CHAPTER

22

Total Quality Management

22.1 INTRODUCTION TO TOTAL QUALITY MANAGEMENT AND STATISTICAL PROCESS CONTROL

Introduction

When speaking about quality control, it is important to know the background of the key people behind developments in this field. Three people from Bell Telephone Laboratories, W. A. Shewhart, H. F. Dodge, and H. G. Roming, contributed much to statistical quality control (SQC) during its early years in the 1920s. Dr. W. Edwards Deming is considered to be the originator of total quality management (TQM), which includes management philosophy and style along with statistical process control (SPC). By the end of the 1930s, Deming (1938) had written a book, helped edit one (Shewhart, 1939) about statistical analysis in regard to quality control, and began working for the U.S. Census Office. During World War II, quality control rose to prominence and with it, the work of Deming. In the 1950s, his ideas on how companies should manage their people and processes were not widely accepted by American management. He took his ideas to Japan, where he started by assisting with their census and is credited with helping that country become highly successful in industry. TQM has two important elements to it: a management philosophy (the human aspect) and methods of process control (the process aspect). Philip B. Crosby has contributed much to the terminology and economic analysis of investments in quality improvement. Dr. Joseph M. Juran contributed to the organization methodology to implement and support project improvement. Juran (1951, 1962) believed that inspection of the final product is not an efficient or successful method of making high quality products. Instead, inspection of materials and methods should be made throughout the process. Quality should not be stamped on the product as the last step but should be incorporated throughout the process. One can discuss quality at length without defining it, but trying to achieve quality control means that specific goals must be kept in mind. Quality has many facets. One of the most obvious in paper products is product variation. It is always desirable to make one's product in a reliable and consistent manner. It is said that the color of your paper is not as important as making it the same color all the time. Quality is also the suitability of a product for its intended purpose. Another aspect is the cost. One can always make a quality product if money is no object; however, a quality product that few can afford does very little good unless you are contracting for the government. TQM involves more than just SPC, which is not a management style, only a tool. This aspect of TQM is considered separately. GOAL/QPC, an organization of proponents and practitioners of TQM in the

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United States, defines TQM as "a structured system for creating organization-wide participation in the planning and implementation of a continuous improvement process that exceeds the needs of the customer."

Deming (1982) has 14 points of management covering aspects of purpose, quality in products, eliminating waste, error and inefficiency, improving methods, removing fear in the workers, communication between departments, and implementing education and self-improvement programs. Deming points out that you pay for mistakes twice: once to make them and once to correct them. If you have 10% of your workers reworking products, that means 20% of your workforce is making and correcting mistakes. Deming also has a list of 66 questions in Chapter 5 to help managers understand their responsibilities. Managers should allow workers to work together in teams throughout this process. An important aspect of this is two-way communication between all parties with a sincere desire to work together, not just hand down orders. TQM assumes that, given the chance, workers (or suppliers) will perform best when they know and understand the company or process goals. Productivity should not be enforced by rules, regulations, monitoring, performance standards, and other degrading methods. Arbitrary standards, personnel evaluations, and other humiliating tools should not be used to increase production and efficiency from workers. One might summarize these aspects of TQM as "you catch more flies with honey than with vinegar." With paper, there are intrinsic tradeoffs in quality. Choices are made about which properties must be decreased to improve others. For example, for any type of paper, there is always a choice between tensile and tear strengths. Improving one means decreasing the other. However, once a choice is made, the tools of TQM and SPC can be used to maintain the process, reduce variation, and improve efficiency.

Deming's 14 Points for Management

Deming (1982) presents 14 points for management in his classic work. They are presented here concisely with examples relating to the pulp and paper industry, but Deming's work must be used to get the full meaning of them.

1. *Constancy of purpose to improve*. The purpose of a paper company is to make high quality paper in an efficient manner with little waste. Teams of employees should always be on the lookout to make the process better, especially with communication between and among all levels.
2. *New philosophies*. The pulp and paper world is a much different place than it was in the past. Management must now compete internationally and use present circumstances.
3. *Cease inspection as the means to quality*. Quality should not be stamped on the product at the end but built into the entire system so that quality is insured, not just a matter of chance.
4. *Do not consider the lowest price as the ultimate bargain*. For example, "Sawmill A" may sell wood chips at $85 per bone dry unit while "Sawmill B" sells wood chips at $90 per ton. "Mill A", however, has 1% more bark, 2% more fines, and 6% more pin chips and actually costs $10 extra per ton to process. Develop long-term relationships of loyalty and trust with suppliers rather than jumping around from supplier to supplier to try to save a dollar. When selecting a supplier for a part that is part of a larger assembly, it is wise to let the supplier help in the design process rather than just making specifications that later need to be altered at great expense.
5. *Always be looking for methods of improving the process*. Process improvement does not necessarily mean buying new equipment. Often the present equipment can be

improved or used more efficiently. The relative amounts of variation by each component of a system must be identified to determine if an improvement (such as new equipment) will actually mean a benefit. For example, it may be useful to work with chip suppliers to decrease the amount of overthick chips rather than purchase an additional chip slicer. It should be clear that putting out fires should be only a minor component of the process engineer's time. In the pulp and paper industry, however, it tends to be a major portion of the engineer's time. If more time were spent on improving the process, then little time would be spent on fighting fires. Unfortunately, the argument is that there is no time to work on the process because of all the fires to fight. This is only short-term thinking and, in the long run, will lead to ruin.

6. *Use on-the-job training*. On-the-job training is very successful because the tools being taught are immediately put to use. Deming says "the greatest waste in America is failure to use the abilities of people."
7. *Leadership*. The goal of leadership should be to help people and machinery do a better job. To merely demand increased productivity without improving the process will lead nowhere. If management spends its time supervising workers, then there are two people doing the same job.
8. *Drive out fear*. Setting production goals, other quotas, and demands of zero defect strongly imply "punishment" if they are not met. If one shows people how to do a good job or improves the process so a good job can be done, quality and production will automatically improve. Management should not assume the worker is failing; the failure may be attributable to the manager.
9. *Break down barriers between departments internally and customers and suppliers externally*. Chip suppliers must know what a pulp mill is looking for in wood chips and why it is important to the pulping process. Management must also promote internal teamwork.
10. *Do not use slogans, work targets, and exhortations to try to increase quality and production*. These techniques lead to fear by implied consequences as described earlier in (8). Furthermore, if the system was capable of higher productivity as is, why is that level of productivity not already being achieved?
11. *Do not manage by objectives, but by leadership*. As in (10), to demand more productivity is not as useful as showing people how the process or testing methods can be modified to achieve higher productivity.
12. *Remove barriers that rob people of pride in workmanship*. One barrier is the annual merit rating. Often the letter of the "law" is followed without the spirit of the "law" so that compliance may appear to be occurring, but in fact, is not. Workers must not feel that they are only following orders but that they are in control of the situation and responsible for the final product.
13. *Make education and self-improvement a goal*. People who are challenged and see growth in themselves will enjoy their jobs more and perform better in the long run.
14. *Everyone is involved in the transformation of the company*. Accomplishments are the result of team effort. This reduces duplication of effort and allows different departments to interact more successfully.

22.2 STATISTICAL PROCESS (QUALITY) CONTROL

Introduction

SPC or SQC involves data collection and analysis, modeling of systems, problem solving, and design of experiments. SPC can be summarized as the application of elementary statistical analysis to control a process. It is the scientific method applied to manufacturing. Shewhart (1939) made the following comparison:

Mass Production	Scientific Method
Specification	Hypothesis
Production	Experiment
Inspection	Test of hypothesis

Statistical Analysis

Statistical analysis of the process is a key part of SPC because it is crucial to determine the random variation and nonrandom variation can be controlled. Anyone who wants to implement SPC must understand elementary statistics, experimental design, and sampling techniques.

There are many good books on statistical analysis, so there is little point including all this information here, but some basic statistical equations are included later. When using statistical analysis, the underlining assumption is that all of the variation is random. SPC tools must be developed when the process is in control and there are no trends in the data. (This does not mean all of the product will be satisfactory, only that the operator is doing the best that he/she can with the equipment.) This is not always easily done because an apparent trend in the short run could be due to statistical fluctuation. Steps can be taken to decrease the random variation so that "actual" changes can be observed more easily.

Most aspects of statistical analysis in common use assume that statistical deviation follows the *normal distribution,* which is symmetrical and has a bell-shaped curve as shown in Fig. 22.1. Many statistical equations are only applicable to this distribution. Most measurements have variations that follow the normal distribution. Some, however, such as the time between failures, follow other distributions. These other distributions can be predicted but require tools

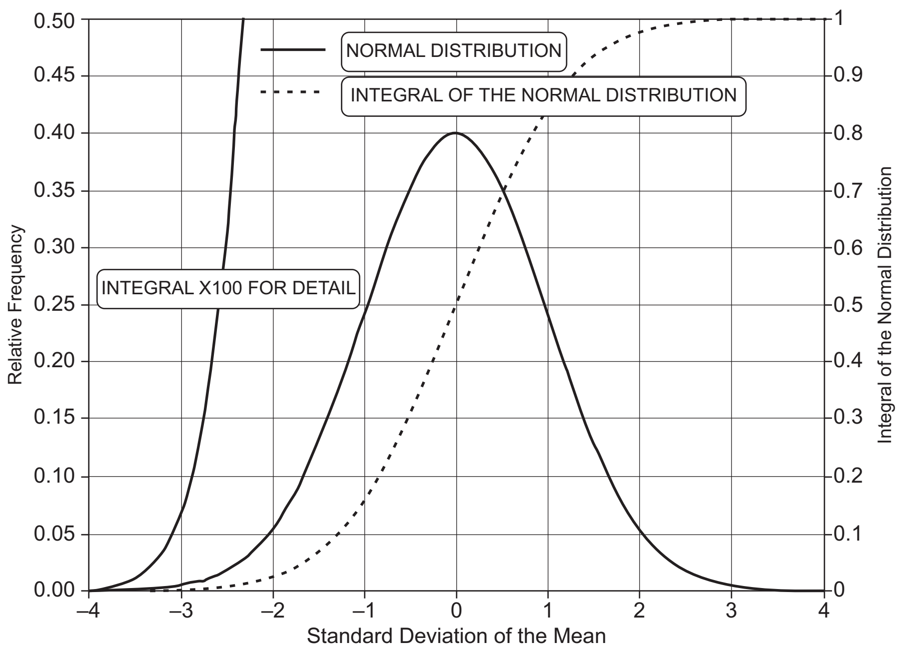

FIGURE 22.1 The normal distribution and its integral for determining probabilities.

generally found in advanced simulation or statistical analysis textbooks.

EXAMPLE 1

What is the probability that a sample from a normal distribution will be 1 or more standard deviations less than the mean?

Solution

The integral in Fig. 22.1 shows that 16% of the values lie below 1 standard deviation.

Because the curve is symmetrical, 32% of the values lie outside ±1 standard deviation of the mean.

EXAMPLE 2

What is the probability that a sample from a standard will be within 2 standard deviations of the mean?

Solution

Because 2.3% are below 2 standard deviations, 4.6 are outside ±2 standard deviations *(a)* of the mean. Stated conversely, 95.4% of the values lie within ±2*a* of the mean.

The invention of statistical analysis for process control can be credited to W. S. Gosset (1908). He published his work in 1908 under the pseudonym of Student because he knew the importance of statistics to control processes, and he did not want his competitors to know that he was using this tool. He discovered the *t*-distribution from a normally distributed population, which is defined as follows:

$$t = \frac{\overline{X} - \mu}{s/\sqrt{n}}$$

This distribution is still called the *Student's t*. The test is used to make inferences about the mean values of populations based on the measurements of relatively small numbers of samples. The value of t is analogous to z of a normal distribution, but the actual standard deviation is unknown and is approximated as s based on a finite sample size. The distribution is dependent on the sample size and approaches z for large sample sizes. Important process variables should be monitored using the concepts of statistical analysis. Process variables are loosely meant to be qualities of the raw materials, important variables in the process itself, and qualities of the product. In kraft pulping the key process variables of the raw material (wood) are chip species, thickness, moisture content, bark content, etc. The key pulping variables are H-factor and liquor characteristics. The key product variables are kappa number and cellulose viscosity. This is the field of SQC or statistical process control (SPC). These techniques should be second nature to any scientist, but they have met with opposition in production facilities where they are treated as one more fad brought down by management. One aspect of this is to reduce product variation. This assumes that all of the important variables are measured in timely manners. It is interesting to speculate on companies that join the SPC bandwagon, indicating that SPC is the best thing they have ever heard; what were these companies doing before they heard of SPC?

The Cost Versus Benefit of SPC

The cost of quality assurance throughout the manufacturing process is an important consideration. With too little quality assurance, high costs will result because there will be a high rejection rate at the end. Too much quality control and the tail wags the dog. The amount of quality control practiced depends on the intended use of the product. Transistors for consumer radios will not be made with the same tight specifications as electronic components designed for space satellites, so the level of SPC is appropriately different in these two products.

Inventions and new processes change the quality control picture dramatically. The best quality control in the design of vacuum tubes will never compete with the transistor, which is inherently of higher quality for most purposes. Computers and computer networks now make many aspects of quality control essentially automatic to the production worker. Data are collected continuously by sensors, sent to computers, graphed, and presented to operators. Recent trends, warnings of process variables going out of a specified range, and other information are given continuously. This allows the operators to see a potential problem long before the quality of the product is seriously affected. These automatic systems also save money by not requiring much operator time. Much of the drudgery of SPC, such as plotting points by hand, should be gone. For other data that are not collected automatically and for teaching purposes, computers with graphic packages should be made available.

22.3 STATISTICAL PROCESS CONTROL TOOLS

Data Collection

It is very important to collect useful data before trying to analyze them by charting and statistical analysis. TAPPI Standard Methods cover areas of sampling for paper, chips, and other materials. If the sample one obtains does not represent the material that is actually being used, then data analysis may do more harm than good by throwing people off track. This has been mentioned in various parts of this book already. For example, a bucket sampler that is filled by the first few chips off a chip truck potentially allows chip suppliers to put poor quality material in the truckload without detection. Mention was also made of a neglectful worker who would collect an entire shift worth of eight samples all at the same time but submit them hourly. Another point to consider is the sampling frequency. Generally, the more variability in a material, the more often it should be sampled. Wood has a very large amount of variability owing to the nature of the material. Wood is not like sodium hydroxide or other chemicals that have relatively little variation between batches. The accuracy of data is paramount. No amount of statistical analysis will detect errors in pulp kappa numbers that are all too low because a buret could not be filled to the top. Such an error is fixed and not random. One should also consider what variables should be tested. In the past, kraft mills tested wood chips on the basis of size for pulping. However, thickness is a much more suitable variable, and the industry now saves millions of dollars every year by testing and separating wood on the basis of its thickness.

Graphs and Charts

Data for SPC can be presented in any form in which data are commonly presented for analysis, presentations, and comparison. These tools include bar charts, histograms, line graphs, pie charts, scatter plots to relate two or more variables, Pareto charts, and control charts.

By graphing the data, *trend analysis* becomes much easier. It is virtually impossible to see subtle trends in data presented in a table, but they become more apparent when presented graphically. For example, one problem was seen to occur with a cycle of the same length as the bleaching cycle changeover from one species to another. By recognizing this fact, it became obvious that the problem was due to some carryover between two tanks. The cause of the problem could be verified by fiber analysis techniques. Once the source of the problem was recognized, several solutions were suggested in a brain-storming session, and the solution implemented with teamwork. One might define SPC as the presentation of useful, accurate information in a timely and useful manner (via the tools of elementary statistics).

Pareto Charts

Pareto charts were invented in 1906 by Vilfredo Pareto. He modified Lorenz type—plots that were first used to show unequal distribution of wealth (Juran, 1962). Pareto charts are histograms assigning failure to various causes. Often just a few causes result in most of the failures, just as a few people control most of the wealth. Fig. 22.2 shows a Pareto chart showing the cause of downtime on a paper machine.

Control Charts

One of the unique tools of SPC is the control chart devised by Dr. Walter A. Shewhart in 1924 (Juran et al., 1962). The control chart is a line graph where the x-axis is the independent variable and the y-axis is the process control parameter or variable. Fig. 22.3 shows a control chart for the kappa number of pulp going to the bleach plant.

Upper and lower boundaries of the "desired" values of y are plotted as lines. These are the upper control limit and lower control limit. The average value (X, said as "X-bar") is centered between the control limits. The range of the control limits, R, depends on the statistical variation of the process, the measurements of the process, and other variations. Usually the range is defined as ± 2 standard deviations of the mean so that 95% of the data points should be within the range if all of the variation is random (not systematic error such as a process upset). If it is defined as ± 3 standard deviations, it will include 99% of the data points. Control charts must be developed when the process is under statistical control, that is, all of the variation is random. Otherwise, the control limits will be in error. One can quickly see if the process control variable is within the control area. If the actual y values (kappa number in this example) are consistently within the boundaries, the process is said to be in control. This allows an operator to make changes when appropriate but not to try to make changes when no action is called for. The data for the chart in Fig. 22.3 were generated by a computer program (described at the end of the chapter) designed to give an average of 30 and a standard deviation of 1.5. In this

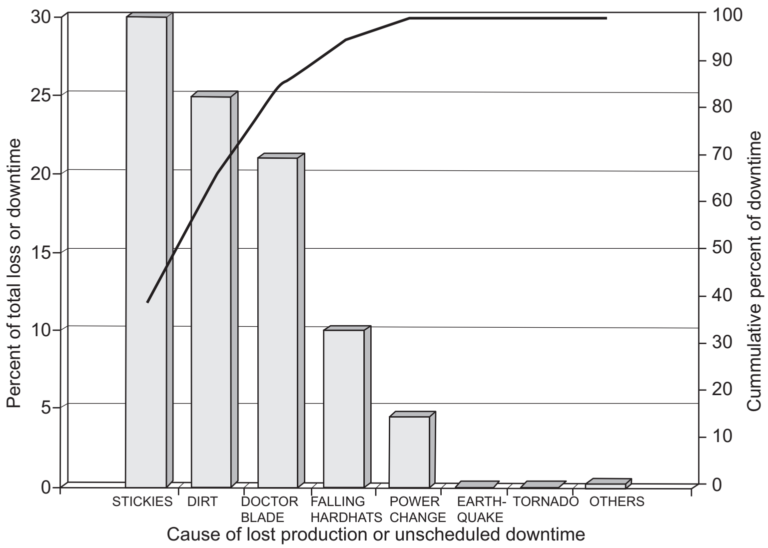

FIGURE 22.2 A Pareto chart for hypothetical downtime of a tissue paper machine due to web breaks.

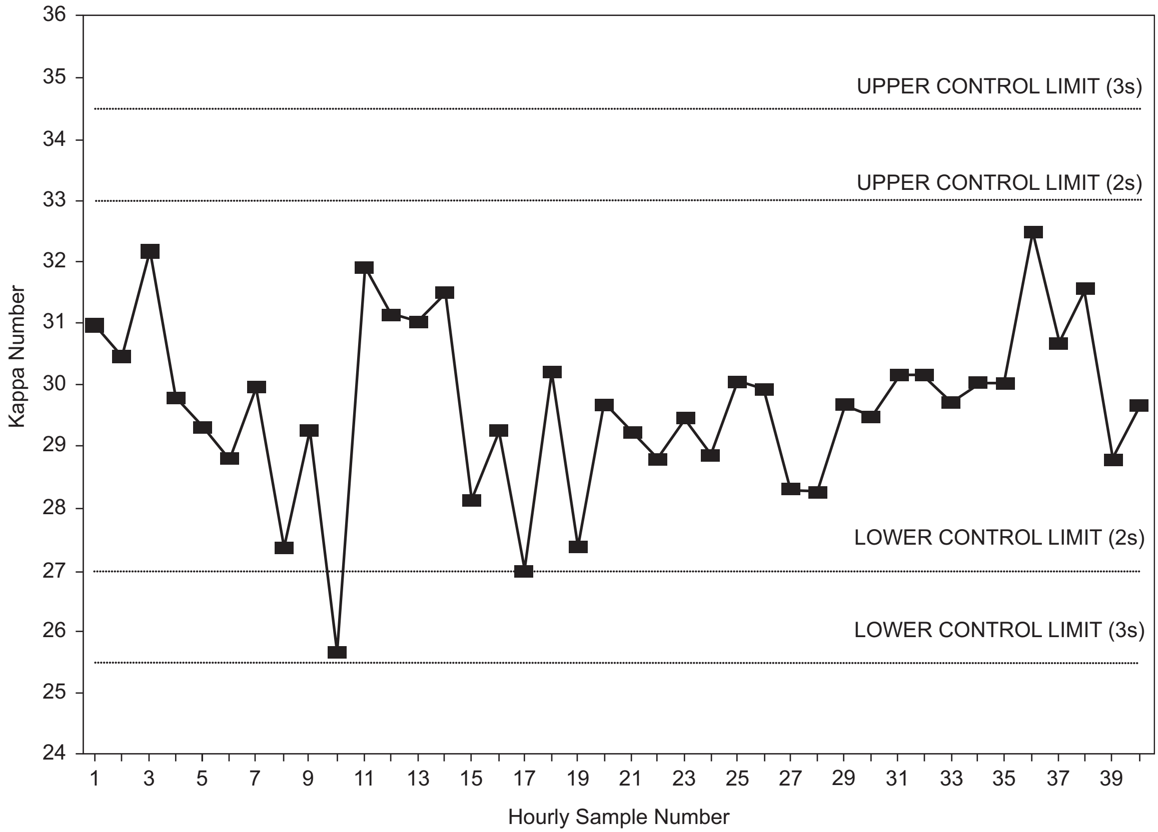

FIGURE 22.3 Control chart for the kappa number of bleachable pulp leaving the pulp mill.

case, all of the variation is random (unless, in the unlikely event, the random number generator used to generate the data is faulty). This data set has an actual average of 30.72 and a standard deviation of 1.45. If it is assumed that the kappa number should be between 27 and 33 for this grade of pulp, then the process or measurement of the process must be improved, as it is uncontrollable owing to the random error. In this case, one might try using an automated device to see if variability of measurement is an appreciable portion of the overall variation (in which case the kappa number may not actually be changing, but one would be tempted to control the process without realizing that). If this does not solve the problem then new SPC techniques that are being introduced in the pulp mill would probably decrease process variability of the pulp going to the bleach plant from the pulp mill.

22.4 IMPLEMENTING TOTAL QUALITY MANAGEMENT AND STATISTICAL PROCESS CONTROL

Commitment of Management

One statement about management that has a lot of truth is that an organization take on the attitude of their top manager (i.e., the attitude comes from the top down). For these tools to work, the top *management must be committed* to the techniques of TQM and SPC. Employees should be trained from the top down, with the level of detail higher at each lower level so that decisions can be made at the front line. The techniques and purposes of TQM and SPC should be explained to the satisfaction of the employees.

Training and implementation should go hand in hand to reinforce the learning process, and so, the relevance of the method is apparent. The expectations of each employee must be clear. Too often TQM and SPC are talked about at length, but what they are and how they relate to the process are never mentioned. For many people this is sheer frustration; for too many others, unfortunately, it is normal to discuss things at great length that they do not understand. Management must also be committed to solving problems once they are identified.

Specify Objectives and Goals Clearly

There must be specific goals and objectives in mind so that improvements can be ascertained. Often the goal might be to meet established specifications with less variation or reject product. Quality improvements often increase production by decreasing reject product. Vague goals cannot be measured, and so improvement cannot be ascertained. Suppliers, and all the other parties in the process, should be involved and kept up-to-date with clear communication. Not surprisingly, if people know what one wants and why it is necessary for one to have this, people will bend over backward to help you. If they do not know why you want something, you have only yourself to blame when you do not get it.

Effective Communication and Feedback

The key to letting people know what is expected of them is effective communication. Be sure to always let someone know when they are doing things well; do not just indicate to them when they are not doing things well. There must be effective feedback for any person to know how they are doing. One cannot control the basis weight of paper on a paper machine if one does not presently know what the basis weight is and what choices one has to change the basis weight. Moreover, a person cannot know how well he or she is doing if there is no feedback!

Verification of Data

It is important to insure that the collected data are correct. The accuracy of sensors should be checked periodically. One should always consider whether parameters are being measured in the most effective way possible. Other questions such as "is this the most effective process?" should be asked. As the systems come under control, the specifications can become tighter.

What to Avoid

One thing that should be avoided at mills is the writing of data by hand on charts or scraps of paper, especially when this data are to be used by others. Rewriting of the data, with the introduction of errors, is time wasted. Data that are directly entered into computer spreadsheets can be immediately evaluated graphically in many forms and transmitted to others who might make use of it. It is not uncommon to see the paper testing laboratory write down the test results (when the measuring devices could automatically enter the values into a computer system) on a scrape of paper to be given to the appropriate paper machine operator (when the "courier" happens to come by the paper testing laboratory) about 30 min later. The data are then rewritten on another chart. Later, others must manually look up the data for monthly production reports or other purposes. Occasionally one sees a small research laboratory in a mill with state-of-the-art equipment such as electronic basis weight scales that are used once or twice a day. Out in the production area, however, paper is still (slowly) weighed on a mechanical balance about eight times an hour with perhaps 2% or more error. One should think of the mill as a giant research experiment where the gathering and analysis of data are just as critical as in the most serious scientific work.

22.5 MISCELLANEOUS TOPICS

ISO 9000 Series Certification

The International Organization for Standardization (ISO) developed the ISO 9000 standards in 1987. The standards focus on 20 criteria of a quality control program. There are three levels of ISO 9000 certification. ISO 9001 is the most comprehensive and includes meeting requirements in design, production, installation, and servicing as applicable to the product. ISO 9002 includes meeting requirements during production and installation. ISO 9003 includes meeting requirements in product quality only by final testing and inspection. (ISO 9004 is a guidance document.) The European Communities (EC) will require most industries to have ISO 9000 certification. Rabbitt and Bergh (1992) give a useful summary of ISO 9000 certification.

Just-in-Time Concept

This concept means that inventory is kept to a minimum and parts are produced almost as needed. The "just-in-time" concept originated in post—World War II Japan. At that time, America was largely using the methods of Henry Ford, who developed the assembly line as a means of manufacturing large numbers of automobiles in an efficient manner. This included having large inventories of each piece that would be brought to the assembly floor in large quantities as needed. Japan simply could not afford to tie up any resource that would not soon become part of a product to be sold. Therefore, methods were developed, which coordinated the manufacture of individual parts with assembly of the whole item to limit the inventory at any time. Today it is realized that large inventories tie up large amounts of capital. Interest must be paid on this capital. Large building and storage costs also result.

22.6 EQUATIONS

A good description of elementary statistics is found in SCAN-G2:63 (1962), although any elementary statistics textbook will have similar information with more detail.

$$\text{mean} = \overline{X} = \sum x/n = (x_1 + x_2 + \ldots + x_n)/n$$

range = R is the difference between the largest and smallest values

standard deviation

$$= s = \left(\sum (X - \overline{X})^2 \Big/ (n-1)\right)^{1/2}$$

$$\text{coefficient of variation} = V = s/\overline{X} \times 100\%$$

22.7 ANNOTATED BIBLIOGRAPHY

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EXERCISES

1. Given the following two sets of kappa numbers, calculate the mean and standard deviation of each set.
   31.0, 32.2, 29.3, 30.0, 29.3, 31.9, 31.0, 28.1, 27.0, 27.3
   29.2, 29.4, 30.0, 28.3, 29.7, 30.1, 29.7, 30.0, 30.7, 28.8
2. Using Fig. 22.3 as a control chart, plot the following data and indicate where the process may be out of control and what the reason might be. These are kappa numbers taken every 2 hours of pulp going to the bleach plant.
   29.2, 29.6, 30.4, 28.9, 30.5, 31.1, 30.9, 31.4, 32.4, 32.2, 34.6, 33.9, 35.3, 34.8, 35.5, 35.8
3. Draw a Pareto chart of the following failures or downgrades during the month of December for rolls of paper.

Low burst strength, 10	low brightness, 4
poor sizing, 3	poorly wound, 18
defects in paper, 2	too narrow, 5

4. Using Fig. 22.1, what percentage of values from a normal distribution lie within 3 standard deviations of the mean and within 4 means?

APPENDIX—GENERATING RANDOM DATA WITH A NORMAL DISTRIBUTION

The data in Fig. 22.3 was computer generated by the program written below in BASIC. This program can be used to generate random data to simulate a process where all of the variation is random and not possibly controllable by the operator. Indeed, attempts to control the process only increase the variability. The data are easily plotted by *importing* the file into a program such as QuattroPro or generating it within QuattroPro with its random number generator.

```
5     OPEN "B:OUTPUT" FOR OUTPUT AS #1
10    RANDOMIZE
20    MEAN = 30: REM THIS IS THE DESIRED MEAN
30    S = 1.5: REM THIS IS THE DESIRED STANDARD
      DEVIATION
40    FOR I = 1 TO 40: REM GENERATES 40
      RANDOM NUMBERS WITH A NORMAL
      DISTRIBUTION
50    Y1 = 2*RND-1
60    Y2 = 2*RND-1
70    R = Y1*Y1 +Y2*Y2
80    IF (R>1 OR R = 1) GOTO 50
90    FAC = SQR(-2*LOG(R)/R)
100   NUM = FAC*Y1: REM THIS IS THE RANDOM
      NUMBER WITH MEAN OF 0 AND S OF 1
110   VAR = NUM*S+MEAN: REM THIS IS
      VARIABLE WITH THE DESIRED MEAN AND S
```

Continued

—cont'd

```
120    PRINT VAR,: PRINT#, VAR: REM PRINTS
       VARIABLE TO SCREEN AND FILE FOR
       GRAPHING LATER
130    STOTAL = (VAR-MEAN)*(VAR-MEAN)+
       STOTAL: REM FOR CALCULATING ACTUAL S
140    MEANTOT=TOTAL+VAR: REM USED TO
       CALCULATE THE ACTUAL MEAN FOR THIS
       SET
150    NEXT I
160    PRINT: PRINT "ACTUAL MEAN OF THIS
       SET = ",(MEAN+MEANTOT/I)
170    PRINT "ACTUAL STANDARD DEVIATION OF
       THIS SET = ",SQR(STOTAL/(I-1))
```

```
Run
Random number seed (-32768 to 32767)? 4

30.95114  30.44624  32.16494  29.78161  29.29416  28.76899
29.95173  27.35375  29.23539  25.62650  31.90901  31.10704
30.99176  31.46926  28.06687  29.24346  26.97691  30.21155
27.33691  29.65250  29.20096  28.75179  29.42387  28.79731
30.03629  29.88838  28.27955  28.22769  29.65059  29.44141
30.13715  30.13631  29.69470  30.01222  30.00990  32.50525
30.65970  31.54469  28.77460  29.65343

ACTUAL MEAN OF THIS SET = 30.72326
ACTUAL STANDARD DEV. OF THIS SET = 1.454831
Ok
```