Part II

Methods Engineering and Layout Planning

Chapter 8

Introduction to Methods Engineering and Operations Analysis

This part of our book contains four chapters that fit under the heading of methods engineering and layout planning. The techniques discussed in these chapters have the following basic objectives:

- To analyze existing work systems
- To make improvements in existing work systems
- To design new work systems
- To plan the facilities in which the work systems operate

Most of the techniques that we discuss are traditional industrial engineering "tools of the trade." Methods engineering is often associated with work measurement, discussed in Part III of the book. The two areas are often referred to collectively as "motion and time study." Many of the motion and time study techniques can be traced to the origins of industrial engineering, when it was referred to as the "scientific management movement." The techniques have been used to analyze, design, and measure work for many decades.

Methods engineering is a broader term than motion study. The scope of this field has expanded well beyond its original focus on human body motions to perform physical labor. We define ***methods engineering*** as the analysis and design of work methods and systems, including the tooling, equipment, technologies, workplace layout, plant layout, and environment used in these methods and systems.[1] Other names have sometimes been used to indicate the same basic approaches of methods engineering. These other names include ***work study***, ***work simplification***, ***methods study***, ***process re-engineering***, and ***business process re-engineering***.

The traditional objectives in methods engineering, whatever the name for this improvement activity, are the following:

- To increase productivity and efficiency
- To reduce cycle time
- To reduce product cost
- To reduce labor content

In addition, other objectives are frequently defined for process improvement efforts. Some of these additional objectives have a more contemporary appeal in today's society. They include the following:

- To improve customer satisfaction
- To improve product and/or service quality
- To reduce lead times and improve work flow
- To increase work system flexibility
- To improve worker safety
- To apply more ergonomic work methods
- To enhance the environment (both inside and outside the facility)

A term closely related to methods engineering is ***operations analysis***, defined as the study of an operation or group of related operations for the purpose of analyzing their efficiency and effectiveness so that improvements can be developed relative to specified objectives.[2] The specified objectives are basically the same as in methods engineering: to increase productivity, reduce time and cost, and improve safety and quality. Thus, methods engineering and operations analysis are very similar terms, except that methods engineering places more emphasis on design. Both terms are widely used in industrial engineering and this is why both names are included in our chapter title.

[1]The definition of methods engineering developed by the Work Measurement and Methods Standards Subcommittee [ANSI Standard Z94.11-1989] is the following: "That aspect of industrial engineering concerned with the analysis and design of work methods and systems, including the technological selection of operations or processes, specification of equipment type and location, design of manual and worker-machine tasks. May include the design of controls to insure proper level of output, inventory, quality, and cost."

[2]The definition of operations analysis developed by the Work Measurement and Methods Standards Subcommittee [ANSI Standard Z94.11-1989] is the following: "A study of an operation or scenes of operations involving people, equipment, and processes for the purpose of investigating the effectiveness of specific operations or groups so that improvements can be developed which will raise productivity, reduce costs, improve quality, reduce accident hazards, and attain other desired objectives."

8.1 EVOLUTION AND SCOPE OF METHODS ENGINEERING

The initial research in the area of methods engineering by Frank Gilbreth in 1885 dealt with the motions performed by workers in bricklaying (Historical Note 1.1). Motion study was truly an appropriate term for Gilbreth's research. The study of manual physical labor in manufacturing and construction was the primary concern of the scientific management movement in the late nineteenth and early twentieth centuries, and motion study was one of the two principal techniques used by the practitioners in that movement (the other, of course, was time study). Today, methods engineering is being applied in many other areas of work, including indirect labor, logistics, service operations, office work, and plant layout design. As these other areas have grown in importance in the economies of industrialized nations, methods engineering has been applied to analyze, improve, and design the work methods.

In terms of the problems that are addressed, methods engineering can be divided into two areas: (1) methods analysis and (2) methods design. ***Methods analysis*** is concerned with the study of an existing method or process, usually by breaking it down into the work elements or basic operations that comprise it.[3] By examining the details of the elements or operations, a systematic search can be carried out to find ways to improve the method or process. The systematic search often consists of checklists of questions and suggestions that offer opportunities for improvement. There are several objectives of using checklists in methods analysis:

- To *eliminate* unnecessary and non-value-adding elements or operations from the larger method or process
- To *combine* multiple elements or operations by performing them at one location and/or simultaneously
- To *rearrange* the elements or operations into a more logical sequence and work flow
- To *simplify* the remaining elements or operations so they can be accomplished more quickly and with minimum effort.

In addition to studying an existing method or process, methods analysis can also be used to analyze a proposed new method for possible improvements. In this regard the two areas of methods analysis and methods design overlap each other.

Methods design is concerned with either of the following situations: (1) the design of a new method or process or (2) the redesign of an existing method or process based on a preceding methods analysis. The design of a new method or process occurs when a new product or service is introduced and/or a new facility or equipment is installed, and there is no existing precedent for the operation. In this case, the method or process must be designed from scratch. This can often be accomplished by referring to best current practice for similar operations and attempting to improve on the current work design. In other cases, an original work design must be developed, including the basic operations,

[3]The definition of methods analysis developed by the Work Measurement and Methods Standards Subcommittee [ANSI Standard Z94.11-1989] is the following: "That part of methods engineering normally involving an examination and analysis of an operation or a work cycle broken down into its constituent parts for the purpose of improvement, elimination of unnecessary steps, and/or establishing and recording in detail a proposed method of performance."

methods, equipment, special tooling, workplace layout, and plant layout. As in other areas of design, guidelines are available, such as the principles of motion economy presented in Chapter 10 and the plant layout planning approach in Chapter 11, and these can be applied in solving the design problem.

Methods engineering studies have traditionally been the province and responsibility of industrial engineers. Today, methods analysis and design are no longer accomplished exclusively by industrial engineers. They are accomplished, with greater or lesser effectiveness, by a variety of individuals, departments, and teams. The workers themselves often participate in the development and improvement of their own work methods, under the assumption that they know their jobs better than anyone else. Industrial engineers often participate in these improvement activities, serving an important role as technical consultant and mentor.

8.2 HOW TO APPLY METHODS ENGINEERING

In this section we present a systematic approach that can be used to accomplish a methods engineering study. We then survey the tools and techniques used in such a study. Finally, we present a procedure for selecting among alternative possible solutions to a methods engineering problem.

8.2.1 Systematic Approach in Methods Engineering

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An underlying assumption in methods engineering is that a systematic approach is more likely to yield operational improvements than an undisciplined approach. Our systematic approach to problem solving in methods engineering has its basis in the *scientific method* used in science, research and development, engineering design, and other problem areas. The systematic approach in methods engineering consists of the steps described below.

problems
1- low productivity
2-waiting
3-poor layout
4-Inventory

Objective
1-improve productivity
2-reduce waiting time
3-change layout
4-Reduce Inventory

Step 1: Define the Problem and Objectives. The problem is the reason for needing a systematic approach to determine its solution. The problem in a methods engineering study may be low productivity, high cost, inefficient methods, or the need for a new method or a new operation. The objective is the desired improvement or new methods design that would result from the methods engineering project. Possible objectives are to increase productivity, reduce labor content and cost, improve safety, or develop a new method or new operation. These are the typical objectives discussed in our chapter introduction. The problem definition and objectives must be specific to the problem under investigation, although there may be similarities with other problems.

Step 2: Analyze the Problem. This step consists of data collection and analysis activities that are most appropriate for the type of problem being studied. The kinds of activities often used in this step include the following:

- Identify the basic function of the operation.
- Gather background information.
- Observe the existing process or observe similar processes if the problem involves a new work design.

- Collect data on the existing operation and document the details in a format that lends itself to examination.
- Conduct experiments on the process.
- Develop a mathematical model of the process or utilize an existing mathematical model such as those developed in Part I on work systems and how they work.
- Perform a computer simulation of the process.
- Use charting techniques such as those described in Chapter 9.

A survey of the analysis techniques used in step 2 is provided in Section 8.2.2.

Step 3: Formulate Alternatives. There are always multiple ways to perform a task or accomplish a process, some of which are more efficient and effective than others. Only by enumerating the alternative ways and comparing them can the most efficient and effective method or process be determined.[4] However, the purpose of this step in the problem-solving approach is not to identify the best alternative but to formulate all of the alternatives that are feasible.[5]

Step 4: Evaluate Alternatives and Select the Best. This step consists of a methodical assessment of the alternatives and the selection of the best solution among them, based on the original definition of the problem and objectives. The selection procedure described in Section 8.2.3 is useful in this step of the methods engineering approach.

Step 5: Implement the Best Method. Implementation means installing the selected solution: introducing the changes proposed in the existing method or operation, or instituting the new method or process. This may involve pilot studies or trials of the new or revised method preliminary to online implementation and application of the method. Implementation also includes complete documentation of the new or revised method and replacement of the previous documentation in the case of a revised method. Unless the old documentation is replaced, the old method may remain as the official method until a new methods engineering study is performed sometime in the future (thus reinventing the wheel).

Step 6: Audit the Study. It is desirable to perform an audit or follow-up on the methods engineering project. How successful was the project in terms of the original problem definition and objectives? What were the implementation issues? What should be done differently in the next methods engineering study? For an organization committed to continuous improvement, answers to these kinds of questions help to fine-tune its problem-solving and decision-making skills.

[4]In the scientific method as applied to research, the alternatives are typically the different proposed theories to explain the observed phenomenon. Ultimately, one theory is selected as the most reasonable in terms of explaining the phenomenon.

[5]Even the infeasible solutions should probably be included in the list. Sometimes the alternatives that initially seem infeasible turn out to be quite doable after all. What made them seem unacceptable on first consideration were artificial or false constraints that proved not to be constraints upon closer scrutiny.

8.2.2 The Techniques of Methods Engineering

A variety of techniques are available for operations analysis. The techniques are most closely associated with the analysis step in methods engineering, although they may also be applicable in some of the other steps as well. As a starting point, we have the basic data collection and analysis techniques discussed in Section 8.3. These are graphical and statistical methods for gathering, plotting, and displaying data. They include histograms and x-y plots as well as other charts and diagrams.

Beyond the basic data collection and analysis techniques, which are applicable in many disciplines other than methods engineering, there are the specialized analysis techniques more closely associated with operations analysis and industrial engineering. They are described briefly in the following sections and more completely in subsequent chapters.

Charting and Diagramming Techniques. There are many charting techniques available for collecting, displaying, and analyzing data on a given work system or operation sequence of interest. They can be classified into the following categories, which are discussed more completely in Chapter 9:

- *Network diagrams.* These are used for analyzing work flow (Chapter 3), assembly line balancing (Chapter 4), and project scheduling (Chapter 7). As noted in these earlier chapters, special algorithms are often available to analyze these network diagrams.
- *Traditional industrial engineering charting techniques.* These are used to symbolize and summarize the details of an existing operation or sequence of operations. The traditional charting techniques can be used to analyze the activities of one human worker, groups of workers, worker-machine systems, materials, parts, and products.
- *Block diagrams and process maps.* These diagrams represent alternative ways of depicting processes. They are sometimes used in place of the traditional IE charting techniques.

Motion Study and Work Design. This area of methods engineering is concerned with the study of the basic motions of a human worker while performing a given task. The basic motions include ***reach*** (using the hand to reach for an object), ***grasp*** (grasping the object), ***move*** (moving the object), and ***release*** (releasing it). All manual tasks performed at a single workplace are composed of these basic motions. There are 17 basic motion elements, most of which involve movements of the arm and hand. By studying the basic motions in the work method used by a worker, unnecessary motions can be eliminated, or some of the motion elements can be combined (for example, using both hands to simultaneously perform motions rather than one arm doing everything), or the method can be otherwise simplified.

Over many years, the study of basic motions in manual operations has resulted in the development of certain principles on how to perform work. Commonly called the ***principles of motion economy***, they provide guidelines for work design in three categories: (1) use of the human body in developing the standard method, (2) workplace layout, and (3) design of the tooling and equipment used in the task. Many of the principles are simple and obvious; for example, "design the work so that both hands are fully utilized." Yet simple work design principles such as these are often neglected in many manual operations performed throughout the world. By having these guidelines available, work methods can be designed to be safer, faster, more efficient, and less fatiguing.

Facility Layout Planning. A facility (e.g., factory, office building, warehouse, hospital) is a fixed asset of the organization that owns (or rents) it. ***Facility layout*** refers to the size and shape of a facility, the arrangement of the different functions and/or departments in it, and the way the equipment is positioned. The layout plays a significant role in determining the overall efficiency of the operations accomplished in the facility. Facility layout planning represents an important problem area in industrial engineering, and we discuss the techniques for solving it within the scope of methods engineering. The problem area includes designing a new facility, installing new equipment, retiring old equipment, and expanding (or contracting) an existing facility.

Plant layout planning and design are best accomplished using a systematic approach, similar to the systematic approach in methods engineering. As in other problem areas in methods engineering, there are tools available to use in a plant layout design project. The approach described in Chapter 11 is called "systematic layout planning," developed by Richard Muther [13].

Work Measurement Techniques. Several of the work measurement techniques discussed in Part III can also be used in methods engineering. We mention two that seem most relevant for studying and analyzing operations and methods: predetermined motion time systems and work sampling.

① A ***predetermined motion time system*** (PMTS) is a database of basic motion elements and their associated normal time values, and it includes procedures for applying the database to analyze manual tasks and establish standard times for the tasks. The principal application of a PMTS is to determine standard times. However, some systems also include tools for analyzing methods and motions in the task, which is a methods engineering function. Predetermined motion time systems are discussed in Chapter 14.

② ***Work sampling*** is a statistical technique for determining the proportions of time spent by workers or machines in various categories of activity. It can be applied to determine machine utilization, worker utilization, and the average time spent performing various types of activities. As such it can be a useful tool in methods engineering for identifying areas that need attention. For example, if a work sampling study finds that workers in a facility spend large amounts of their time waiting for work, then this is a management problem that should be addressed. Work sampling is covered in Chapter 16.

New Approaches in Methods Engineering. Nearly all of the preceding techniques have been used for many decades, some even longer.[6] More recently, alternative approaches for improving production and service operations have evolved from these traditional techniques. These alternative approaches include lean production (based on

[6]An example: Frank Gilbreth's interest in motion study dates from 1885 (Historical Note 1.1); his book, *Motion Study*, was published in 1911.

the famed Toyota Production System), total quality management, and Six Sigma. These approaches are discussed in Chapters 20 and 21.

It is the view of this author that most of the tools used in these more recent approaches are basically adaptations and modifications of good industrial engineering techniques and principles. Not to demean their importance, they are often used with good effect to identify and solve problems and to make improvements. And they sometimes successfully serve the function of providing a rallying point for motivating workers who might not be motivated by something called motion and time study. Their objectives are generally the same as the objectives of methods engineering, and we include them in Part IV of our book, titled New Approaches in Process Improvement and Work Management.

8.2.3 Selecting Among Alternative Improvement Proposals

Evaluating the alternative improvement proposals and selecting the best among them (step 4 in the systematic methods engineering approach) can be a difficult process in methods engineering. As always, it is helpful to use a systematic procedure to decide which improvement proposal(s) should be selected. The procedure recommended here is most applicable when the selection is to be made among specific proposals—for example, alternative process designs or different equipment proposals from vendors. The alternatives have been developed to address a specified problem or a need of the customer organization. Each proposed solution has its relative strengths and weaknesses, and the selection procedure must weigh the pros and cons in a fair and logical way. The procedure is explained as follows.[7]

Prior to the development of proposals, a list of technical features and functional specifications for the given application must be prepared by the customer organization. This is an essential part of the problem definition step (step 1) in the methods engineering approach. The operations analyst(s) or equipment vendors will use this list as the basis for formulating alternative solutions and proposals (step 3 in the systematic approach). The same list will be used by the customer organization to evaluate the proposals. The features and specifications should be divided into two categories:

1. *Must features.* These are the features and specifications that the proposal must satisfy. If these are not satisfied, then the proposal is not suitable for the application.
2. *Desirable features.* These are features and specifications that are not necessarily required to satisfy the application, but they are desirable.

After all of the proposals have been submitted, the evaluation process begins. The tabular format shown in Table 8.1, sometimes referred to as a ***criteria matrix***, is used. First, the proposals are evaluated against the must features. A candidate proposal must satisfy all of the must features or it is dropped from further consideration.

[7]Although we are presenting this selection procedure as a decision-making tool in methods engineering, its applications are much broader and more diverse. For example, it can be used for selecting which new car to buy, deciding which job offer to accept (assuming there is more than one offer), or even choosing a prospective spouse.

TABLE 8.1 Evaluation of Alternative Industrial Robots for a Welding Application in Example 8.1

	Industrial Robot Candidates			
	Model A	Model B	Model C	Model D
Must features:				
Continuous path control	OK	OK	OK	OK
Six-axis robot arm	OK	OK	Not OK	OK
Walkthrough programming	OK	OK	OK	OK
Desirable features:				
Ease of programming (0–9)	6	4		6
Capability to edit program (0–5)	4	2		5
Multipass features (0–4)	2	2		2
Work volume (0–9)	5	8		6
Repeatability (0–5)	5	2		4
Lowest price (0–5)	4	5		3
Delivery (0–3)	1	1		3
Evaluation of vendor (0–9)	6	5		8
Totals:	33	29		37

Source: [6].

Next, the proposals are compared against each of the desirable features. For each feature, a rating score is given to each candidate to indicate how well it satisfies that feature. No doubt there will be differences in the relative importance of the different features, and this is taken into account by assigning a maximum possible point score to each desirable feature. For example, if a particular feature is judged to be twice as important as another, then the more important feature is assigned a maximum score of, say, 10 points, while the less important feature is given a maximum of 5 points. These maximum point scores are judgment calls made by the methods engineer or by the collective wisdom of the project team doing the selection. Scoring each proposal on each feature is also a judgment call based on the relative merits of each candidate.

Finally, for the proposals that still remain after elimination of those that failed one or more of the must features, the scores of each proposal are tallied and the proposal with the highest total score is selected as the winner.

Of course, economics must play a role in the selection process. One might be inclined to simply choose the low cost bidder. However, that is often a mistake. Cost is rarely the only factor in implementing a new process, purchasing a piece of equipment, or making other investment decisions. The cost factor can be included as one of the desirable features in the list and given an appropriate weighting score to reflect its importance. The following example illustrates the use of this procedure to select a robot for a welding application.

Example 8.1 Selecting a Welding Robot[8]

Four industrial robots were being considered to satisfy an arc-welding application at the company. They are identified in Table 8.1 as Models A, B, C, and D. As suggested in the selection

[8]This example is based on an industrial case study in which the author participated. The case study was first reported in [7]. The company remains anonymous.

procedure, the features and specifications are divided into two categories: "must" and "desirable." The must features were considered essential for the application. The desirable features were assigned maximum point scores as shown in the table. The entries in the table for each robot indicate how that candidate was scored in each of the features. Note that one of the features was price, but it was not considered to be the most important feature.

Conclusion. First, model C was eliminated from consideration because it did not satisfy one of the "must" features. For the three remaining models, model D was selected because it had the highest point score among the desirable features. ∎

8.3 BASIC DATA COLLECTION AND ANALYSIS TECHNIQUES

The data collection and analysis techniques discussed in this section are used by scientists, engineers, mathematicians, and statisticians.[9] Most of them are statistical charting tools used to record and/or exhibit data so that it can be interpreted more readily. The techniques also have value for analysis. When used to measure and analyze production and service operations, these statistical tools are often associated with a field known as ***statistical process control*** (SPC).[10] Statistical process control and other quality-oriented programs are discussed in Chapter 21. In these programs, worker teams are organized to study operational problems. To enable the teams to be more effective, they are trained in the use of these basic tools. Thus, industrial engineers are not the exclusive users of these techniques in operations analysis. Instead, IEs must often serve as team leaders, training instructors, and expert consultants for the worker teams who carry out the studies.

Histograms. A ***histogram*** is a statistical graph consisting of bars representing different values or ranges of values, in which the length of each bar is proportional to the frequency or relative frequency of the value or range, as shown in Figure 8.1. Also known as a bar chart, it is a graphical display of the ***frequency distribution*** of the numerical data. What makes the histogram such a useful statistical tool is that it enables the analyst to quickly visualize the features of a complete set of data. These features include (1) the shape of the distribution, (2) any central tendency exhibited by the distribution, (3) approximations of the mean and mode of the distribution, and (4) the amount of scatter or spread in the data.

Example 8.2 Frequency Distribution and Histogram

Part dimension data from a manufacturing process are displayed in the frequency distribution of Table 8.2. The data are the dimensional values of individual parts taken from the process, while the process is running normally. Plot the data as a histogram and draw inferences from the graph.

Solution: The frequency distribution in Table 8.2 is displayed graphically in the histogram of Figure 8.1. We can see that the distribution is normal (in all likelihood), and that the mean is

[9] This chapter is based largely on Section 21.3 in [7].
[10] Although we are giving due recognition to the field of statistical process control, it should also be noted that many of these basic tools have been taught for many years in industrial engineering courses and used by practicing industrial engineers to study problems in methods engineering and operations analysis.

TABLE 8.2 Frequency Distribution of Part Dimension Data

Range of Dimension	Frequency	Relative Frequency	Cumulative Relative Frequency
$1.975 \leq x < 1.980$	1	0.01	0.01
$1.980 \leq x < 1.985$	3	0.03	0.04
$1.985 \leq x < 1.990$	5	0.05	0.09
$1.990 \leq x < 1.995$	13	0.13	0.22
$1.995 \leq x < 2.000$	29	0.29	0.51
$2.000 \leq x < 2.005$	27	0.27	0.78
$2.005 \leq x < 2.010$	15	0.15	0.93
$2.010 \leq x < 2.015$	4	0.04	0.97
$2.015 \leq x < 2.020$	2	0.02	0.99
$2.020 \leq x < 2.025$	1	0.01	1.00

around 2.00. We can approximate the standard deviation to be the range of the values (2.025–1.975) divided by 6, based on the fact that nearly the entire distribution (99.73%) is contained within $\pm 3\sigma$ of the mean value. This gives a σ value of around 0.008. ■

Pareto Charts. A ***Pareto chart*** is a special form of histogram, illustrated in Figure 8.2, in which attribute data are arranged according to some criteria such as cost or value. When appropriately used, it provides a graphical display of the tendency for a small proportion of a given population to be more valuable than the much larger majority. This tendency is sometimes referred to as ***Pareto's law***, which can be succinctly stated:

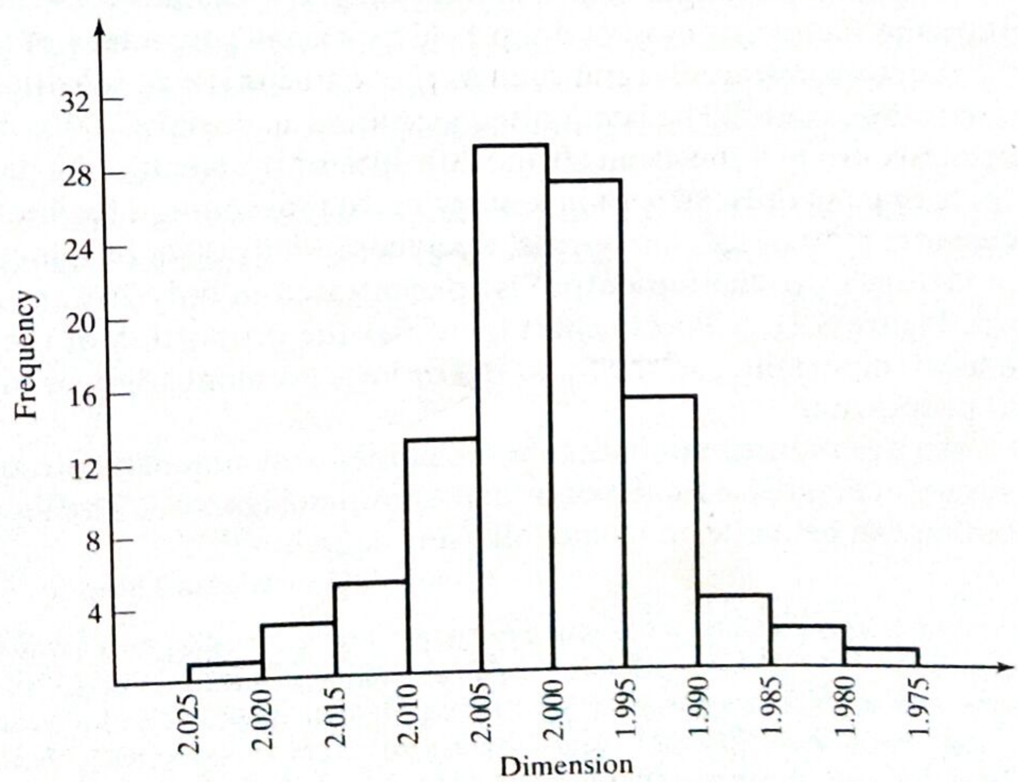

Figure 8.1 Histogram of the data in Table 8.2.

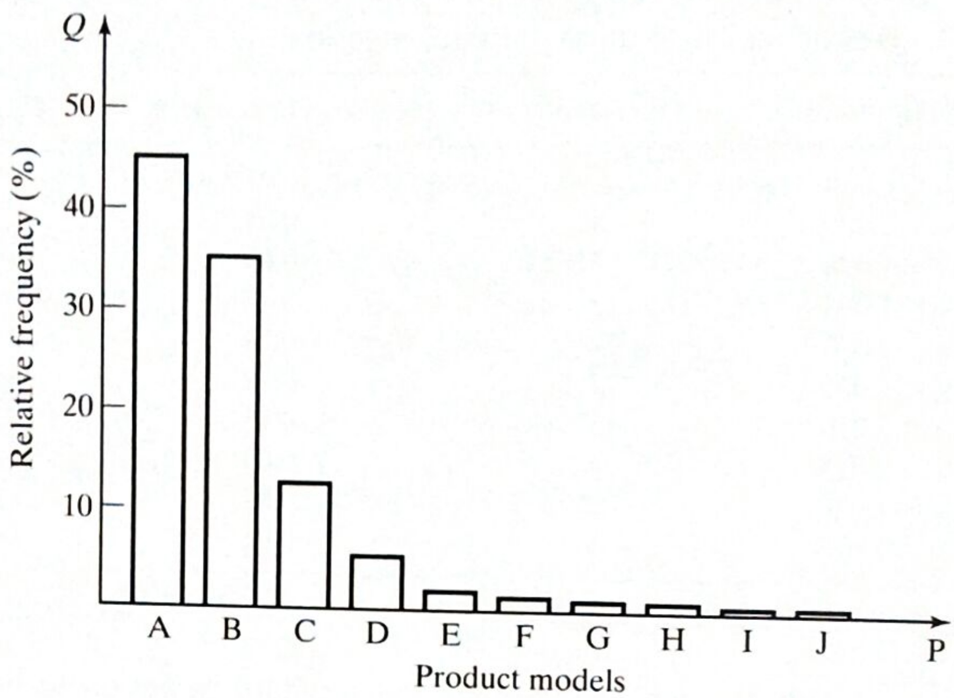

Figure 8.2 Typical (hypothetical) Pareto distribution of a factory's production output. Although there are ten models produced, two of the models account for 80% of the total units. This chart is sometimes referred to as a *P*-*Q* chart, where P = products and Q = quantity of production.

"the vital few and the trivial many."[11] The "law" was identified by Vilfredo Pareto (1848–1923), an Italian economist and sociologist who studied the distribution of wealth in Italy and found that most of it was held by a small percentage of the population.

Pareto's law applies not only to the distribution of wealth, but to many other distributions as well. The law is often identified as the 80%–20% rule (although exact percentages may differ from 80 and 20): 80% of the wealth of a nation is in the hands of 20% of its people; 80% of inventory value is accounted for by 20% of the items in inventory; 80% of sales revenues are generated by 20% of the customers; and 80% of a factory's production output is concentrated in only 20% of its product models (as in Figure 8.2). A Pareto chart identifies the proportion of the population that is the most important, and the focus in any improvement study or project should be on that proportion.

A Pareto distribution can also be plotted as a cumulative frequency distribution, as shown in Figure 8.3 for the same data shown in Figure 8.2. The Pareto cumulative distribution can be modeled by the following equation:[12]

$$y = \frac{(1+A)x}{A+x} \quad \text{for} \quad 0 \le y \le 1 \quad \text{and} \quad 0 \le x \le 1 \tag{8.1}$$

[11] The statement is attributed to J. M Juran [8].
[12] Based on Bender, P., "Mathematical Modeling of the 20/80 Rule: Theory and Practice," *Journal of Business Logistics*, Vol. 2, No. 2, 1981, pp 139–157.

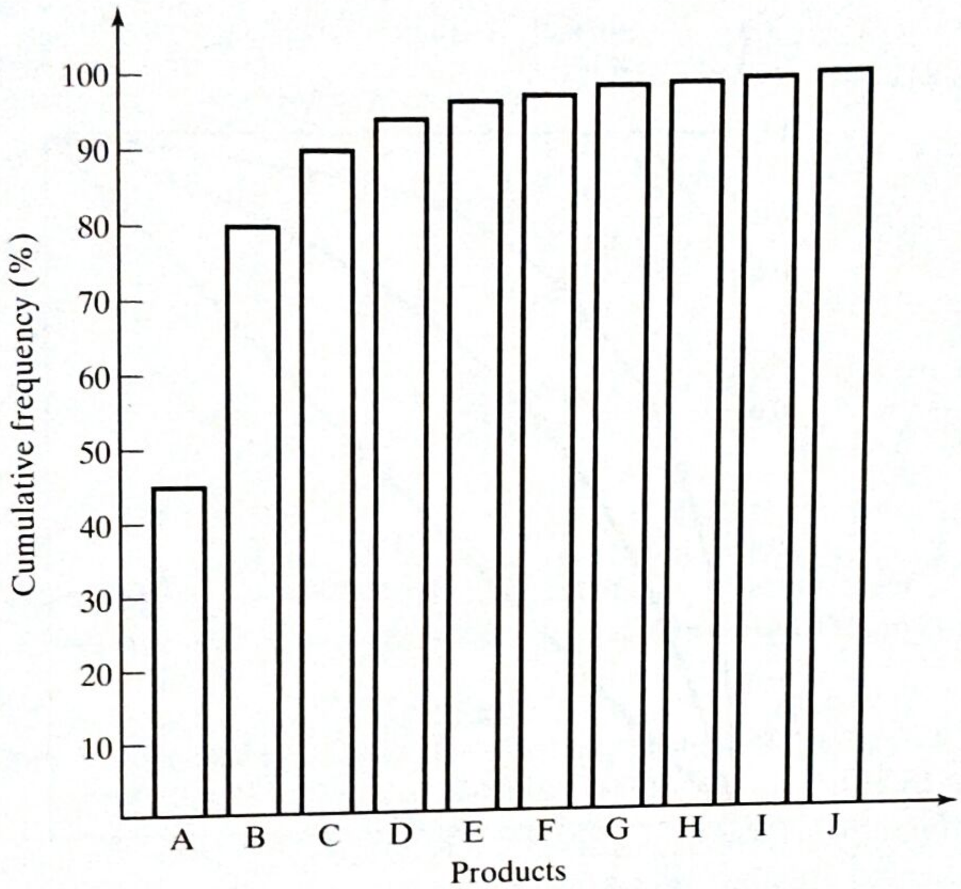

Figure 8.3 Pareto chart plotted as a cumulative frequency distribution for the same data shown in Figure 8.2.

where y = cumulative fraction of the value variable (e.g., wealth, inventory value, sales revenue), x = cumulative fraction of the item variable (e.g., population, inventory items, customers), and A is a constant that determines the shape of the distribution. Values of A between zero and infinity provide shapes that possess the Pareto characteristic, as shown in Figure 8.4. When $A = 0$, the equation reduces to $y = 1$ for all x, and when $A = \infty$, the equation becomes $y = x$.

To determine the appropriate value of A for a given situation or set of data, equation (8.1) can be rearranged to solve for A as a function of x and y, as follows:

$$A = \frac{x(1-y)}{y-x} \tag{8.2}$$

where x and y are the cumulative frequencies of the two variables at a given point in the distribution. The following example illustrates the approach.

Example 8.3 Pareto Cumulative Distribution

It is known that 20% of the total inventory items in a company's warehouse accounts for 80% of the value of the inventory. (a) Determine the parameter A in the Pareto cumulative distribution equation. (b) Given that the relationship is valid for the remaining inventory, how much of the inventory value is accounted for by 50% of the items?

Solution **(a)** To find A, we use equation (8.2) given that $x = 0.20$ and $y = 0.80$ (20% of the items, 80% of the value).

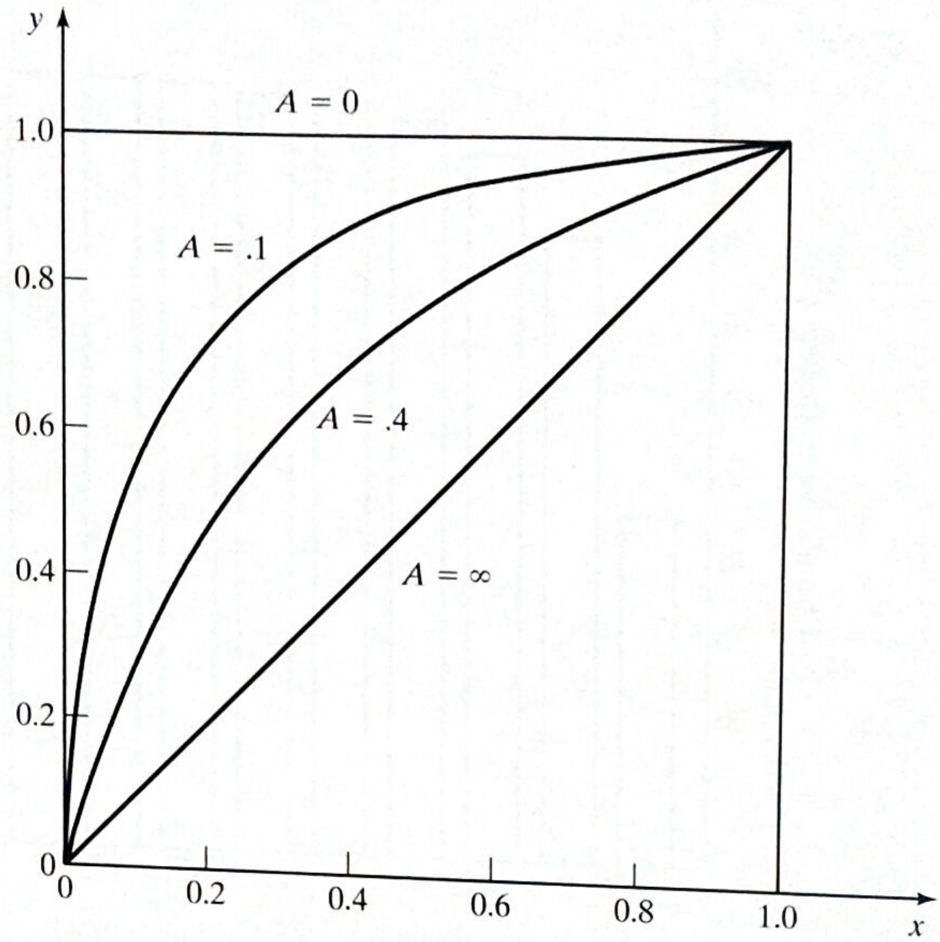

Figure 8.4 Shape of plots of equation (8.1) for several values of A.

$$A = \frac{0.20(1-0.80)}{0.80-0.20} = 0.06667$$

(b) Now that we know the value of A, the following Pareto cumulative distribution equation can be used:

$$y = \frac{(1.06667)x}{0.06667 + x}$$

For $x = 0.50$, the equation can be used to calculate y:

$$y = \frac{(1.06667)(0.50)}{0.06667 + 0.50} = 0.941$$

We expect that 50% of the items in inventory account for 94.1% of the value of the inventory. ■

Pie Charts. A ***pie chart*** is a circular (pie-shaped) display that is sliced by radii into segments whose relative areas are proportional to the magnitudes or frequencies of the data categories comprising the total circle. The visual effect is similar to a Pareto chart, in the sense that the important categories can be immediately recognized because of their relative sizes. Multiple pie charts can be displayed side by side to indicate not only the relative category sizes within a circle but also the relative sizes of the circles. Figure 8.5 shows two consecutive years of company sales, indicating how sales increased the second year and how the increase was distributed among types of customers.

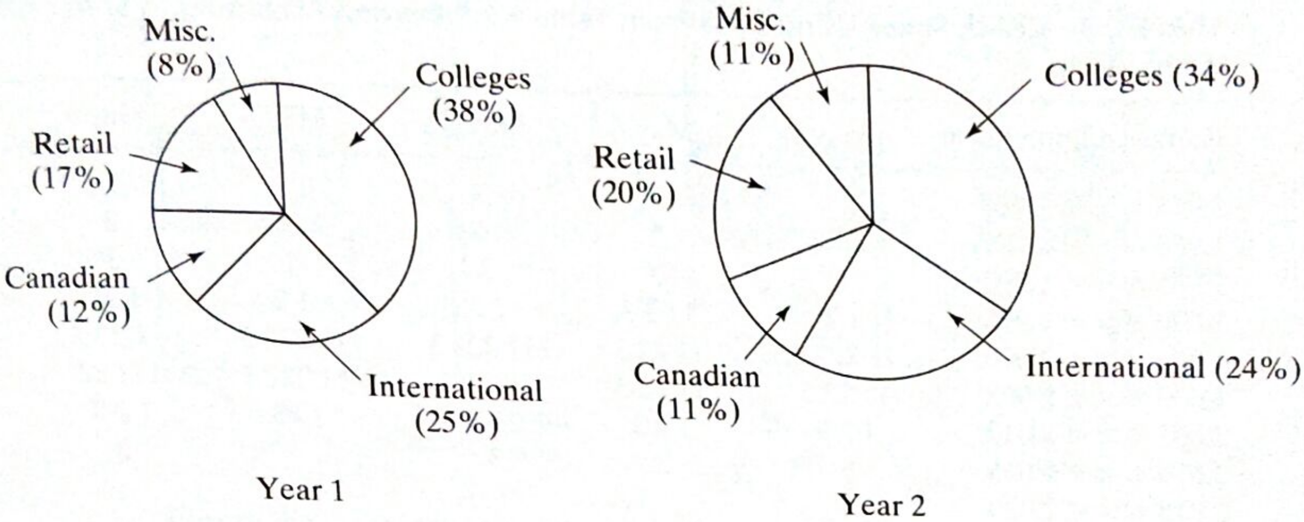

Figure 8.5 Pie charts showing two annual sales revenues and the customer distributions for the two years. Sales in year 2 increased 43% over year 1.

Check Sheets. The ***check sheet*** (not to be confused with "check list") is a data gathering tool generally used in the preliminary stages of the study of a problem. The operator running a process (for example, the machine operator) is often given the responsibility for recording the data on the check sheet, and the data are often recorded in the form of simple check marks.

Example 8.4 Check Sheet Application

For the dimensional data in the frequency distribution of Table 8.2, suppose we wanted to see if there were any differences between the three shifts that are responsible for making the parts. A check sheet has been designed for this purpose, and data have been collected. Analyze the data.

Solution: The check sheet is illustrated in Table 8.3. The data include the shift on which each dimensional value was produced (shifts are identified simply as 1, 2, and 3). The data in a check sheet are usually recorded as a function of time periods (days, weeks, months), as in our table.

It is clear from the data that the third shift is responsible for much of the variability in the data. Further analysis, shown in Table 8.4, substantiates this finding. This should lead to an investigation to determine the causes of the greater variability on the third shift, with appropriate corrective action to address the problem.

We also note from Table 8.4 that the average daily production rate for the third shift is somewhat below the daily rate for the other two shifts. The third shift seems to be a problem that demands management attention.

■

Check sheets can take many different forms, depending on the problem situation and the ingenuity of the analyst. The form should be designed to allow some interpretation of results directly from the raw data, although subsequent data analysis may be necessary to recognize trends, diagnose the problem, or identify areas of further study.

Defect Concentration Diagrams. The defect concentration diagram is a graphical method that has been found to be useful in analyzing the causes of product or part defects. It is a drawing of the product (or other item of interest), with all relevant views displayed,

TABLE 8.3 Check Sheet Using Data from Table 8.2 Recorded According to Shift on Which Parts Were Made

Range of Dimension	May 5	May 6	May 7	May 8	May 9	Weekly Totals
1.975 ≤ x < 1.980			3			1
1.980 ≤ x < 1.985		2		3	3	3
1.985 ≤ x < 1.990	1	3	3	1	3	5
1.990 ≤ x < 1.995	1 2	11 2 3	1 2	1 2	1 22	13
1.995 ≤ x < 2.000	11 222 3	11 22 3	111 222 3	11 222 3	11 22 3	29
2.000 ≤ x < 2.005	11 22 3	11 22 3	111 22 3	11 222 3	111 22	27
2.005 ≤ x < 2.010	1 2 3	1 2 3	22 3	1 33	1 2 3	15
2.010 ≤ x < 2.015	3	3	3		3	4
2.015 ≤ x < 2.020	3			3		2
2.020 ≤ x < 2.025	3					1
Total parts/day	20	20	21	20	19	100

TABLE 8.4 Summary of Data from Check Sheet of Table 8.3 Showing Frequency of Each Shift in Each Dimension Ranges

Range of Dimension	Shift 1	Shift 2	Shift 3	Totals
1.975 ≤ x < 1.980			1	1
1.980 ≤ x < 1.985		1	2	3
1.985 ≤ x < 1.990	2		3	5
1.990 ≤ x < 1.995	6	6	1	13
1.995 ≤ x < 2.000	11	13	5	29
2.000 ≤ x < 2.005	12	11	4	27
2.005 ≤ x < 2.010	4	5	6	15
2.010 ≤ x < 2.015			4	4
2.015 ≤ x < 2.020			2	2
2.020 ≤ x < 2.025			1	1
Weekly total parts/shift	35	36	29	100
Average daily parts/shift	7.0	7.2	5.8	

onto which the various types of defects or other problems of interest have been sketched at the locations where they each occurred. By analyzing the defect types and corresponding locations, it may be possible to identify the underlying causes of the defects.

Montgomery [11] describes a case study involving the final assembly of refrigerators that were plagued by surface defects. A defect concentration diagram (Figure 8.6) was utilized to analyze the problem. The defects were clearly shown to be concentrated around the middle section of the refrigerator. Upon investigation, it was learned that a belt was wrapped around each unit for material handling purposes. It became evident that the defects were caused by the belt, and corrective action was taken to improve the handling method.

Scatter Diagrams. In many industrial problems involving manufacturing operations, it is useful to identify a possible relationship that exists between two process variables. The scatter diagram is helpful in this regard. A ***scatter diagram*** is an x-y plot of the data taken of the two variables of interest, as illustrated in Figure 8.7. The data

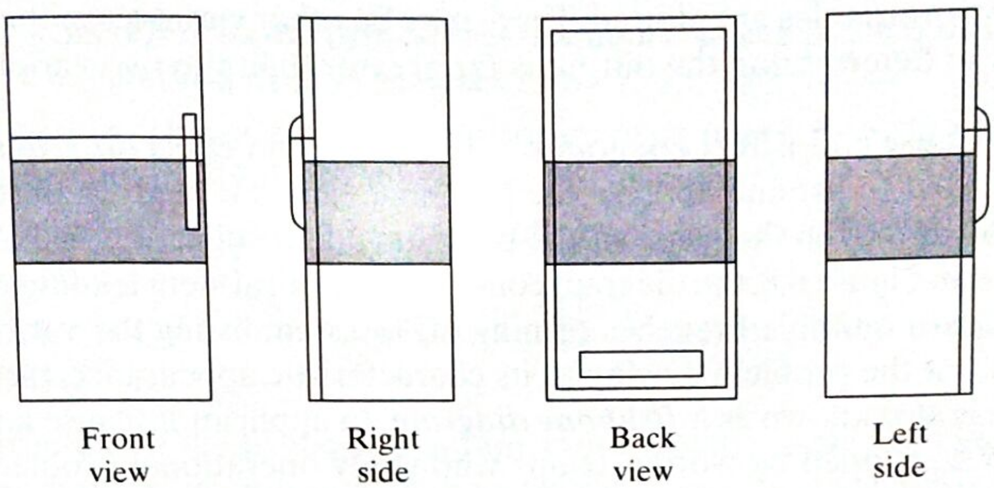

Figure 8.6 Defect concentration diagram showing four views of refrigerator with locations of surface defects indicated in shaded areas.

are plotted as pairs; for each x_i value, there is a corresponding y_i value. The shape of the data points considered in aggregate often reveals a pattern or relationship between the two variables. For example, the scatter diagram in Figure 8.7 indicates that a negative correlation exists between cobalt content and wear resistance of a cemented carbide cutting tool. As cobalt content increases, wear resistance decreases.

One must be circumspect in using scatter diagrams and in extrapolating the trends that might be indicated by the data. For instance, it might be inferred from our diagram that a cemented carbide tool with zero cobalt content would possess the highest wear resistance of all. However, cobalt serves as an essential binder in the pressing and sintering process used to fabricate cemented carbide tools, and a minimum level of cobalt is necessary to hold the tungsten carbide particles together in the final product. There are other reasons why caution is recommended in the use of the scatter diagram, since

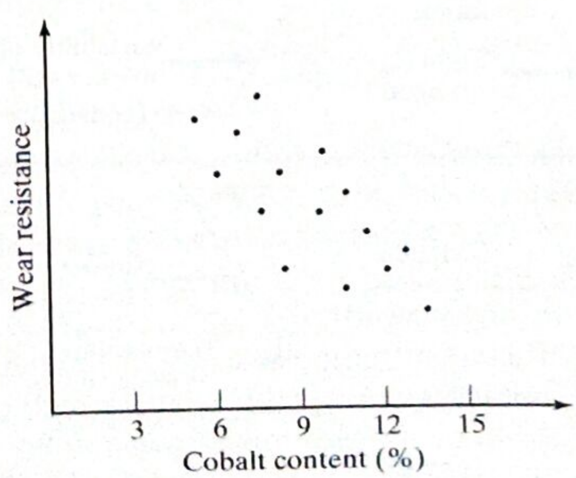

Figure 8.7 Scatter diagram showing the effect of cobalt binder content on wear resistance of a cemented carbide cutting tool insert.

only two variables are plotted. There may be other variables in the process whose importance in determining the output is far greater than the two variables displayed.

Cause and Effect Diagrams. The ***cause and effect diagram*** is a graphical-tabular chart used to list and analyze the potential causes of a given problem. It is not really a statistical tool, in the sense of the preceding data collection and analysis techniques. As shown in Figure 8.8, the diagram consists of a central stem leading to the effect (the problem), with multiple branches coming off the stem listing the various groups of possible causes of the problem. Owing to its characteristic appearance, the cause and effect diagram is also known as a ***fishbone diagram***. In application, cause and effect diagrams are often developed by worker teams who study operational problems. The diagram provides a graphical means for discussing and analyzing a problem and listing its possible causes in an organized and understandable way. Members of the team collectively identify the branches of the diagram (causes of the problem) and then attempt to determine which causes are most consequential and how to take corrective action against them.

As a starting point in identifying the causes of the problem (the main branches in the fishbone diagram), six general categories of causes are often used because they are the factors that affect performance of most production and service processes. Called the 5Ms and 1P [4], they are as follows:

1. *Machines.* This refers to the equipment and tooling used in the process.
2. *Materials.* These are the starting materials in the process.

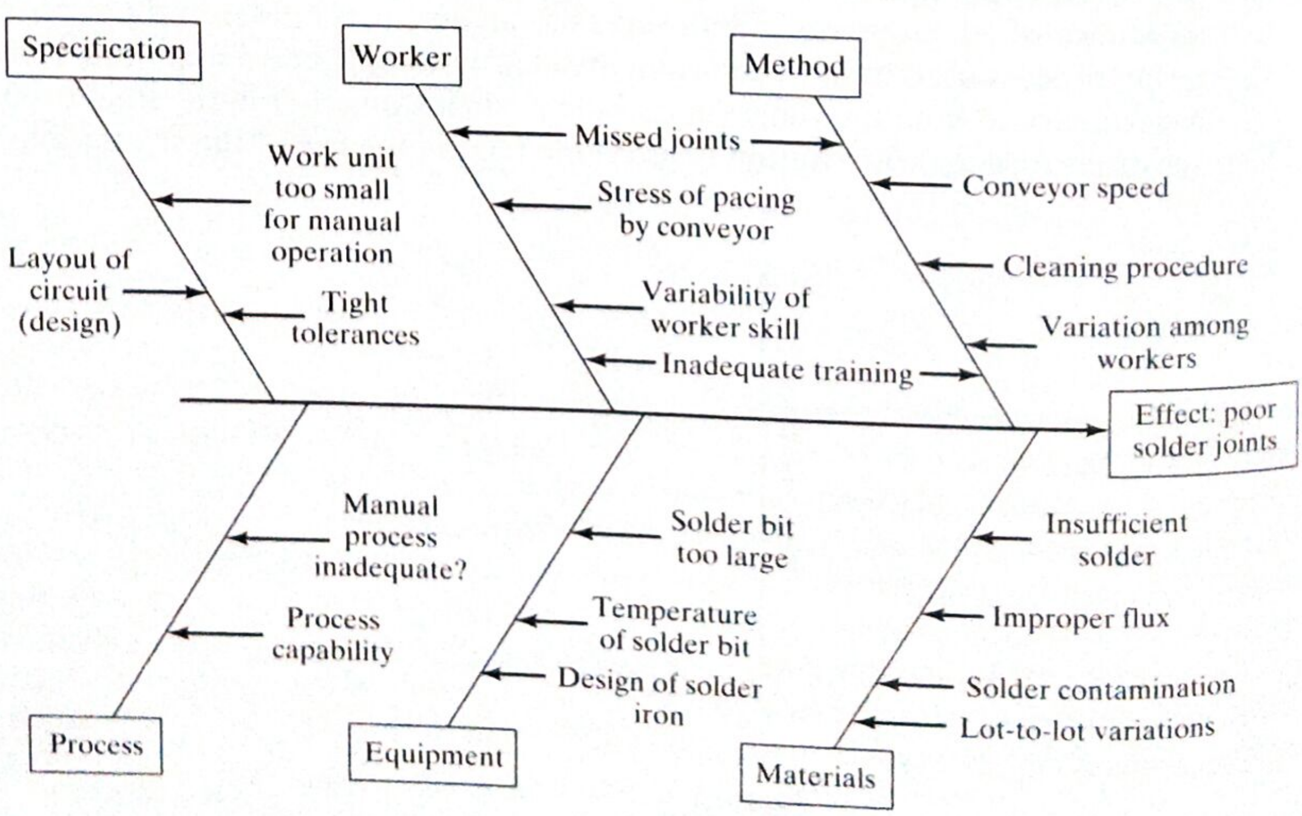

Figure 8.8 Cause and effect diagram for a manual soldering operation. The diagram indicates the effect (the problem is poor solder joints) at the end of the arrow and the possible causes are listed on the branches leading toward the effect.

3. *Methods.* This refers to the procedures, sequence of activities, motions, and other aspects of the method used in the process.
4. *Mother Nature.* This is a pseudonym for environmental factors such as air temperature and humidity that might affect the process.
5. *Measurement.* This relates to the validity and accuracy of the data collection procedures.
6. *People.* This is the human factor. Does the worker bring the necessary skills to the process?

During construction of the fishbone diagram, more specific causes and issues are listed on the smaller branches within each of these six categories as the analysis team pursues a solution to the problem.

8.4 METHODS ENGINEERING AND AUTOMATION

The issue of automation arises frequently in methods engineering. The analysis of an operation may lead to the conclusion that an automated or semiautomated work system is preferable to performing a task manually. However, a certain caution and respect must be observed in applying automation technologies. In this section, we offer three approaches for dealing with automation projects in methods engineering: (1) the USA Principle, (2) ten strategies for automation, and (3) an automation migration strategy.[13]

8.4.1 USA Principle

The USA principle is a commonsense approach to automation projects. Similar procedures have been suggested in the manufacturing and automation trade literature, but none have a more captivating title than this one. USA stands for three steps in the analysis and design procedure:

1. *Understand* the existing process.
2. *Simplify* the process.
3. *Automate* the process.

Described in [10], the approach is so general that it is applicable to nearly any automation project. One might argue that the USA principle is basically an abbreviated version of the methods engineering approach (Section 8.2.1).

The purpose of the first step in the USA principle is to understand the current process in all of its details. What are the inputs? What are the outputs? What exactly happens to the work unit between input and output? What is the function of the process? How does it add value to the product? What are the upstream and downstream operations in the production sequence and can they be combined with the process under consideration?

Some of the basic charting tools used in methods engineering are useful in this step, such as those discussed in Chapter 9. Applying these kinds of tools to the existing process provides a model of the process that can be analyzed and searched for weaknesses

[13]This section is based largely on Section 1.5 in [7].

and opportunities. The number of steps in the process, the number and placement of inspections, the number of moves and delays experienced by the work unit, and the time spent in storage can be determined from these charting techniques.

Mathematical models of the process may also be useful to indicate relationships between input parameters and output variables. What are the important output variables? How are these output variables affected by inputs to the process, such as raw material properties, process settings, operating parameters, and environmental conditions? This information may be valuable in identifying what output variables need to be measured for feedback purposes and in formulating algorithms for automatic process control.

Once the existing process is understood, then the search begins for ways to simplify the process (step 2). This often involves a checklist of questions about the existing process. What is the purpose of this operation or this transport? Is that operation necessary? Can this step be eliminated? Is the most appropriate technology being used in this process? How can this step be simplified? Are there unnecessary steps in the process that might be eliminated without detracting from the function? These are basic questions in a methods engineering study.

Some of the ten strategies for automation (Section 8.4.2) may be used to simplify the process. Can steps be combined? Can steps be performed simultaneously? Can steps be integrated into a manually operated production line? Simplifying the process may lead to the conclusion that automation is not necessary, thus saving the significant investment cost that would be entailed.

When the process has been reduced to its simplest form, then automation can be considered (step 3). The possible forms of automation include those listed in the ten strategies discussed in the following section. An automation migration strategy (Section 8.4.3) might be implemented for a new product that has yet to prove itself.

8.4.2 Ten Strategies for Automation

The USA Principle is a good first step in any automation evaluation project. As suggested previously, it may turn out that automation is unnecessary or cannot be cost justified after the process has been simplified. If automation seems a feasible solution to improving productivity, quality, or another measure of performance, then the following ten strategies provide a road map to search for these improvements.[14] Although we refer to them as strategies for automation, some of them are applicable whether the process is a candidate for automation or just simplification.

1. *Specialization of operations.* Analogous to the concept of labor specialization for improving labor productivity, this strategy involves the use of special-purpose equipment designed to perform one operation with the greatest possible efficiency.
2. *Combined operations.* Production almost always occurs as a sequence of operations. Complex parts may require dozens, or even hundreds, of processing steps.

[14]These ten strategies were first published in my book *Automation, Production Systems, and Computer-Aided Manufacturing* (Prentice Hall, 1980). They seem as relevant and appropriate today as they did in 1980.

The strategy of combined operations involves reducing the number of distinct workstations through which the work units must be routed. This is accomplished by performing more than one operation at a given workstation, thereby reducing the number of separate workstations needed.

3. *Simultaneous operations.* A logical extension of the combined operations strategy is to simultaneously perform the operations that are combined at one workstation. In effect, two or more operations are performed at the same time on the same work unit, thus reducing total processing time.
4. *Integration of operations.* This strategy involves linking several workstations together into a single integrated mechanism using automated work handling devices to achieve continuous work flow. With an integrated sequence of workstations, several work units can be processed simultaneously (one at each station), thereby increasing the overall output of the system.
5. *Increased flexibility.* This strategy attempts to achieve maximum utilization of human and equipment resources for low and medium volume situations by using the same resources for a variety of work units. It involves the use of the flexible automation concepts that are implemented using computer systems.
6. *Improved material handling and storage.* The use of automated material handling and storage systems is a great opportunity to reduce nonproductive time. Typical benefits include reduced work-in-process and shorter lead times. In information service operations, the counterpart is a the use of advanced database and data processing technologies.
7. *On-line inspection.* Inspection for quality is traditionally performed after the process. This means that any poor quality product or service has already been completed by the time it is inspected. Incorporating inspection into the process permits corrections during the process. This brings the overall quality level closer to the nominal specifications intended by the designer.
8. *Process control and optimization.* This includes a wide range of control schemes intended to operate individual processes and associated equipment more efficiently. By using this strategy, the individual process times can be reduced and quality improved.
9. *Plant operations control.* Whereas the previous strategy is concerned with control of the individual process, this strategy is concerned with control at the plant level. It attempts to manage and coordinate the aggregate operations in the plant more efficiently. Its implementation usually involves a high level of computer networking within the facility.
10. *Computer integrated manufacturing (CIM).* Taking the previous strategy one level higher, we have the integration of factory operations with engineering design and the business functions of the firm. CIM involves extensive use of computer applications, computer databases, and computer networking throughout the enterprise.

The ten strategies constitute a checklist of the possibilities for improving the work system, through automation or simplification. They should not be considered as mutually exclusive. For many situations, multiple strategies can be implemented in one improvement project.

8.4.3 Automation Migration Strategy

Because of competitive pressures in the marketplace, a company often needs to introduce a new product in the shortest possible time. The easiest and least expensive way to accomplish this objective is to design a manual production method, using a sequence of workstations operating independently. The tooling for a manual method can be fabricated quickly and at low cost. If more than a single set of workstations is required to make the product in sufficient quantities, as is often the case, then the manual cell is replicated as many times as needed to meet the demand. If the product turns out to be successful and high demand is anticipated in the future, it makes sense for the company to automate production. The improvements are often carried out in phases. Many companies have an ***automation migration strategy***—a formalized plan for evolving the manufacturing systems used to produce new products as demand grows. The following phases are included in the typical automation migration strategy:

Phase 1: ***Manual production*** using single station manned cells operating independently. This is used for introduction of the new product for reasons mentioned above: quick and low-cost tooling to get started.

Phase 2: ***Automated production*** using single station automated cells operating independently. As demand for the product grows and it becomes clear that automation can be justified, the single stations are automated to reduce labor and increase production rate. Work units are still moved between workstations manually.

Phase 3: ***Automated integrated production*** using a multistation automated system with serial operations and automated transfer of work units between stations. When the company is certain that the product will be produced in mass quantities and for several years, then integration of the single station automated cells is warranted to further reduce labor and increase production rate.

This strategy is illustrated in Figure 8.9. Details of the automation migration strategy vary from company to company, depending on the types of products they make and the processes they perform. But well-managed companies have policies like this one. There are several advantages to such a strategy:

- It allows introduction of the new product in the shortest possible time, since production cells based on manual workstations are the easiest to design and implement.
- It allows automation to be introduced gradually (in planned phases), as demand for the product grows, engineering changes in the product are made, and time is allowed to do a thorough design job on the automated manufacturing system.
- It avoids the commitment to a high level of automation from the start, since there is always a risk that demand for the product will not justify it.

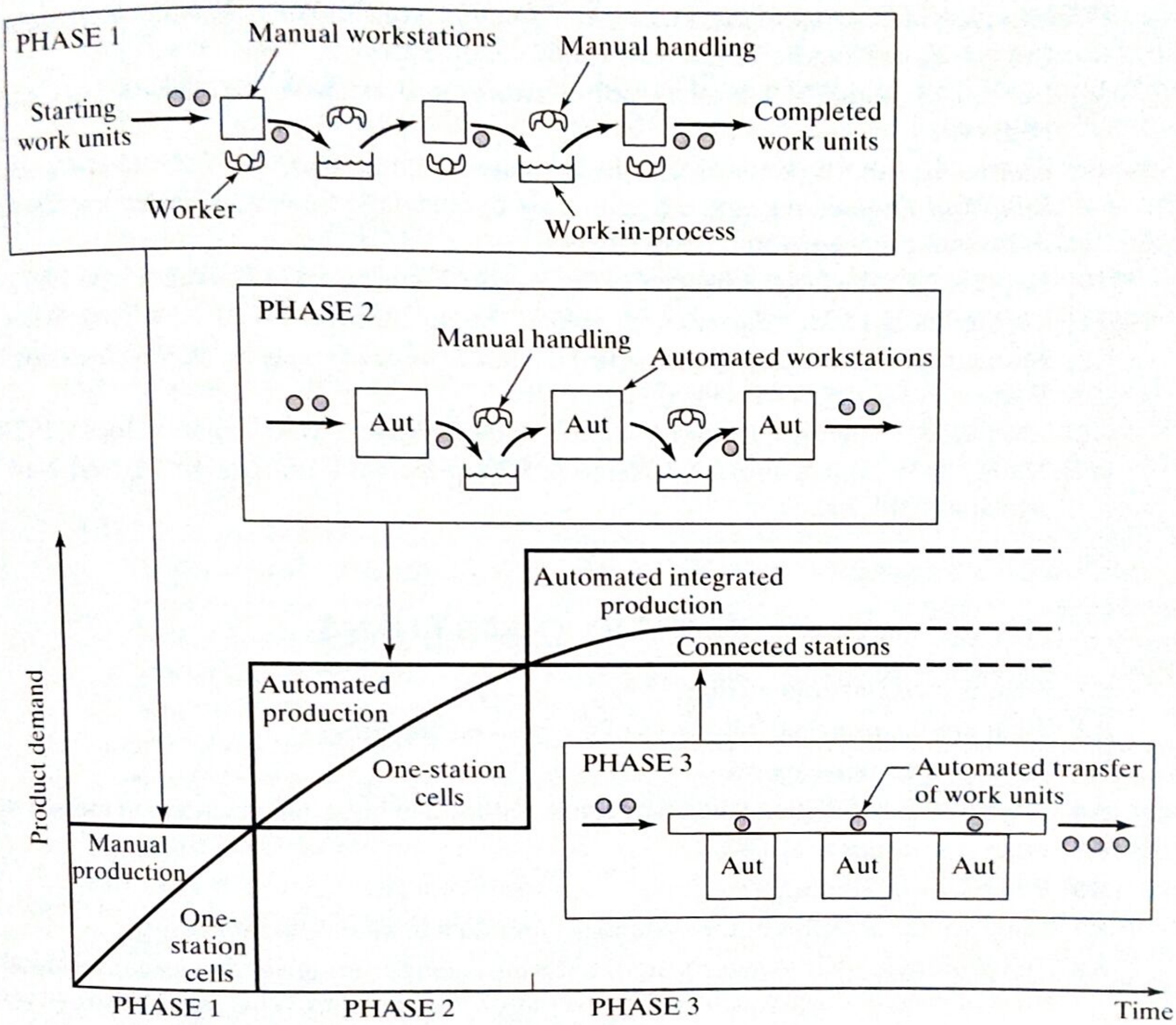

Figure 8.9 The three phases of a typical automation migration strategy: (1) manual production with single independent workstations, (2) automated production stations with manual handling between stations, and (3) automated integrated production with automated handling between stations.

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REVIEW QUESTIONS

8.1 What is methods engineering?

8.2 What are the principal objectives of methods engineering?

8.3 What is operations analysis?

8.4 What was the operation studied by Frank Gilbreth in his initial research on motion study?

8.5 What is methods analysis?

8.6 What is methods design?

8.7 What are the six steps of the systematic approach in methods engineering?

8.8 The procedure offered in the text for selecting among alternatives divides the technical features of proposed equipment alternatives into two categories. What are the two categories?

8.9 What is a histogram?

8.10 What is a Pareto chart?

8.11 What is a check sheet?

8.12 What is a defect concentration diagram?

8.13 What is a scatter diagram?

8.14 What is a cause and effect diagram?

8.15 What does "USA" stand for in the USA principle?

8.16 What are the three phases in the automation migration strategy?

8.17 Why would a company want to use manual production methods instead of automated methods at the beginning of production of a new product?

PROBLEMS

8.1 A factory has 10 departments, all of which have quality problems leading to delays in shipping products to customers. A breakdown of the number of quality problems for each department (listed alphabetically) is as follows: (1) assembly, 16; (2) final packaging, 9; (3) finishing, 37; (4) forging, 73; (5) foundry, 362; (6) machine shop, 294; (7) plastic molding, 120; (8) receiving inspection, 124; (9) sheet metalworking, 86; and (10) tool-making, 42.

(a) Construct a Pareto chart for this data. (b) Assuming that all quality problems are of equal value, in which department would you start to take corrective action to reduce the quality problems? (c) Determine the percentage of total quality problems that are attributable to the two departments (20% of the departments) with the most quality problems.

8.2 Using your answer to part (c) of the preceding problem, (a) determine the parameter A in equation (8.1) representing the Pareto cumulative distribution. Use 20% of the departments as the x value in your computations. (b) Construct the idealized Pareto chart based on your answer to part (a) and discuss the comparison between this idealized chart and the actual data in the previous problem. Use a spreadsheet program to calculate the data for part (b).

8.3 Assume that 75% of the sales in a retail company are accounted for by 25% of the customers. (a) Determine the parameter A in the Pareto cumulative distribution equation. (b) Given that the relationship is valid for the remaining sales, how much of the sales value is accounted for by 50% of the customers?

8.4 The inventory policy of a retail company is to hold only the highest sales volume items in its distribution center and to ship the remaining lower sales volume items direct from the respective manufacturers to its stores. This policy is intended to reduce transportation costs. Total annual sales of the company are $1 billion. It is known that half of this amount is accounted for by only 15% of the items. In addition, it is assumed that equation (8.1) in the text can be used to model the Pareto cumulative distribution. (a) If the company wants to stock the top selling 35% of the items in the distribution center, what is the expected value of these items in terms of annual sales? (b) On the other hand, if the company wants to stock only those items accounting for the top 75% of annual sales, what proportion of the items corresponds to this sales volume?

8.5 The marketing research department for the Stitch Clothing Company has determined that 22% of the items stocked account for 70% of the dollar sales. A typical outlet store carries 1000 items. The items accounting for the top 60% of sales are replenished from the company's distribution center. The rest are shipped directly from the supplier (manufacturer) to the stores. How many items are represented by the top 60%?

8.6 Consider some process or procedure with which you are familiar that manifests some chronic problem. Develop a cause and effect diagram that identifies the possible causes of the problem. This is a project that lends itself to a team activity.