3	1.02	0	2.57
4	.73	0	2.28
5	.58	0	2.11
6	.48	0	2.00
7	.42	.08	1.92
8	.37	.14	1.86
9	.34	.18	1.82
10	.31	.22	1.78

NOTES

Figure 24
Completed Shewhart Control Chart

hug the $\bar{R}$ line. This is defined as being out of control (see Figure 17I).

This second example reveals two out of control conditions. In the $\bar{X}$ chart, day five is an out of control condition as denoted by instability. Days 1 through 8 on the R chart show an out of control condition known as hugging. Both out of control conditions need to be specifically identified and the causes corrected before attempting to narrow the common cause variation remaining in the system.

As mentioned earlier, Shewhart control charts are used principally for the detection of production problems. Once detected, other tools must be used to specifically identify the cause of the problem so that a cause and effect relationship can be traced. Table 18 lists seven such tools. The first four on the table have already been employed in the text and will briefly be described once again. The last three (cause and effect charts, flow charts, and Pareto charts) will be detailed in the following paragraphs. The reader should also recognize that any one of these charts may be sufficient in identifying problem sources. On other occasions several charts may be needed.

TABLE 18 PROBLEM IDENTIFICATION TOOLS
1. Histogram
2. Scatter Diagram
3. Run Chart
4. Control Chart
5. Cause and Effect Chart
6. Flow Chart
7. Pareto Chart

1. Histogram

A histogram is a bar chart of a frequency distribution as shown in Figure 25. (This is the same as Figure 2 and reproduced here for reader convenience.) It consists of a set of vertical bars. The value of the variables being measured are placed on the horizontal axis. The bars are the same width and are essentially equal class intervals. The height of each bar corresponds to the frequency of the class it represents. The area of each bar is proportional to the frequencies represented in that class.

2. Scatter Diagram

A scatter diagram shows plotted points of relationships between variables; the dependent variable is located on the horizontal or Y axis and the independent variable is located on the vertical or x axis. The scatter diagram helps to determine if two variables are related in a cause and effect relationship and helps determine the type of relationship that might exist. Figure 13 is an example. Figure 26 shows other possible relationships. Figure 26a shows a strong linear relationship between dependent variable Y and independent variable X. It is a strong relationship because data points cluster tightly around the dotted slope line. If all points fit exactly on the line then the relationship would be perfectly positive. Figure 26b shows a weaker relationship because the points scatter more widely around the dotted slope line. Figure 26c is still linear but shows a negative (inverse) relationship between Y and X.

Figures 26d and 26e show curvilinear relationships of a positive and negative character, respectively. Both show strong connections between dependent and independent variables. Points more widely

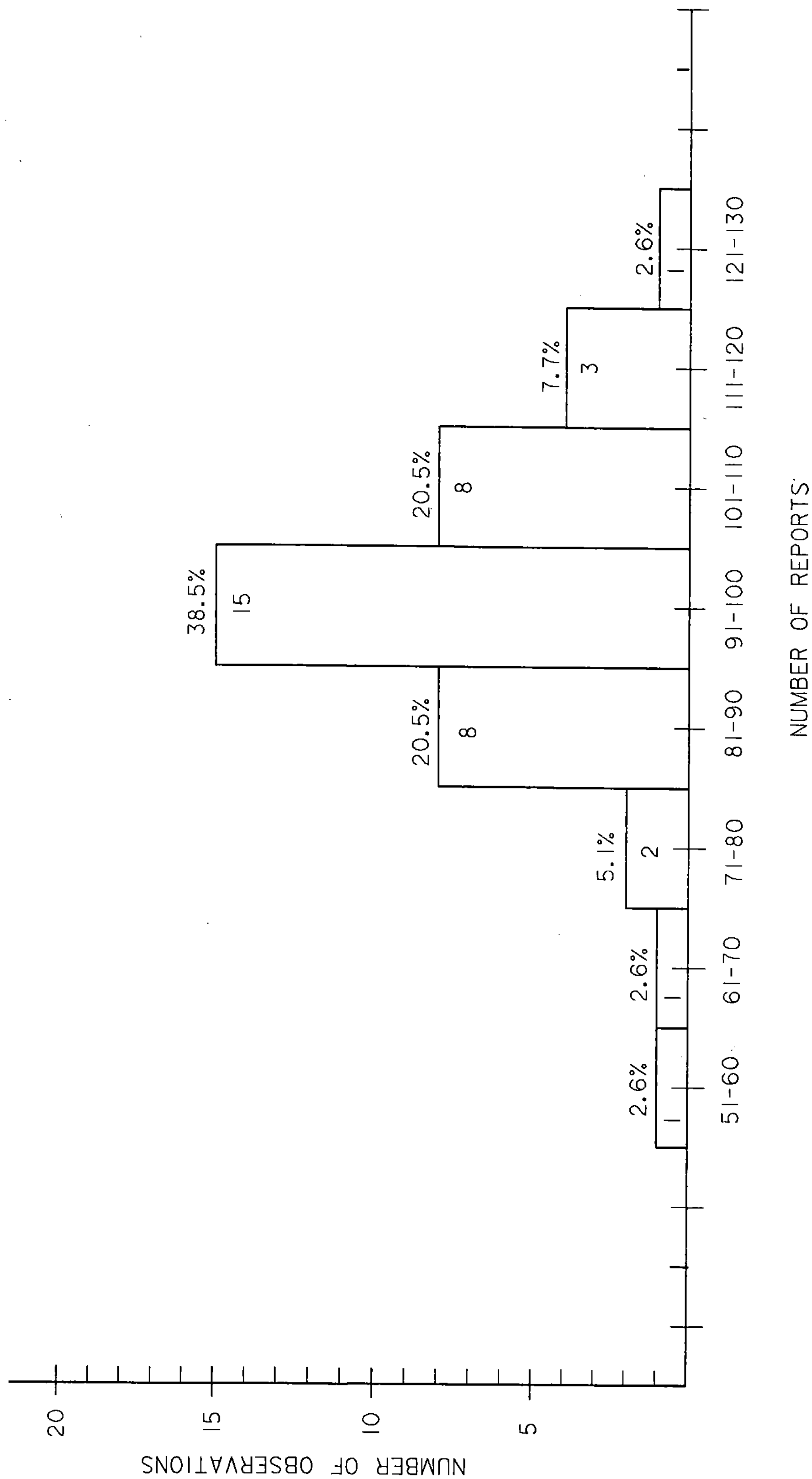


Figure 25
Construction of Class Intervals for the Development of a Frequency Distribution

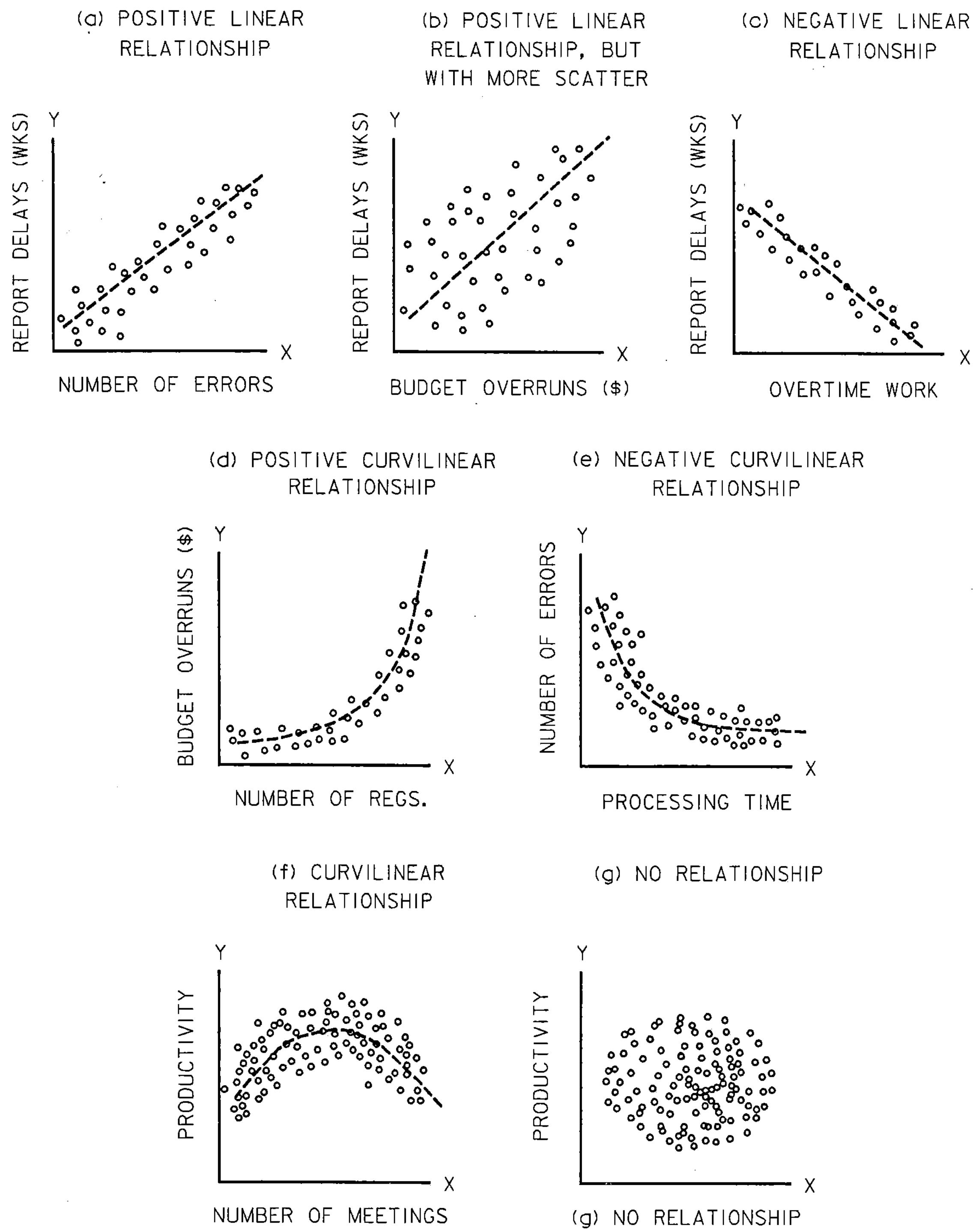


Figure 26
Examples of Scatter Diagrams

scattered than those illustrated would represent weaker relationships much like 26b.

Figure 26f shows another type of curvilinear relationship; first a positive curvilinear shape, then an inflection point, and lastly a negative curvilinear relationship. Many other curvilinear relationships and curves are possible.

Finally Figure 26g shows a scatter diagram which resembles a shotgun blast; no clear relationship between Y and X exists. Note that one line does not fit better through the scatter of points than any other line. No trend is apparent.

There is a quantitative estimate which measures the degree of relationship called the coefficient of correlation. This statistic is beyond the scope of this text.

3. Run Chart

The run chart is the first step in the preparation of a Shewhart control chart and can also be used in and of itself as a powerful analytical tool. A run chart illustrates trends in data over time. Figure 14 provided an example. The run chart allows the user to focus on truly vital changes that can take place over time and aids in understanding of changes in the system. Figure 27 A, B, and C illustrate a variety of run charts. Figure 27A shows a chart of weekly budget expenditures over time. Note how the run chart allows the viewers to quickly identify the extreme expenditure period as week 2. Visual impact is very effective. Figure 27B reveals variation in tracking losses, and gains in schedule slippage, and gains over time. Note that this helps identify cause and effect relationships. Finally Figure 27C shows the trend in accumulated cost in project expenditures over time. That is, cause information it is conveyed that it is not likely apparent in a table of the same information. Notice how costs rise slowly at first (week 10 and 20), rise rapidly (weeks 30-40), then taper off (weeks 40-60). This indicates that the middle period (weeks 30-40) is most active.

Run charts are valuable in conveying a visual impact and in identifying patterns and trends not necessarily apparent in tables consisting of the same data. It is the second step in preparation of a Shewhart control chart but is a chart which can be used apart from control chart development.

4. Control Chart

The best example of a control chart structure has already been given and explained in the text. Figure 28 is a culmination of that effort. (This is the same chart as Figure 16 and reproduced here for reader convenience.) The chief uses of the control chart are to determine the sources of production process variation, identify common and special causes, and in evaluating system control and stability.

5. Cause-and-Effect Chart

A cause and effect chart is self-explanatory. Figure 29 shows an example. This example is tied to the subject of the first part of this text. The special causes have been detected by the control chart. The next step is to identify the source of the special cause. By use of brainstorming or brain reading, a group can evaluate the factors which were operating at the time the special cause occurred. These factors can then be divided into subfactors. For example, suppose that a brainstorming session resulted

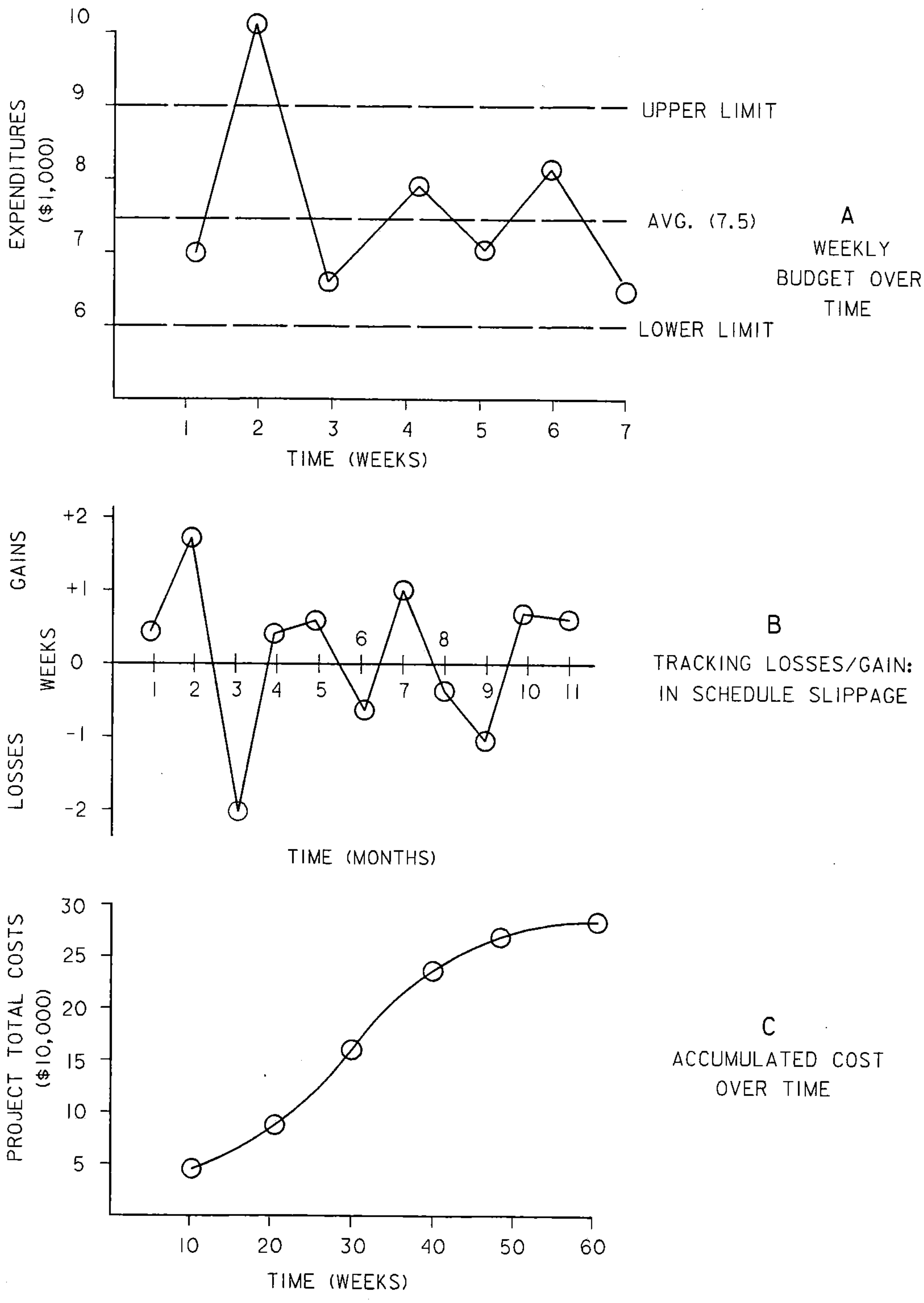


Figure 27
Examples of Run Charts

SHEWHART CONTROL CHART

PROJECT NAME: ANALYSIS OF PERMIT REPORT COMPLETION TIME DATE: 10 JUNE 1993

DIVISION: CONSTRUCTION/OPERATIONS

BRANCH: CO-R

SECTION: CO-RR

COMMENTS: USE $\bar{X}$ AND $\bar{R}$ CHARTS TO EVALUATE PROCESS CAPABILITY [SUBGROUP SIZE = 3]

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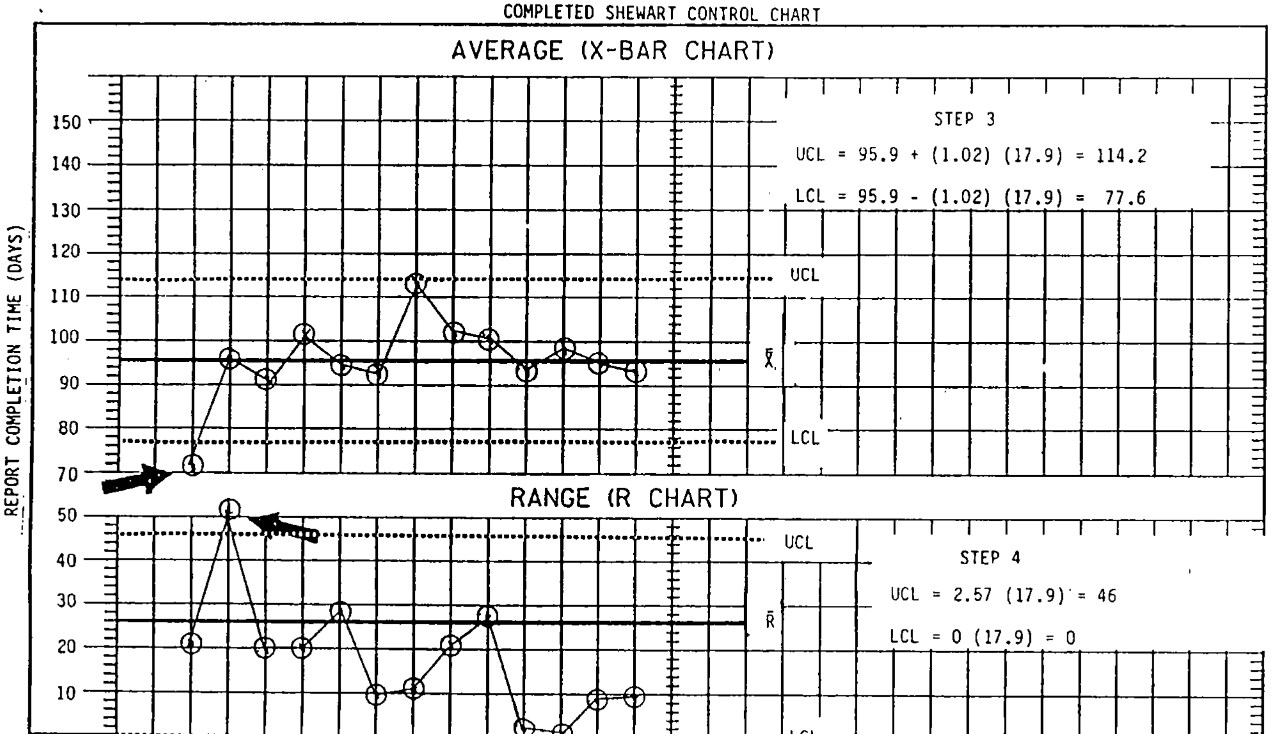
Team Galveston

COMPLETED SHEWART CONTROL CHART



DATE / DAY	1	2	3	4	5	6	7	8	9	10	11	12	13
ATTRIBUTE 1	60	130	81	90	107	100	109	108	118	93	99	97	100
2	71	81	90	103	103	90	110	90	91	94	99	92	91
3	81	77	101	110	78	90	120	111	91	95	98	100	92
4	--	--	--	--	--	--	--	--	--	--	--	--	--
5	--	--	--	--	--	--	--	--	--	--	--	--	--
SUM	212	288	272	303	288	280	339	309	300	282	296	289	285
X-BAR	71	96	91	101	96	93	113	103	100	94	99	96	94
RANGE	21	53	20	20	29	10	11	21	27	2	1	8	9

STEPS 1 AND 2

$\bar{\bar{X}} = \sum \bar{X}/N = 1247/13 = 95.9$

$\bar{R} = \sum R/N = 232/13 = 17.9$

TABLE OF X AND R CONTROL FACTORS

SUBGROUP SAMPLE SIZE (n)	X CHART FACTORS FOR CONTROL LIMITS (A_2)	R CHART FACTORS FOR CONTROL LIMITS (D_3)	(D_4)
2	1.88	0	3.27
3	1.02	0	2.57
4	.73	0	2.28
5	.58	0	2.11
6	.48	0	2.00
7	.42	.08	1.92
8	.37	.14	1.86
9	.34	.18	1.82
10	.31	.22	1.78

NOTES

Figure 28
Completed Shewhart Control Chart

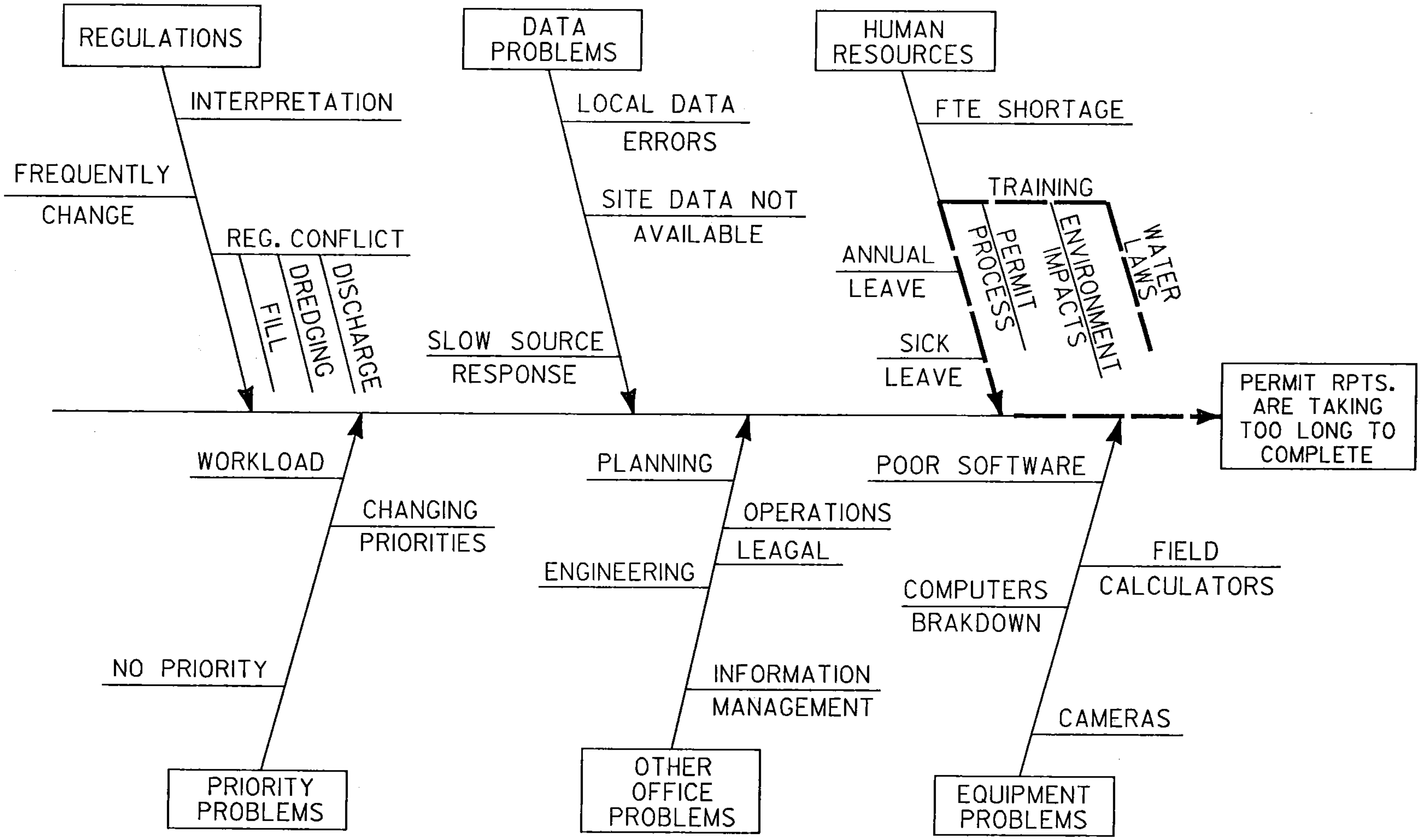


Figure 29
Cause-and-Effect Diagram of Unscheduled Task Problem

in a conclusion that six factors may have played a role in the special cause variance. They included: REGULATIONS, DATA PROBLEMS, HUMAN RESOURCES, PRIORITY PROBLEMS, OTHER OFFICES AND EQUIPMENT PROBLEMS. The subfactors are tied to the main factors as branches. Once the source has been specifically identified, its impact can be traced through the system. In this case, the sub factor lack of training (on water laws; dotted line) was the culprit. Someone was assigned to do the report who had no training in a specific, need area which resulted in longer than usual time for report completion. Remember also, there may be multiple causes at work. This example illustrates a very simple cause and effect chart. One that would outline our permit report special cause problem would likely be considerably more complex, although the example might make a good outline of a more detailed one.

Cause and effect charts are sometimes called fishbone charts. It may help the user to think of a cause as either a random event or special cause event in the context of control chart vocabulary. This dichotomy alone may reduce the number of cause factors in the cause and effect chart. Recall that random or special cause events cannot be explained by specific factors but may be systems induced. Special causes can be specifically identified because of their systematic behavior (trends, cycles, sudden jumps, etc.) or due to instability (lie outside the standard deviation limit).

6. Flow Chart

A flow chart is typified in Figure 30. It is designed to trace through sequences of events, actions and decisions to clarify what impacts occur as a result of some factual result or simulated result. It is valuable in tracking down cause and effect relationships as system decision loops take place. As the figure illustrates, a diamond shape represents a decision point, a circle represents the decision linkage, a rectangle for a fact or activity and the arrows show the direction or flow of the process. Actual flow charts for even the simplest decision loops are far more complex.

The flow chart allows the user to understand the whole process and helps establish the boundaries of the process, problems, and opportunities for improvement. It is a systems analysis tool.

7. Pareto Chart

A Pareto chart shows relative importance, priorities and gives users a starting point for complicated problem resolutions. Figure 31 shows the basic structure of a Pareto chart. The process of constructing a Pareto chart usually follows a pattern as listed below:

1. Ask a group of knowledgeable people to list a comprehensive set of potential causes plaguing an operation. This is often done in a group process known as "brainstorming". Another approach would be the "nominal group" technique.

2. Next consolidate the list. Then, ask the group to rank in order of importance or significance what each potential cause has on the problem to be resolved.

3. Consolidate the results as shown in the example figure.

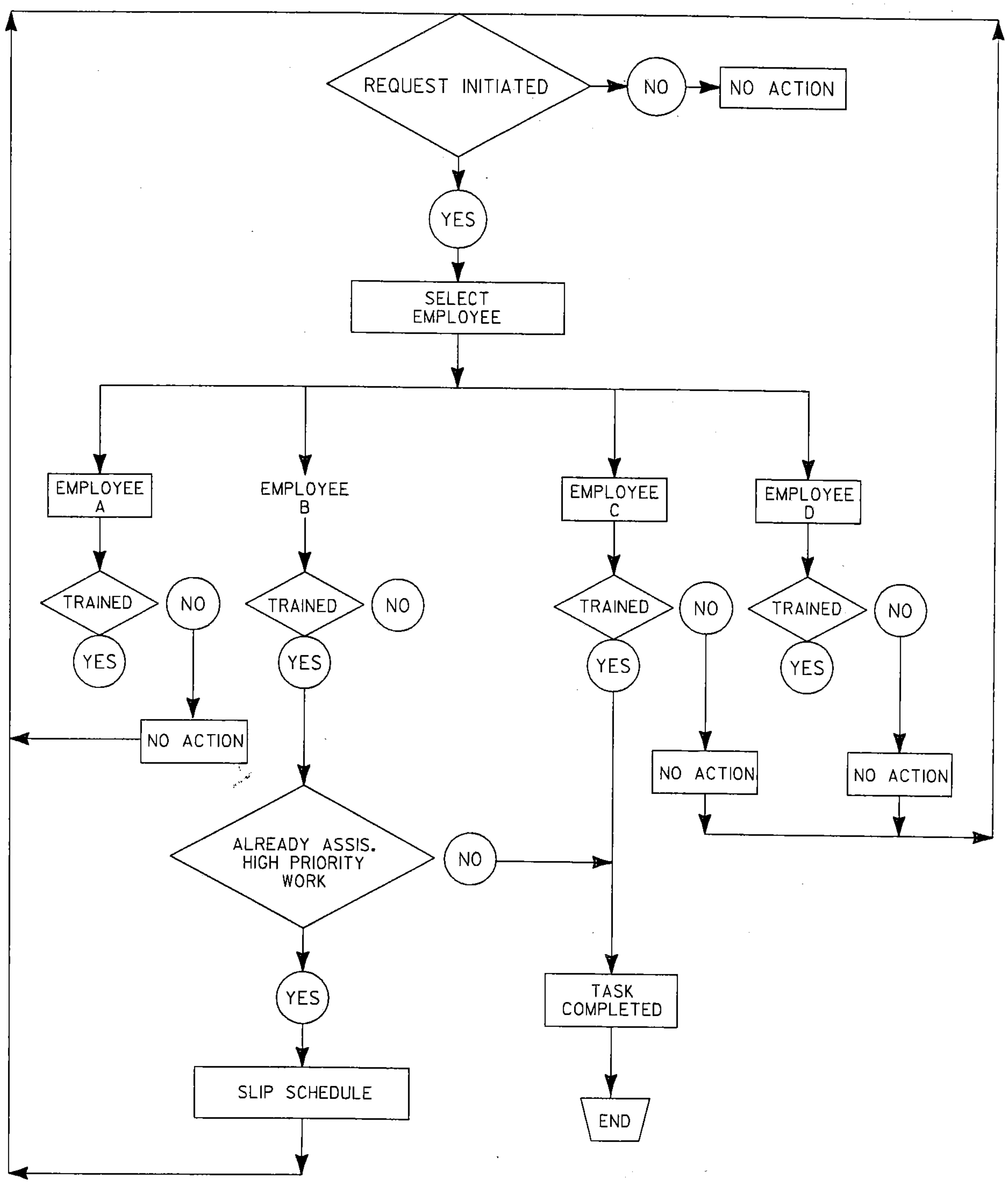


Figure 30
Flow Chart of Unscheduled Task Problem

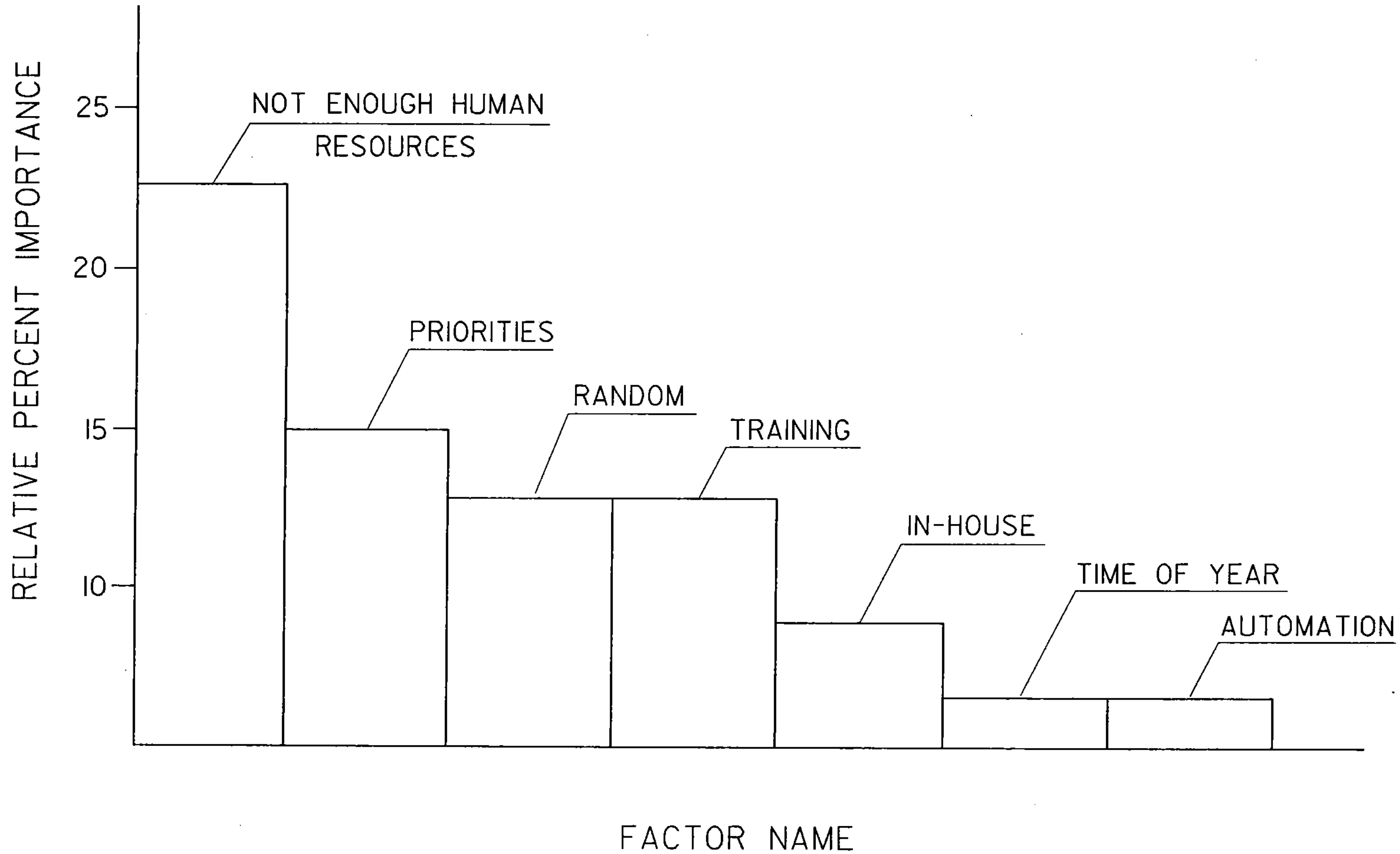


Figure 31
Pareto Analysis of Relative Importance - Unscheduled Tasks

The above process need not be done as part of a brainstorming or round table format. It could also be accomplished by a survey instrument when the number of participants gets large, i.e., a Division, District, etc.

The Pareto chart is in essence a vertical bar chart in which the bars are arranged from left to right in descending order. Each bar represents a problem, cause, element, or important source. Its premise lies in the idea that only a few causes represent most problems. If these few important sources are dealt with, the majority of problems would be resolved.

Figures 32a and 32b show an important distinction which must be made for the reader to understand the difference between two fundamental concepts: one is the upper and lower control limits (UCL and LCL) and the other is the upper and lower specification limits (USP and LSL) [McConnell, 1992].

Figure 32a depicts the usual Shewhart control chart with a process mean $\bar{\bar{x}}$ and an upper and lower control limit (UCL and LCL, respectively). The chart shows a process that is in statistical control.

Figure 32b is a histogram constructed from the same data as the Shewhart control in Figure 32a. Note that the histogram shows specification limits LSL and USL. The UCL and LCL in Figure 32a are natural limits constructed from the raw process data itself. The LSL and USL in Figure 32b are "artificial" limits imposed by some requirements such as constraints needed to satisfy customer needs or it represents minimally acceptable tolerances. The two concepts are different but related. Figure 32a is designed to analyze process stability whereas Figure 32b was designed to show process capability. An example is needed for clarification. The specification limits can be placed on the same chart as the control limits. This will be done in the following paragraphs.

Remember that special causes are usually tied to an individual, a specific anomaly or a particular local condition. When these are brought under control, the process is said to be stable or is in statistical control. Figures 33A through 33D represent control charts formed by a stable (all special causes removed) process showing how long it typically takes to complete a reconnaissance report for a small urban flood control study. Figure 33d shows the average to be 50 days with a range from 30 to 70 days as depicted by the LCL and UCL, respectively. No one should be surprised if a new start for a similar study took 65 days even though the mean is only 50 days. The process has defined the chart parameters. Since the process is stable, any improvements such as the narrowing of the LCL and UCL band or moving the average lower than 50 days is a process problem, i.e., management's problem.

Suppose misinformed management decides to "improve" results by demanding that the process average fluctuation be lowered to 40 days when the process mean is 50 days as in Figure 33A (LSL = 40 days). This is a noble goal but the employees are functioning as a prisoner to the established or existing process - with a mean of 50 days. The demands wanted by management are self destructive. The new capability is one that management must develop itself through a reduction in common causes variation. Staff or employees cannot perform any better than the system will allow. Any effort by employees to meet a 40-day mean schedule will only result in increased errors, frustration, waste and rework after review by higher authority. This will result in low ratings for the reports. It is expected that any attempt to shortcut the average 50-day

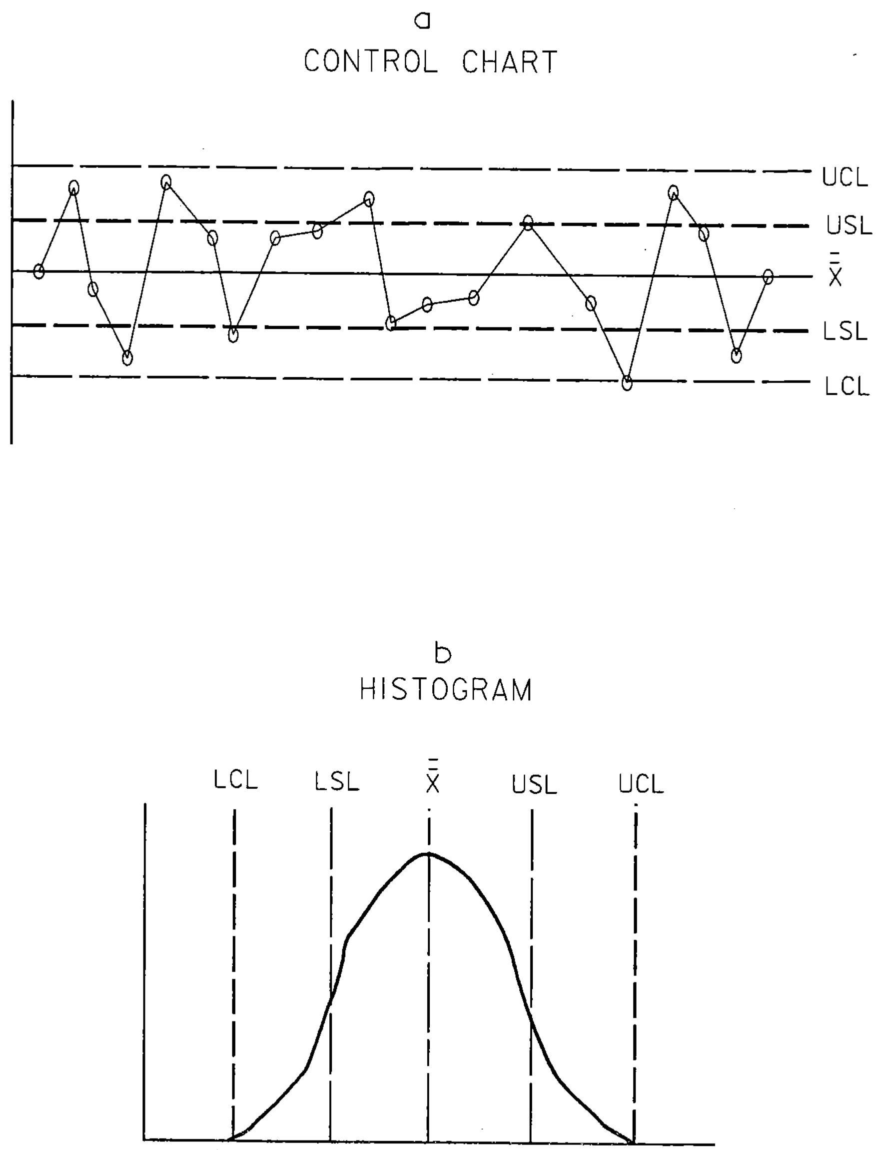


Figure 32
Control Limits vs. Capability Limits

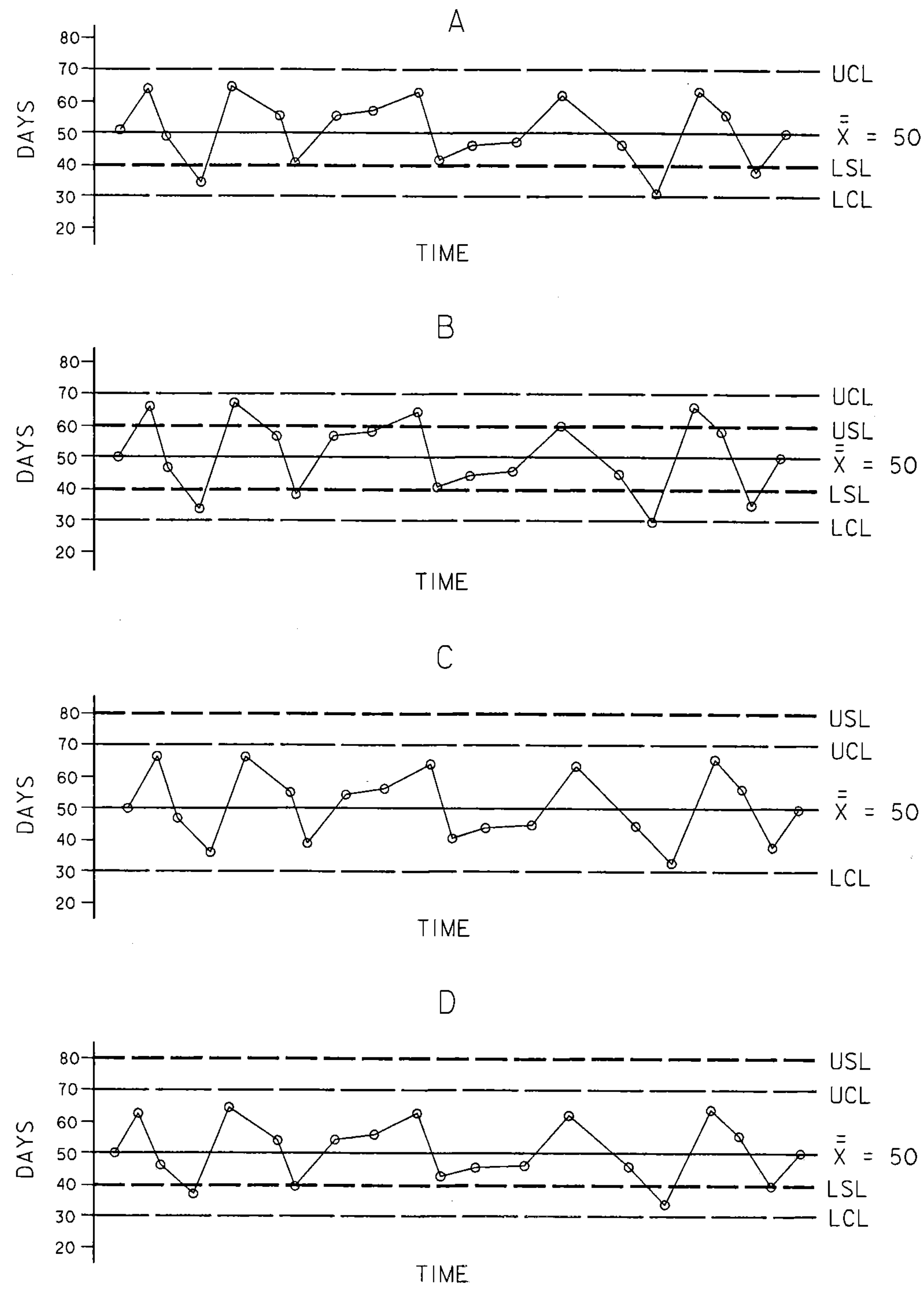


Figure 33
Process Capability Analysis

time will be fraught with error, poorly supported, or downright wasted.

Figure 33B represents a more dire set of imposed schedules. The report process with a mean of 50 days and a process range of between 30 and 70 days is being "boxed in" much tighter than the data dictates that it can. Without management action to improve the system, this situation is intolerable and cannot be sustained.

Figure 33C is a reversal of the situation of Figures 33A and 33B. Here, the specification limits have been set with a USL limit of 80 days. This is a "sloppy" management approach because the system already performs much better than this, but management does not keep charts and cannot know this.

Figure 33d represents a case of both imposing an unrealistically high standard or specifications at the LCL level with the LSL of 40 and a process average of 50. Similarly, the top end of performance indicates a UCL performance at 70 days yet management has set this upper end performance at 80 days - less efficient. This situation may arise because the specification limits were not charted (current practices) and management "guessed" at the proper limit.

The four examples above graphically illustrate what problems may unknowingly arise as a result of not charting or ignoring charting results by artificially imposing process capability specifications on a system that is "statistically stable". This is often done out of ignorance of in an effort to meet a schedule, budget, or other nonsystem determined constraint. Management steps on its own toes and wonders about staff or employee loyalty. Such is the case when charting is not used or its results ignored. No amount of pressure, fist pounding, or progress reporting can make a statistically stable system perform beyond its inherent capability. Management cannot impose improvement by force. No higher degree of efficiency is possible as workers are already doing their best under the circumstances.

Recall that in these examples we are dealing with process improvements. The problem lies in common variation experienced in the outcomes or final products produced. These are nothing more than the cumulative effect of variation from each step in the process. The real damage done by meeting targets, schedules, or goals occurs when people are held accountable to guarantee that such artificial restrictions are met, even when the data indicate that the process is incapable of meeting the targets, schedules, or goals. Such "deadlines" cannot be viewed with rigid determinism as is often found in most scheduling charts, PERT charts, MBO, or micromanagement. The consequences of attempting to do this may introduce or inject the system with a new special cause resulting in waste, rework, increased costs, errors, etc.

and for the lower limits:

Equation (17):

$$Z_{LSL} = (LSL - \bar{X})/s_X(est)$$

Let us set some arbitrary limits as an example within which the market indicates it requires to satisfy customers. They are 105 for the maximum specification and 75 for the minimum specifications. Specification limits need not be symmetrical as shown here.

Z_{USL} = (105-94.4)/7.69 = 1.38 = 0.084 = 8.4%

Z_{LSL} = (75-84.4)/7.69 = -1.22 = 0.111 = 11.1%

Refer to Table 9 for 1.38 to find how to get the 8.4%. To find how we arrived at 11.1% look at 1.22 in Table 9. The Z table converts Z_{USL} and Z_{LSL} into percentages for values of the upper and lower specification limits. The analyst can then compare the natural process percentages with the upper and lower specification limits, respectively. Total process output that exceeds specification limits (representing waste) can now be evaluated as: 8.4 + 11.1 = 19.5%. In other words Process Capability (PC) = 80.5%. As one tightened the limits, measured PC goes down; and as the limits are widened, PC goes up. Note that this technique not only measures variance or spread, but also accounts for the process average being off center for the sample used.

Figure 34 illustrates in schematic terms the numerical process above. Note the location of LSL and USL with regard to the mean. All production of goods or services falling to the left of LSL is scrap. Similarly, all production of goods or services falling to the right of USL is also scrap. These outputs are wasted resources because they did not meet customer determined quality as specified by LSL and USL. The natural process (only common cases are operating) indicates an LCL and UCL of:

LCL = 94.4 - 3(7.7) = 71.3
UCL = 94.4 + 3(7.7) = 115.4

respectively. Thus, even though the process was under control, the process was not fully capable:

LSL < LCL or 75 > 71.3 by 11.1%

USL > UCL or 105 < 115.4 by 8.4%

The result was a 19.5% waste of what was produced. This becomes an added cost of doing business and is subsequently added to customer price.

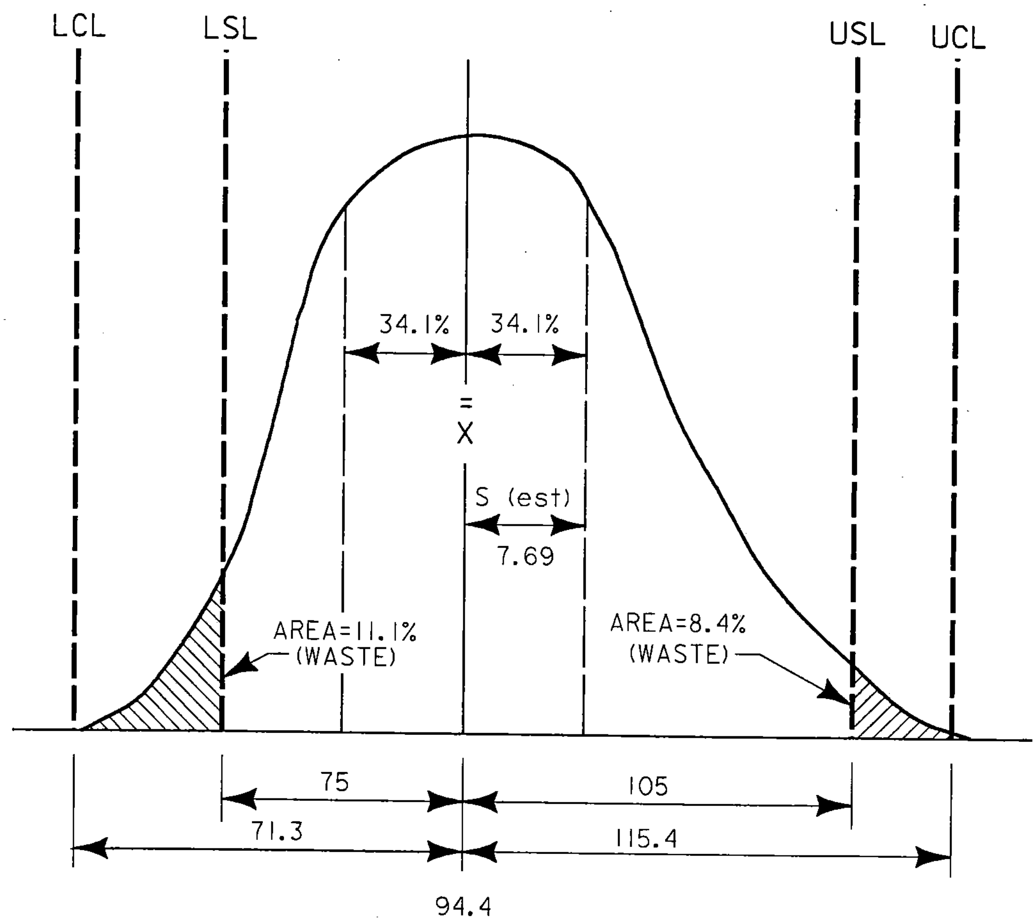


Figure 34
Using Z-Scores to Determine
Process Capability

Thus far the $\bar{X}$ and R charts have been the only set of control charts described. There are six other types of control charts used by industry to detect special and common cause variation and changes in the process mean [AT&T, 1958]. The $\bar{X}$ and R charts are the single most powerful and the most sensitive to process change. Control charts can be classified into two basic types. They are control charts for variables and control charts for attributes.

Control chart for variables are designed for specific quality features which can be measured, i.e., time, dollars, inches, etc. The three charts of this type are the $\bar{X}$ and R chart, the $\bar{X}$ and S chart, and the Median chart.

The $\bar{X}$ and R chart has been the topic of this text. These are called the average and range charts. They are used to track the behavior of information which is averaged over time and over which the data varies. The R chart is a test or measure of process stability.

The $\bar{X}$ and S charts look like the $\bar{X}$ and R charts. The $\bar{X}$ chart as before, measures process average. Instead of the R chart, the S (for standard deviation) is used. The standard deviation is a better measure of variation than the $\bar{R}$ when large data samples are used and is more sensitive to change.

The median charts are alternatives to the $\bar{X}$ and R charts for control of a process, using measured information. They result in similar information but have the following advantages.

- ❑ They are easy to use and do not require daily data input.
- ❑ Can show the spread of process on a single chart.
- ❑ Can be used to show the output of multiple outputs.
- ❑ Use median of values rather than mean to plot the centerline.

The $\bar{X}$ and R chart is overall the best analytical tool to use with COE work. The other charts are of value under specific circumstances.

Control charts for attributes show process variation or performance for non measured data. For example, did something pass inspection or fail inspection, or was something produced satisfactorily or unsatisfactorily, etc. There are four kinds of attribute charts; p-charts, np-charts, c-charts, and u-charts.

P-charts (percentage charts or proportion charts) represents the proportion of bad output compared to total output - the percent defective. It reveals the same defects as do the $\bar{X}$ and R charts, but is more useful in analyzing details once the problem has been detected by the $\bar{X}$ and R chart.

The np-chart is like the p-chart. If samples plotted on the p-chart are all the same size, then it is simpler to plot the number of defectives found in each sample rather than plot the percentages using the p-chart.

The c-chart is a variation type of the p-chart which employs the number of defects rather than the number of defectives. A defect is a unitary failure to meet a specific request. A defective is a feature of a product or service which consists of one or more defects. A unit of product or service can contain many defects but be counted only as one defective.

Each type of chart has advantages and disadvantages. Overall the $\bar{X}$ and R charts are the most flexible, sensitive, and easily understood. Table 19 shows a summary of the two basic types.

TABLE 19
TYPES OF CONTROL CHARTS

Control Charts for Variables - $\bar{X}$ and R - $\bar{X}$ and S - Median
Control Charts for Attributes - P-Charts - Np-Charts - C-Charts - U-Charts

Quality and efficiency problems are most commonly associated with human error. The term error as used herein encompasses mistakes, slip-ups, delays, blunders, inefficiency, ineffectiveness, low productivity and any other quality influencing characteristics. The sources and types of errors are daunting. Table 20 attempts to broadly classify error. Part of this list came from Rosander, [1989], but his version was modified and expanded by this author to depict COE experience. This list is mind expanding and needs to be reviewed from time to time in the search for special and common cause variation. The tools described earlier - Pareto chart, cause-and-effect chart, flow chart, etc. - can be used to help identify the items listed in Table 20. Many kinds of errors overlap, such as accountability, neglect, etc., and show up multiple times. Other cause attributes can be added.

The reader hopefully does not get the idea that all causes are human. Materials, resources, equipment, weather, etc. play an important role and are often out of human influence. However, the human role is overwhelmingly pervasive in comparison.

TABLE 20
KINDS OF ERRORS IMPACTING QUALITY [1/]

I	MISTAKES	
	1.	Incorrect Values
	2.	Incorrectly Recorded Facts
	3.	Incorrect Methods, Procedures, and Process
	4.	Deviation from Rules, Laws or Regulations
	5.	Misused Procedures and Applications
	6.	Departure From Safe Procedures and Behavior
	7.	Rejection of Improvements, Better Methods
	8.	Poor Judgment and Decisions
	9.	Incorrect Analysis and Synthesis
	10.	Observation Errors
	11.	Lack of Experience, Training or Skills
	12.	Overloads
	13.	Accountability

TABLE 20
KINDS OF ERRORS IMPACTING QUALITY [1/]

II	DELAY AND NEGLECT ERRORS	
	1.	Benign Neglect
	2.	Wasted Time (Poorly Used or Lost)
	3.	Absolute Neglect (Intentional)
	4.	Poor Time Budgets and Estimates
	5.	Opportunity Cost of Time
	6.	Inelasticity of Time
	7.	Accountability
III	OVER SERVICE ERRORS	
	1.	Quality Above Customers Needs
	2.	Quality To Satisfy Servant
	3.	Redundancy
IV	IMPEDIMENTS, HINDRANCES, AND COMPONENTS	
	1.	Conflicting Goals and Objectives
	2.	Personality Conflicts
	3.	Poor Motivating Environment
	4.	Policy Differences
	5.	Philosophy Differences
	6.	Outdated and Excessive Application of Rules and Regulations
	7.	Political Decisions
	8.	Blind Acceptance
	9.	Artificial Constraints
V	INTENTIONAL AND UNINTENTIONAL DESTRUCTION OF DATA	
	1.	Carelessness
	2.	Indifference
	3.	Disgruntled Employees/Managers
	4.	Accidental
	5.	Lack of Back-up

TABLE 20
KINDS OF ERRORS IMPACTING QUALITY [1/]

	1.	Neglect
	2.	Delay
	3.	Manual vs Computer
	4.	Accountability
VII	ERRORS IN COMMUNICATIONS	
	1.	Crossing Cultures
	2.	Crossing Disciplines
	3.	Crossing Languages
	4.	Crossing Education Barriers
	5.	Crossing Environmental Barriers
VIII	RISK AND UNCERTAINTY ERRORS	
	1.	Bounded Rationality (Knowledge and Data)
	2.	Lack of Backstop (Back-up, Alternative)
	3.	Individual vs Group Decisions
	4.	Failure To Be Inclusive
IX	EMOTIONS	
	1.	Fear
	2.	Anger
	3.	Jealousy
	4.	Gratification
	5.	Job Satisfaction
	6.	Job Ownership
	7.	Empowerment
	8.	Control (Over/Under)

1/ Taken in part from: Rosander, A.C. The Quest For Quality In Services. Wisconsin: Quality Press. 1989.

The tools and techniques previously described can go a long way in reducing costs, increasing output, and more importantly, improving quality of products and services. A vital issue remains. How do you demonstrate or prove that the adoption of a new TQM method, task, program, measure, action or process actually improves process capability? Under TQM there is ample opportunity for exorbitant claims with regard to system improvements.

Table 21 lists some of the more useful analytical tools frequently adapted by business enterprises to evaluate process and system capability gains. Of the 18 tools and techniques listed, 6 are adaptable to measuring performance gain in the corporate environment of the COE. Items 13 through 18 include those tools which can be employed by all elements within a District, Division, OCE, etc. The remaining techniques have aberrations and attributes which make them less unsuitable for COE purposes. Some, like simulations and linear programming - are overly complicated for our purposes.

The control chart itself is an excellent tool and can be used to measure savings, gains in efficiency, and quality improvements. Since a measurement tool is only as good as the data which supports it, backup is vital. A long run $\bar{X}$ and R chart which shows progress similar to that depicted in Figure 19, is proof enough of progress. Whatever actions were taken to eliminate special causes and reduce variation proves the vendibility of these actions. Thus variance reduction expressed in standard deviation units over time is evidence itself of progress.

A spinoff of the control chart analysis is the process capability (PC) framework. Recall the calculations used in the PC example. Suppose for a moment that the plot was dollars spent on report completion times and that for a one year period, permit reports cost $1,000,000 annually to complete. The waste of 19.5 percent (percent exceeding specification limits) represents $195,000 annually ($1,000,000 X .195 = $195,000). This loss had been estimated to cost the district $195,000 in annual slippages (value of time spent on flash fire battles which would have been applied toward intended study completion) and a management solution reduced that from 19.5 percent to 13.5 percent; an annual savings of $60,000. If an overhead factor of 2.8 is correct, total district savings would be: 2.8 X $60,000 or $168,000 annually.

The benefit-to-cost ratio (BCR) is a method the COE is quite familiar with. A benefit-to-cost ratio is found by dividing benefits derived by costs incurred. It is also very applicable to demonstrating real improvements instituted by management to improve process capability. To illustrate let us continue with the previous example which resulted in a savings of $168,000 annually. In finding the solution that resulted in the 6 percent savings, 3 members of a QMB expended eight hours discussing the problem and a 5 member team chartered to identify the cause spent 32 hours of flow charting. Total cost of the solution has been

TABLE 21 ASSESSMENT TECHNIQUES
1. Savings Investment Ratio (SIR)
2. Net Present Value (NPV)
3. Discounted Payback Period (DPR)
4. Equivalent Uniform Annual Cost (UAC)
5. Efficiency/Productivity Increases (EPIR)
6. Profitability Index (PI)
7. Input-Output analysis (I-O)
8. Breakeven Analysis (BE)
9. Accounting Rate of Return
10. Simulations
11. Linear Programming
12. Cash Payback Period
13. Control Charts ($\bar{X}$, R)
14. Process Capability (PC)
15. Benefit-To Cost Ratio (BCR)
16. Output Per Unit of Input
17. Questionnaire/Surveys/Delphi
18. Flow Charts

determined to be $13,552. Was the effort worth it? Clearly a BCR of ($60,000/13,600) 4.4 to one indicates it was. The net annual savings is $46,000. The BCR approach is apropos for this type of investigation. This simplified example could easily be true. More complex analysis may been detected by the control chart, identified by a flow chart as due to time spent on flash fires and evaluated by the process control (PC) analysis. Assume a management solution has resulted in a reduction of this wasted flash fire time from 19.5 percent to 13.5 percent with a resultant savings of 6.0 percent or ($1,000,000 X 0.06) $60,000 annually. In other words, flash fires have require discounting and present value analysis among other factors. The BCR approach also allows for comparison of complex alternatives as well as the one solution case.

The concept of output per unit of input is an efficiency notion more than a method. Often times savings are expressed in total dollars and gains in system capability are claimed. This is not necessarily correct; in fact it could be grossly misleading. For example, has efficiency been achieved if a reduction in force (RIF) results in the savings of $500,000 annually? The answer is not necessary. For example suppose 400 employees cost $60,000,000 in salaries and overhead but produce $100,000,000 worth of product or service. The efficiency of this resource allocation is: $100,000,000/400 employees is $250,000 per full time employee (FTE). A RIF takes place reducing the number of FTE's to 350 with a cost in salaries and overhead of $525,000; a savings of $7,500,000. Is it? The 350 employees may only be capable of producing $75,000,000 worth of goods and services with a new efficiency of $75,000,000/350 or $214,286. Cost has gone down but so has efficiency. A real gain would have been realized if the 350 employees produced $100,000,000 in goods and services. The claimed savings of $7,500,000 was more than offset by a loss in output of $25,000,000. The lesson is that cost savings must be weighed against production losses.

There are a number of process capability gains that cannot be quantified in terms of savings in dollars or time, such as customer satisfaction. Sometimes all the analyses and techniques do not tell the story. A survey or questionnaire sent to customers can say a lot that numbers cannot. This approach is very efficient. It prevents wasting time on guesses, theories, conjectures, etc. Surveys can be done for internal and external customers. An interesting variation of the survey approach is the Delphi method. This method queries groups of experts to arrive at a consensus on specific questions. Table 22 is an example. The impact of the results speaks for itself.

A tool introduced earlier - the flow chart - can go a long way in proving a process has been made more capable. By examining a flow chart of a process or system before an improvement has been made and comparing it to the flow chart for the same process after an improvement was instituted impacts can be identified. If there is less connectiveness, less redundancy, and the process simpler without a quality change, then the change is probably good.

An organizational structure is a specific relationship among and between human and non human resources in a productive system [Certo, 1993]. The interrelationships in the structure are designed to facilitate the use of each resource in such a way as to optimize the attainment of its mission. An organizational chart well suited for TQM is found in Figure 35. This structure consists of a lead group called the Executive Steering Committee (ESC), a Quality Management Board (QMB), Process Action Teams (PATs) and a group of Facilitators [ARPERCEN, N.D.] and [Dewar, 1980]. Each has a distinct role.

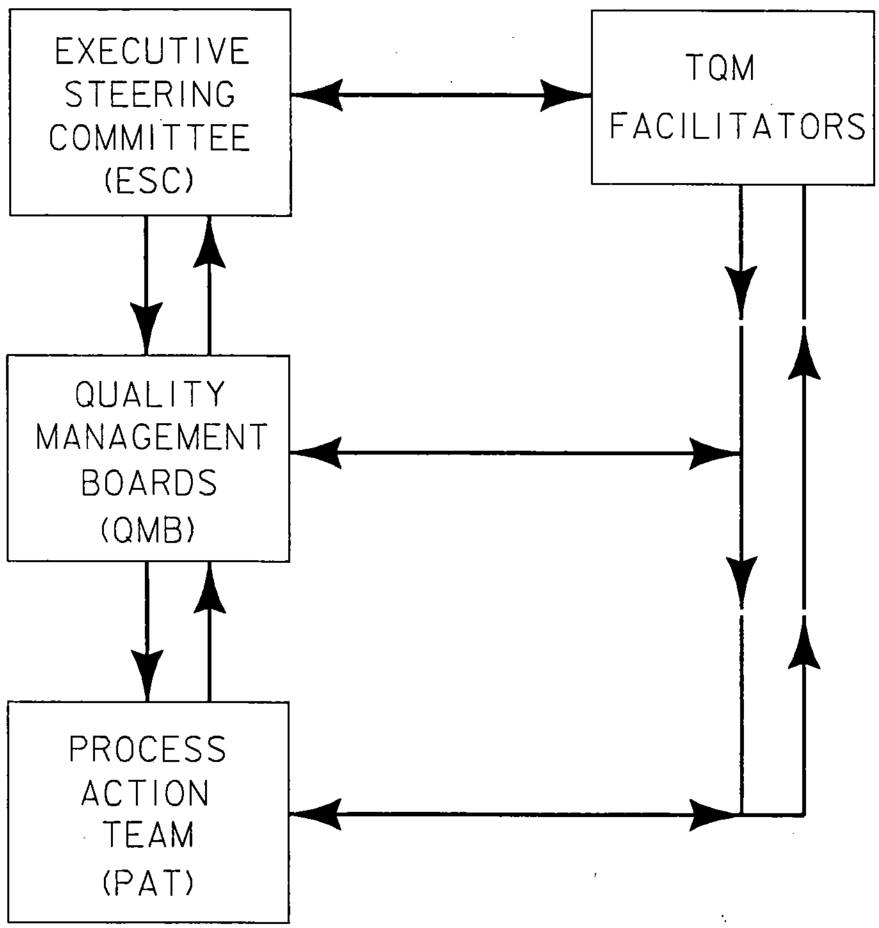
The ESC is a forum of people who direct the course of Quality Circle activities [Dewar, 1989]. A Quality Circle is a group of employees who are assigned a quality related problem to solve. The objective of quality circles are to:

- Implement constancy of purpose for quality improvements
- Improve communications
- Build in problem prevention
- Decrease cost and enhance productivity
- Find ways to meet customer needs

Figure 35 is a Quality Circle. The heart of the Quality Circle is the PAT. The ESC is much like a board of directors in the corporate world. Their prime reason for existence is to set goals and objectives and establish guidelines and controls for the organization. It is the policy making element of TQM. Membership in principle usually consists of a broad array of individuals from various backgrounds and disciplines. It is most often staffed by top management although a good case can be made to include other organizational personnel as a contribution to employee empowerment.

It is also possible for the ESC to operate with some members on a rotational basis to prevent patronization, to keep new ideas flowing, and to decrease group fossilization. Membership can also be extended to include labor, unions, equal employment opportunity members, educational interests, etc. or any desired interest. The Chairman of the ESC must be interested in an open interchange of ideas and accept voting as a basis for reaching consensus. The focus of the committee is on continuous process improvement within the system and between organizations. Membership also supports quality circle activities by providing as needed resources.

QMB's provide direction and guidance at a more detailed level. QMB's clarify ESC goals, objectives, and policy. These boards are assigned specific missions by the ESC, i.e., organizational cost reduction, organizational training, improvements in corporate communications, etc. Consequently, QMBs must precisely more define the activities for the PATs (described next). QMB members, like the ESC, can consist of any group of individuals but is frequently staffed by mid-level managers and supervisors. As with the ESC a good case can be made to mix membership. They can be thought of as project managers. Other QMB purposes are to provide PATs with the necessary resources, select PAT



STRUCTURE MAY VARY BASED UPON ORGANIZATIONAL NEEDS.

Figure 35
TQM Structure

membership, monitor PAT progress, and implement PAT recommendations.

The PAT is where the action is. The goal of the PAT is to carry out the assigned mission of the QMB in identifying problems and recommending solutions. There may be a number of PATs serving one QMB. Membership is frequently and most effectively made up of volunteers (6-10) and membership is best anchored when those knowledgeable about the QMB assigned mission are present. It may also include the customers as an effective PR program. The PAT leader is not usually appointed but rather evolves as a natural process of selection. The PAT team also requires a team recorder - usually a secretary but may be an engineer, economist or other specialty if the subject is highly technical. The PAT team leader may appoint subcommittee members from its ranks as needed for special tasks. PAT meetings are best when regularly scheduled and with a predetermined agenda. The PAT is dissolved when its assigned task is accomplished.

PAT teams generally undergo behavioral stages in group development and problem resolution [Toseland and Rivas, 1984]. The beginning phase is usually associated with orientation and resistance. A middle phase is often associated with group exploring and testing, problem solving, negotiation, bonding and cohesion. The final stage elicits such behavior as decision making, separation, and termination of purpose.

The initial phase of group behavior finds group members behaving in a tentative manner. This is often an uncomfortable phase where interaction is vacillating. There is hesitation and unwillingness to accept responsibility. Key fears are tied to suspicions. There is a fear of isolation, rejection, or hostilities emanating from self expression.

The middle stage is the collective feeling that interaction is potentially safe and even rewarding. Matters of autonomy, power and control begin to evolve. PAT members often turn to one another for support to build subgroups, and identify with the comfort of alliances. This is usually a high conflict stage where team members express anger toward the team leader or opposing subgroups. This enchantment, withdrawal, rejection, and confusion are frequent experiences.

The final stages of group interaction encompasses personal involvement, increases in moral, decreased conflict, and a deepening group commitment to the intended purposes. Motivation is high and trust has grown. This phase also sees spontaneous disclosure of feelings and opinions sought after. The group has matured as a working body with a common purpose and a high degree of consensus among members. This is also the phase of final decision making and a realization that the group purpose is coming to a close.

The facilitator (one per PAT team) coordinates PAT activities [Dewar, 1989]. He or she is selected to work with a PAT as soon as the PAT has been established and a task assigned. The ESC "or coordinator" selects the facilitator based upon its particular objective. The facilitator's role is to serve as a coach, teacher, coordinator, promoter, statistician, innovator, and enthusiast for the PAT. The duties of the facilitator are to attend PAT meetings, provide backup coordination, expedite, and smooth out the PAT proceedings. In defraying potential arguments the facilitator must sometimes attempt to create a win-win situation - not so easy a task. Facilitators must also avoid conflict of interest problems such as being impacted by the decision process..

Quality Circle failures are most frequently tied to a few important constituents. The most common reasons for nonsuccess include [Rosander, 1989]:

- Resistance to change.
- Insufficient knowledge.
- Poor materials to work with.
- Inadequate instruction or training.
- Conflicts arise between managers, supervisors, and facilitator whose early TQM goals differ.
- Unconvinced attitudes by managers and employees (this is another fad).
- Institutional barriers.

XVII - ORGANIZATIONAL TRANSFORMATION - THE PATH TO REDUCING COMMON CAUSE VARIATION

As a basis for implementing TQM we can examine the works of such experts as Deming, Juran and Shewhart. Although the principles and philosophies of these and others in the field may differ in some details, there is considerable overlap. Some of the principles endowed in the various proponents are nearly impossible to adapt in the short run for government because of statutory constraints. Despite these shortcomings we can "benchmark" from Deming's work; especially his "14 Points" [Deming, 1982]. These are provided in Table 23. As these basic paradigms are discussed, the reader must keep in mind that we are dealing with the transforming of large, established systems (government organizations) into operating with new processes.

Although Shewhart control charts were designed to measure process variation for factory or mass production systems they can easily be adapted to the service sector and the government. Some of the more significant differences attributable to service industries include [Rosander, 1989]:

1. Face-to-face meetings are more frequent between employees and customers.

2. Significant paperwork is generated.

3. Service problems and defects are related to human failure or equipment failure or both.

4. Control over variation is more difficult and less attainable because people vary more than manufactured parts.

With these differences in mind, let us now examine Deming's 14 points and how they relate to process control. Each point on Table 23 will be repeated before discussing it for reader convenience.

#1. Create constancy of purpose toward improvement of product and service, with the aim to become competitive and to stay in business, and to provide jobs.

Point One of Deming's philosophy is the quintessential ingredient for instituting TQM. The graphical equivalent to this statement can be found in Figure 19. The constancy of purpose is the striving of an organization to persist in removing special causes of product or service variation, then focus on a reduction in common cause variation through management action. This requires a continuous effort on the part of commanders, supervisors, and managers with the aid of employees. This particular philosophical goal is ideally suited for the use of Shewhart control chart procedures. If you do not adapt measurement techniques to detect and identify causes of product and service variation (uniformity) as governed by customer expectations then the transformation threshold will not be attained. In today's world this is a guarantee of death by fossilization. Determining what to chart can come from an organization's Corporate Priority List, a Statement of Goals, Tactical and Strategic Plans, or Vision Statements.

TABLE 23 DEMING'S 14 POINTS FOR ORGANIZATIONAL TRANSFORMATION [1/]	
1.	Create constancy of purpose toward improvement of product and service, with the aim to become competitive and to stay in business, and to provide jobs.
2.	Adopt the new philosophy. We are in a new economic age. Western management must awaken to the challenge, must learn their responsibilities, and take on leadership for change.
3.	Cease dependence on inspection to achieve quality. Eliminate the need for inspection on a mass basis by building quality into the product in the first place.
4.	End the practice of awarding business on the basis of price tag. Instead, minimize total cost. Move toward a single supplier for any one item, on a long-term relationship of loyalty and trust.
5.	Improve constantly and forever the system of production and service, to improve quality and productivity, and thus constantly decrease costs.
6.	Institute training on the job.
7.	Institute leadership. The aim of supervision should be to help people and machines and gadgets to do a better job. Supervision of management is in need of overhaul, as well as supervision of production workers.
8.	Drive out fear, so that everyone may work effectively for the company.
9.	Break down barriers between departments. People in research, design, sales, and production must work as a team, to foresee problems of production and in use that may be encountered with the product or service.
10.	Eliminate slogans, exhortations, and targets for the work force asking for zero defects and new levels of productivity. Such exhortations only create adversarial relationships, as the bulk of the causes of low quality and low productivity belong to the system and thus lie beyond the power of the work force.
11a.	Eliminate work standards (quotas) on the factory floor. Substitute leadership.
11b.	Eliminate management by objective. Eliminate management by numbers, numerical goals. Substitute leadership.
12a.	Remove barriers that rob the hourly worker of his right to pride of workmanship. The responsibility of supervisors must be changed from sheer numbers to quality.
12b.	Remove barriers that rob people in management and in engineering of their right to pride of workmanship. This means, abolishment of the annual or merit rating and management by objective.
13.	Institute a vigorous program of education and self-improvement.
14.	Put everybody in the company to work to accomplish the transformation. The transformation is everybody's job.

1/ Deming, W. Edwards. Out Of The Crises. MA: Massachusetts Institute of Technology, Center for Advanced Engineering, 1982.

These broad plans can be interpreted in detail starting with the Executive Steering Committee (ESC), further defined by a Quality Management Board (QMB), and carried out by Process Action Teams (PATs) with the aid of well trained facilitators. The actual charting can be carried out at any level. Each level can also use Pareto charts, flow charts, or cause-and-effect charts to isolate problems. This approach bodes well with employee empowerment and job ownership. It also fits into modern management philosophies such as Theory Y in McClelland's dichotomy of Theory X and Theory Y as depicted in Table 24.

The concept of constancy of purpose can be viewed as a four step system process. Figure 36 shows the four steps as a Plan-Do-Check-Act action plan. This figure is a flow chart representation of Figure 19. Note that the cycles in this figure are indicative of moving to the right on Figure 19. The basic tools and techniques described in this text can be employed at any stage along the path of the four step chart.

#2. Adopt the new philosophy. We are in a new economic age. Western management must awaken to the challenge, must learn their responsibilities, and take on leadership for change.

Point two is connected to point one but is more holistic in intent. Once established a customer friendly process is not self perpetuating. The reader should take note of the following: "A moment of truth is any episode in which the customer comes into contact with any aspect of the organization and gets an impression of the quality of its service" [Turner, 1993]. Remember why and who we work for. Adopting a new philosophy is not restricted to establishing the technical aspects of control charting. It is an attitude and a commitment to service which starts at the top and filters throughout an organization. Remember also as stated in the first part of this text that there are two customers; external and internal (Table 2). As illustrated in Table 25 customers want courteous behavior, they want their needs satisfied, your previous reputation follows you, word of mouth travels, and promptness is a major ingredient in service. Table 26 tells the story by type of service sector. Top of the line service retains customers. It maintains and creates jobs, too. It is interconnected with "partnering".

The new philosophy is connected to a term called "communication" which has been in vogue a long time yet two-way communications and "listening" often appear to be ignored. We often forget that communication contains things of value especially when feedback is part of the process. It must be remembered that communication; other than the written word or verbal exchange is also important. Nonverbal communications send a message as well (eye contact, ambulation, posture, localism, et al). Listening is not just hearing; it is the sharing of information and all its content. It is sometimes surprising to think that we actually need to be trained to listen when we hear so much. Another important characteristic of communication is that two-way is most effective, especially when both parties verbally acknowledge andunderstand the other's position. One-way can and does create misunderstanding.

Another element related to point two is a current management view of favoring short term gains over long term. "Buy now, pay later" is one of the reasons why American businesses are not keeping pace with Japanese businesses. It is also why COE elements may not be performing as

TABLE 24
MCGREGOR'S THEORY-X THEORY-Y ASSUMPTIONS ABOUT THE NATURE OF PEOPLE[1/]

Theory X Assumptions	Theory Y Assumptions
The average person has an inherent dislike for work and will avoid it if he or she can.	The expenditure of physical and mental effort in work is as natural as play or rest.
Because of this human characteristic of dislike of work, most people must be coerced, controlled, directed, and threatened with punishment to get them to put forth adequate effort toward the achievement of organizational objectives.	People will exercise self-direction and self-control in the service of objectives to which they are committed.
The average person prefers to be directed, wishes to avoid responsibility, has relatively little ambition, and wants security above all.	Commitment to objectives is a function of the rewards associated with achievement.
	The average person learns, under proper conditions, not only to accept but to seek responsibility.
	The capacity to exercise a relatively high degree of imagination, ingenuity, and creativity in the solution of organizational problems is widely, not narrowly, distributed in the population.

1/ Certo, C. Samuel. Principles of Modern Management: Functions And Systems. Allyn and Bacon, 1988.

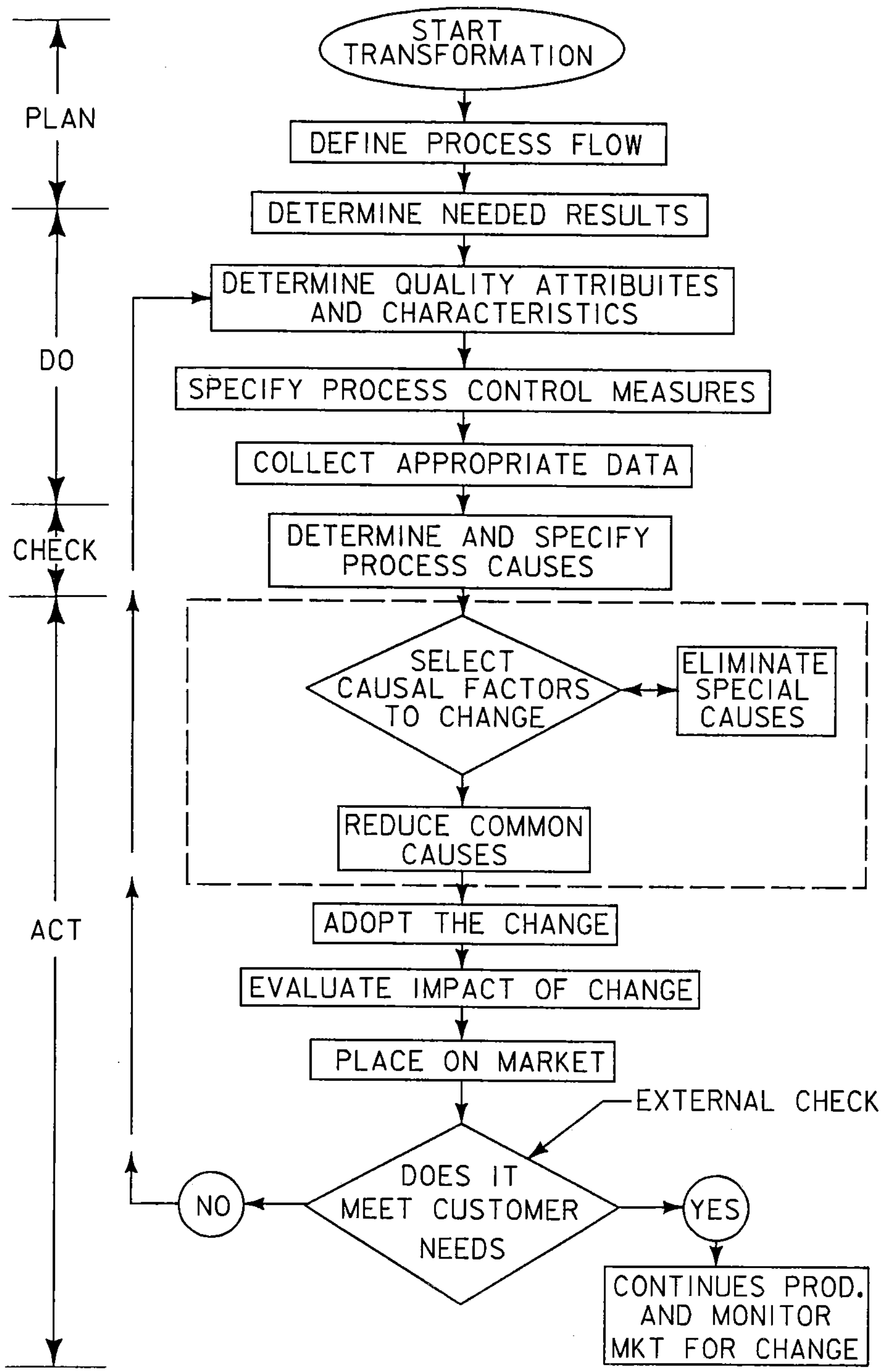


Figure 36
Continuous Process Control

TABLE 25
REASONS GIVEN FOR POOR QUALITY OF SERVICE[1/]

1.	Work not done right	39%
2.	Too slow	30
3.	Too expensive	20
4.	Indifferent personnel	20
5.	Unqualified personnel	12
6.	Lack of courtesy	10
7.	Poor service (unspecified)	10
8.	Lack of personnel	5
9.	Poor scheduling	4
10.	Reservation problems	2
11.	Poor food	2
12.	Miscellaneous	11
13.	No answer	1
	Total	166%

Condensed Table

Employee behavior, attitudes, competence	81%
Time (too slow)	30
Price (too expensive)	20
All other	35
Total	166%

1/ Consumer Perceptions concerning the Quality of American Products and Services conducted for the American Society for Quality Control, The Gallup Organization (Princeton, NJ: September 1985), pp. 39-40.

TABLE 26
REASONS FOR POOR QUALITY BY SERVICE INDUSTRY[1/]

Reason	Total %	Rep	Bank	Auto Insur	Govt	Hosp	Air Lines
1. Work not done right	39%	63%	19%	12%	19%	9%	5%
2. Employee behavior, etc.	42	15	45	39	44	60	32
3. Too slow	30	19	29	31	40	23	8
4. Too expensive	20	26	7	18	0	20	0
5. Poor service	10	5	15	8	6	6	3
6. Lack of personnel	5	1	6	1	6	12	0
7. All other	20	5	9	13	12	17	72*
Number of Interviews	593	256	104	96	91	83	52

* Poor scheduling 425, reservations 15%

1/ Consumer Perceptions concerning the Quality of American Products and Services conducted for the American Society for Quality Control, The Gallup Organization (Princeton, NJ: September 1985), pp. 39-40.

effectively as they could. District engineers have a two or three year planning horizon and sometime manage on that basis. Districts need a twenty year planning horizon as well. Short term, intermediate and long term planning are needed. Currently, there is little impetus to think of the district level in terms of twenty years. This may be true with other COE elements where leadership turnover is frequent.

Finally in order to institute a new philosophy, some old ideas need to be abandoned. Rules, regulations and guidance should not be adhered to exclusively. There are usually good reasons to have regulations but in many cases they were not meant to be exclusive. It is impossible to write regulations to cover every nuance and sometimes they just do not apply. They often become inflexible and tend to apply to everyone all the time; and sometimes to the point beyond reason. Such an attitude costs money and stymies creativity. They are the essence of a failing bureaucracy when interpreted in a ridged fashion. This requires an attitude change or a form of countervailing power. It also requires a rewriting of the rules and regulations so that an arthritic interpretation is the exception.

#3 Cease dependence on inspection to achieve quality. Eliminate the need for inspection on a mass basis by building quality into the product in the first place.

Point three is the epitome of bureaucracy. The process of inspection and reinspection or multiple layers of review is one of the prime forces behind delay and customer dissatisfaction. Once a report (Feasibility, PED) is finished it may take anywhere from 3 to 6 months for the review process to be completed. The internal steps include review by District, Division, OCE, WRLC, OMB, and sometimes special review. This says nothing about interim reviews and meetings. Inspection and reviews can be considerably reduced if consistency of purpose takes hold. Reduce the need for review by eliminating special causes of defects and be persistent in dealing with common causes.

#4 End the practice of awarding business on the basis of price tag. Instead, minimize total cost. Move toward a single supplier for any one item, on a long-term relationship of loyalty and trust.

Point four is complicated by law. This issue has merit but is fraught with a number of problems. Issues of fairness, monopoly power, minority employment, small business interests, patronization, etc. are factors the government must take exception to. Government is not strictly a business but must deal with social, environmental and related issues in a national context.

#5 Improve constantly and forever the system of production and service, to improve quality and productivity, and thus constantly decrease costs.

Point five is in part tied to points one and two. Point five, however, engenders a greater role for employees. Cost reduction is connected with special and common cause system defects. Eliminating or reducing them reduces cost. Remember the current practice is to plan for defects as part of doing business; we actually subsidize our own problems by allowing them to occur and pass the cost on to the customers in terms of "lower" quality products and services and built-in scrap or waste. Figure 37 vividly portrays this in terms of our control chart frequency distribution language. The topic of cost reduction is ideal for a QMB and several PATs. It is a target rich subject with the potential for many areas and charting variables, and many opportunities for cost savings.

There has been a surge in program, policy, and technical changes coming out of Washington in recent years under the guise of TQM. Everyone is tagging their new programs as a TQM endeavor. Some of these people may not know what TQM is and are only looking for "image" support by name association. They will do more to increase cost and confuse sincere efforts than any other special cause identifiable. These programs need to be screened by those trained or knowledgeable in TQM and terminated even if they took months to develop. If we do not, we will pay the price for years.

#6 Institute training on the job.

Point six is a necessary condition if transformation is to take place. Competition for quality products and services is keen and the cost of doing business during periods of financial constraint must be controlled. While technology has played an enormous role in the efficiency of operations and has certainly improved quality, it is people power that drive a process or system of production. A second look at Table 20 supports this contention. While almost any kind of new skill or knowledge acquisition is beneficial, training in the principles of statistical process control is paramount. This should include technical analysis as presented herein and transformation philosophy. The basic tools should include those listed in Table 18. The need for better skills in the use of statistical process control tools and philosophies is driven by a pragmatic requirement for data driven decision making in a time of increasing complexity (information age is causing data overload), rapidly changing (environmental, social, political, economic, and technical) conditions, and evolving customer needs. Advanced tools should also be a part of a training program and are listed in Table 27, as well. Other tools abound but those in the table are a good start. Remember, the most important aspect of TQM training is the understanding of variation; particularly for management.

#7 Institute leadership. The aim of supervision should be to help people and machines and gadgets to do a better job. Supervision of management is in need of overhaul, as well as supervision of production workers.

Point seven deals with leadership. Leadership in the Deming and Juran context is more than situational approaches, quality approaches and functional approaches. It means removing barriers to improvement and be teachers, coaches, facilitators and mentors. A leader's job is to help people. A good leader will be well informed, especially on the methods of determining process stability and capability, including where to look for improvement. It is far wiser to gauge employees on their ability to maintain process control than to gauge their inability to meet some target. Management by objective (MBO) and micro management are not the tools of today's leaders. Those who focus on process capability and product and service uniformity are the leaders. Traditional leadership skills have focused on situational leadership, functional leadership and qualities leadership.

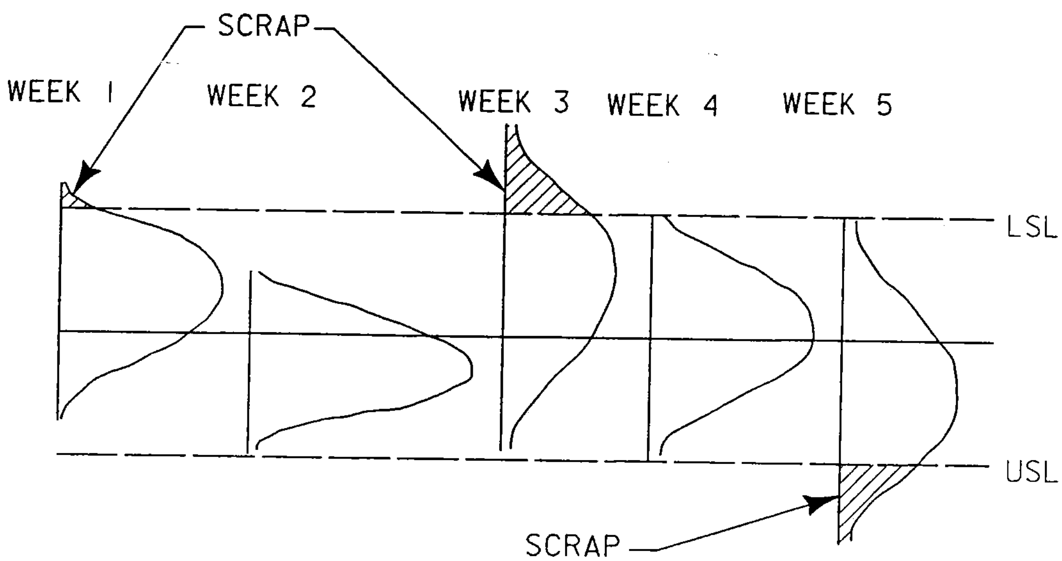


Figure 37
A Shifting Mean

TABLE 27
TOOLS, TECHNIQUES, AND RELATED TQM TRAINING

Who	Introductory What[1/]	Introductory How Long	Advanced What[1/]	Advanced How Long
General Staff	1-8	2-4 days	--	--
Supervisors	1-8	2-4 days	9, 12, 15	5-7 days
Middle Management	1-8	2-4 days	9, 12, 15	2-3 days
Upper Management	1-8	2-4 days	9, 12, 15	--
PAT Members	1-8	2-4 days	9, 12, 15	2-3 days
QMB Members	1-8	2-4 days	15	1-2 days
ESC Members	1-8	2-4 days	15	1-2 days
Facilitators	1-8	2-4 days	9-16 ,	10-15+ days

Note: All should receive annual refresher training and periodic updates.

1/ What
1. General Philosophy
2. Flow Charts
3. Cause-and-Effect Charts
4. Pareto Charts
5. Histograms
6. Run Charts
7. Scatter Diagrams
8. Control Charts
9. Sampling Theory
10. Regression Analysis
11. Correlation Analysis
12. Distribution Theory
13. Modeling/Simulation
14. Advanced Statistics
15. Advanced Control Charts
16. Measurement Techniques

Previously we had discussed and defined such concepts as process, system, quality and customer. We also covered the basic statistics underlying Shewhart control charts, control chart construction and interpretation. We also used the term "process capability". Capability was not defined earlier. A process can be said to be capable "if the natural process limits (3 standard deviations on either side of the mean) are less than specified tolerance limits" [Meek et al, 1986].

Process capability can only be performed on a stable system. That is, all special causes as noted in Figure 17 have been eliminated and only common cause variation or fluctuations remain. At this point the process is stable and no improvements can be made without working in the system. Any attempt to do so may adversely impact the process itself and make it worse off than before.

A process capability study requires an estimate of the process variance (S_x) which was done earlier for our permit reports. This can be accomplished in two ways. One is to employ Equation (4) and the other is to use $\bar{R}$ values in Equation (10). We will use data from the latter.

The mean range of our original data was 17.9 (Figure 12). Recall, however, that before a capability study can be performed, the system process must be under control and void of special causes. Thus, we need to recalculate our $\bar{R}$ values, assuming the out of control value of 53 (Figure 12) has been corrected with a new value of 30. The 30 value is arbitrary but was used to imitate a process in control. In doing this our new $\bar{R}$ value is 13.0.

We can now calculate an estimate of S_x by using the following:

Equation (15)

$$S_x(est) = \bar{R}/d_2$$

or

$$S_x(est) = 13.0/1.69 = 7.69$$

where d_2 is found in Table 15.

S_x is the estimated standard deviation of the sample distribution of means.

Note that the old process mean of 95.9 (Figure 16) was recalculated by first replacing the out of control value of 130 (Table 8a, #4) by the number 70 to arrive at a new $\bar{\bar{x}}$ of 94.4. The value of 70 was again arbitrary but necessary to eliminate the special cause effect of 130 and imitate a controlled state.

The new mean of 94.4 has been substituted for the old mean (with special causes) of 95.9 (Figure 17) again to imitate a controlled process.

Two more equations are needed to complete the process, one to establish an upper specification limit and the second a lower specification limit. The equation for establishing for upper specification limit is:

Equation (16):

$$Z_{USL} = (USL - \bar{\bar{X}})/S_x(est)$$

Figures 12 through 16 presented an example of how to construct a control chart using a fictitious but realistic example of report completion times in a regulatory branch. Figures 20 through 24 provide a second example of how to plot Shewhart control charts. This example, however, consists of an actual case study in an Economics Branch. It involved evaluating the number of hours a staff of five expends on unscheduled tasks per day for 20 consecutive days.

Figure 20 shows, as before, the beginning of the data recording stage. The row labeled "DATE/DAY" shows the work days 1 through 20. The period of time sampling started 1 February 1992. The alpha/numeric characters E1, E2, etc. represent employee 1, 2, etc. The values used in each row, i.e., 8, 3, 0 are the number of hours worked by employee E1 on unscheduled tasks; 8 hours on day 1, 3 hours on day 2, 0 hours on day 3, etc. The data in rows E2-E5 are interpreted in the same manner. The $\bar{X}$ row is the average for each column (8+7+5+3+0/5 = 23, 23/5 = 4.6) and the R or range values 8,7, and 10 are the ranges in values for each column. The plot points show little information at this point. By the way, unscheduled work here is defined as "doing work on activities not scheduled for that day", i.e., flash fires, changed priorities, etc.

Figure 21 represents a scatter diagram of all 20 consecutive days. Generally the data do not fluctuate a large amount except in day five on the $\bar{X}$ chart.

Figure 22 confirms the general observations of the previous figure that connecting the plot points shows some expected (common cause) variation with the point at day 5 showing a much larger movement (special cause?) than the other points on the $\bar{X}$ chart. The R chart shows good consistency. Day 19 on the R chart rises above the others but is not exceptionally out of line; we will keep an eye on it to see if it is or is not a special cause as well.

Figure 23 shows the plotting of the means of the $\bar{X}$ chart ($\bar{\bar{x}}$) and the R chart ($\bar{R}$). For calculating the mean of the $\bar{X}$ we use Equation (9) to plot the mean of the R chart we use Equation (10). The means on both the $\bar{X}$ and R charts collaborates our previous observations that both plots are fairly stable with some suspicion of day five on the $\bar{X}$ chart and to a lesser extent day 19 on the R chart. Note steps 1 and 2 at the bottom of the chart show the calculations.

Figure 24 shows the completed Shewhart control chart. In this figure, steps 3 and 4 are added to calculate the upper and lower control limits for the $\bar{X}$ and R charts, respectively. Our previous suspicions that day five on the $\bar{X}$ chart represented an out of control condition is correct; it is clearly outside the 3 standard deviation limits (instability, Figure 17a). Day 19 on the R chart is not fraught with an out of control condition. However, some evidence suggests that days 1 through 8 may reveal an out of control problem called "hugging" discussed earlier. There are 8 points in a row which

TABLE 22
HOW QUALITY OF SERVICES IS DETERMINED - MULTIPLE RESPONSE OF 1,005 PERSONS[1/]

1.	Courteous or polite behavior	21%
2.	Satisfy your needs	18
3.	Past experience	13
4.	Recommendation by others	12
5.	Promptness	12
6.	Price	11
7.	Attitude of personnel	10
8.	Helpful personnel	9
9.	Friendliness	8
10.	Reputation	7
11.	Advertising	6
12.	Personal attention	6
13.	Cleanliness	6
14.	Trouble-free accuracy	6
15.	Efficiency of staff	4
16.	Dependability	3
17.	All other	27
	Total	179%
Condensed Table		
Employee behavior, attitudes, competence		67%
Satisfy needs		18
Time (promptness, quick service)		12
Price		11
Experience		13
All other		58
	All Other	179%

1/ Consumer Perceptions concerning the Quality of American Products and Services conducted for the American Society for Quality Control, The Gallup Organization (Princeton, NJ: September 1985), pp. 39-40.

The key to improving quality and reducing costs is to discover system problems emanating from special causes and to have management continually reduce common cause variation in products and services. The path to continual improvement requires a change in attitude of corporate and government levels. Traditional management theories are diminishing in their effectiveness as witnessed by international competitiveness. Management, employees alone, and individual elements within organizations alone are not the key to improvement. To improve quality every element has to improve. For Districts in the COE to improve without other COE commands also going through the transformation will not work - we are interdependent but often operate independently. We need to work toward a common goal. TQM/TAQ provides the road map that shows the way to transformation or a quality organization to serve its customers with quality products and services.

Situational leadership states that in any group the situation encountered will lead to the person best suited to deal with the problem to emerge as the natural leader. While studies have shown that there is much merit to this approach to leadership, it does not state what to do when it is not possible to change leadership as situations arise. Situational leaders possess specific knowledge or skills not employable to all situations.

The functional approach relies on what a leader must do. Having the right qualities is an advantage as well as being knowledgeable in a particular discipline. Neither can substitute for realizing what has to be done in order to become an effective leader; it focuses on what leaders must do, not what they must be.

The qualities approach simply states that if a person has certain qualities, that person is likely to become a leader. Some of these qualities (historically) have included: integrity, courage, sense of duty, perseverance, imagination, and knowledge. The list can go on and on. This approach assumes leaders are born, not made. It is personality and character that are important. If this is true, there is little room for leadership training. How can someone who does not possess these traits select someone for a leadership position.

Some of the above may always be true to some degree. As is apparent, the Deming approach to leadership departs from standard theory and norms. It is the principle by which Japan choose their leadership in business enterprises. An important point is being made here.

#8 Drive out fear, so that everyone may work effectively for the company.

Point eight says to drive out fear. Fear is a negative and frequently destructive emotion that often results in lower quality products and services, increases costs, and demoralizes employees. Fear can often be picked up on control charts. Figure 38a and 38b are classic Deming examples [Deming, 1982]. In Figure 38a the supervisor is corrupting data as indicated by "hugging" just under the upper specification limit. Fear prevents him from showing non performance of his staff. Upper management set artificially high standards which could not be met due to system failures from common causes. Fear of not meeting a quota resulted in false reporting. Everyone losses. Figure 38b shows another case of where "hugging" dominates. In this case the responsible party decides to use a strategy of hiding in the norm (getting buried in the averages) to prevent from being discovered. The problem again was that the system of common causes has not been dealt with nor understood by those setting quotas.

Often the terms responsibility, accountability, error, blame, mistake, schedule, slippage, etc. are associated with some dire consequences. Fear takes over and more errors are made. The connotations are that you're no good! You screwed up! You idiot! Dirt bag! Low life! Note, you destroy self esteem and motivation which sometimes results in "getting even" and stymies creativity as well. Fear probably cannot be completely removed from a system and perhaps some fear is useful to motivate some employees. Fear should not be a strong nor dominant factor in a Deming enterprise. Remember, things go wrong due to common causes of variation which is management's responsibility (recognizing that there are poor performers).

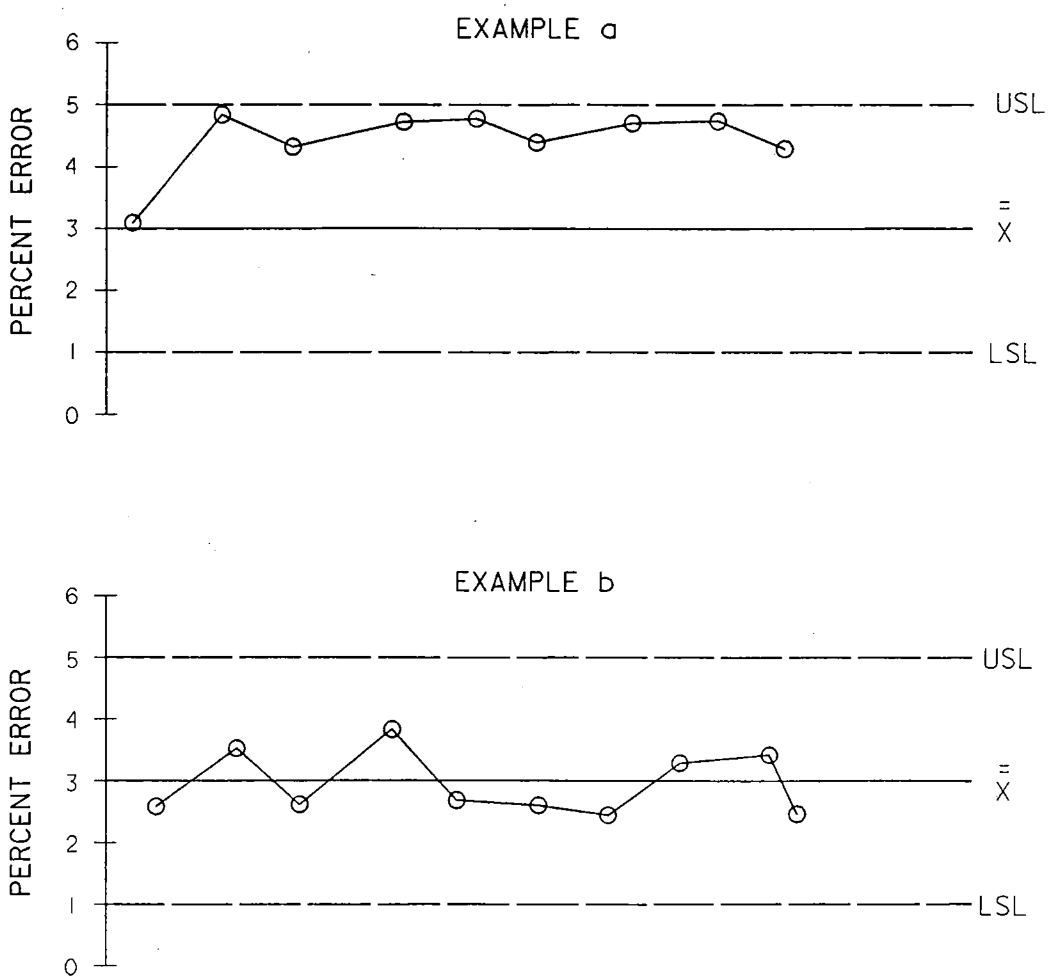


Figure 38
Examples of Fear in the System

#9 Break down barriers between departments. People in research, design, sales, and production must work as a team, to foresee problems of production and in use that may be encountered with the product or service.

Point nine is about teamwork. Only the process counts. If the purpose is to improve the process or system it will be necessary to form a multidisciplinary team approach and attitude. Team building is a process of getting groups of people to work toward a common objective or goal. In an effective team, group members are mutually aware of their own and the other guy's strengths and weaknesses. Individual differences are accepted and do not serve as barriers to the team's mission or function. This entails that interpersonal relationships have been established. Decisions are rational and all ideas and opinions are examined. Members are also aware of what their individual roles are as a team member and with the team's goal in mind.

A team can operate in a variety of ways. Two of the more common approaches that groups or teams can use to develop ideas and arrive at conclusions are brainstorming" and the "nominal group technique". These also tie in with communications.

Brainstorming is a group problem solving technique which allows for a broad array of creative solutions to evolve [Toseland and Rivas, 1984]. Essentially, each team member elicits a suggestion or suggestions which have potential for being a solution to a specific problem. A round-robin procedure can be employed. This technique encourages "wild ideas" as a stimulus-response mechanism for others. These ideas are recorded for potential use or implementation. The final choice of which idea or ideas to use may require other tools as discussed earlier such as Pareto charts, flow charts or a nominal group involvement.

During the brainstorming session, the total effort is focused on creative thinking rather than on analysis or evaluation. This is because analytical and evaluative processes can dampen the creative process. This is also done to thwart criticism which also impedes the creative thought process. There are four basic rules used to manage the group's behavior during the brainstorming sessions. They include: freewheeling, criticism is ruled out, lots of ideas are encouraged, and the merging or combining of ideas is encouraged.

The purpose of generating "wild ideas" embodies the encouragement of the expression of all ideas, regardless of how unusual or weird they might be. It is this type of behavior that often leads to new and better ways of accomplishing work activities.

Criticism is not wanted because this adversely effects creativity. This factor is often part of a group's written "code of conduct" to emphasize its importance.

One of the prime reasons brainstorming is so valuable is that quantity is a desired byproduct. One in ten ideas may be good and one in fifty may be outstanding, but among all of the ideas generated only a few will likely be adopted.

This technique seems and is simple. It is also very powerful and gets results. Also, the more heterogenous the membership the better the outcome.

A nominal group technique is similar to brainstorming but is more structured [Toseland and Rivas, 1984]. It differs because it focuses not on ideas but on consensus. Ideas are recorded an a blackboard or flipchart. The list is condensed to weed out duplicate notions and to clarify meaning. Priority is set by voting which ranks each selection by vote count. An action plan is established focusing on highest ranked solutions first, then proceeding down the list an the basis of order of importance. This is similar to the process used to develop a Pareto chart.

#10 Eliminate slogans, exhortations, and targets for the work force asking for zero defects and new levels of productivity. Such exhortations only create adversarial relationships, as the bulk of the causes of low quality and low productivity belong to the system and thus lie beyond the power of the work force.

Slogans, posters, declarations and buttons as stated in point ten do not promote TQM advancements. They are often image creating devices to impress the reader (an outsider or higher authority) that something important or significant is being done. The employees know better; they have seen this before. Such tactics fail to provide a method, and do not provide for leadership nor direction. They do not increase knowledge of the system or make it work better.

#11a Eliminate work standards (quotas) on the factory floor. Substitute leadership.

#11b Eliminate management by objective. Eliminate management by numbers, numerical goals. Substitute leadership.

Points 11a and 11b are very similar. As described earlier trying to impose output or similar quotas on a system which cannot produce such quotas is self destructive. Remember, a system is only capable of producing within its own limits regardless of any effort by any individual or group. Focusing on outcomes will result in less than optimum resource use. The effort needs to be placed on input and the process with a prime focus on satisfying customer needs. A plan focusing on continuous process improvement will bring better results. Imposing quotas or output constraints as a top down objective tends to introduce fear and provide a false measure of employee performance when in fact, it is the system (common causes) that fails. This is a management responsibility.

#12a Remove barriers that rob the hourly worker of his right to pride of workmanship. The responsibility of supervisors must be changed from sheer numbers to quality.

#12b Remove barriers that rob people in management and in engineering of their right to pride of workmanship. This means abolishment of the annual or merit rating and of management by objective.

Points 12a and 12b are interconnected. These barriers include those listed on Table 28. Quality should be substituted for numerical targets or quotas. It is enormously destructive to compel employees to meet such objectives because lower quality results when targets or quotas increase without matching process improvements. Employees feel they produce

TABLE 28 1/
BARRIERS TO PRIDE OF WORKMANSHIP

1.	Numerical quotas or targets
2.	Piecework
3.	Inappropriate reward system
4.	No understanding of the concept of variation
5.	Output reporting
6.	Performance appraisals
7.	Management based on budgets alone
8.	Fear
9.	Inadequate or poor purchasing policies

1/ Deming, W. Edwards. Out Of The Crises. MA: Massachusetts Institute of Technology, Center for Advanced Engineering. 1982.

garbage. This cannot be motivating and it certainly could reflect in a loss in customers

and subsidize defects. A phase frequently heard around many offices is "we don't have time to do it right the first time, but plenty of time to do it over". Many, if not most COE employees, have watched as pressured, higher level management or supervisors seeking to meet schedules have promised their bosses that something would be completed by such-and-such a date. The schedule was met at high expense in dollars and in moral with the completed product being of questionable quality and having to be redone again later at even higher expense. This is the wrong message! The sad part is that those involved know it; and so do their employees.

Employee rating systems are significantly flawed. The example above demonstrates that producing to meet a schedule is a highly rewarding endeavor. Employees operating under that system would appear incompetent and thusly treated. The problem rested with management.

Abolishment of a rating system in government is against statutory and regulatory mandates. However, Deming's notions about rating of employees based upon statistical analysis has some merit. It is possible to be rated as outstanding one year and average the next because of the system and circumstances.

#13 Institute a vigorous program of education and self-improvement.

Point thirteen is the backbone of the Deming version of TQM. It is also tied to point six discussed earlier. It covers both employees and managers. It also goes beyond point six which stressed skills necessary to do work and on the job training. Training needs to go beyond statistical process control to include cross training, training in related fields, and training for future needs. It is a long term view. This type of ethos broadens skills and capability to go beyond specialization. It also helps prevent job burnout and aids in retaining employees in the long haul.

#14 Put everybody in the company to work to accomplish the transformation. The transformation is everybody's job.

Point fourteen involves the leadership of an organization and the involvement and interest they convey in TQM. Interest must be real, sincere, and demonstrated by personal action and authoritative deeds. Quality is a management responsibility and a TQM approach must be driven by management. Enthusiasm will set an example and is necessary for a TQM paradigm to grow and permeate all levels of an organization.

TOTAL QUALITY MANAGEMENT

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13. ABSTRACT *(Maximum 200 words)*
The document was written as a functional user manual, reference, and implementation framework. There is encough information enclosed to provide the tools and techniques needed to fully implement TQM except perhaps for some fine details. It can serve as a guide for several years of TQM growth and development. It should be supplemented with periodic but continous outside training in the form of seminars and workshops. The reference in the bibliography are also very useful. The reader will likely find the material "intense" due to its technical character and will likely need to read the document two or three times before all the implications can be absorbed. Re-inventing government is bringing with it a whole new understanding of what management is about. TQM is a powerful element in that understanding.

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