1

The Role of Statistical Methods in Modern Industry and Services

1.1 The different functional areas in industry and services

Industrial statistics has played a key role in the creation of competitiveness in a wide range of organizations in the industrial sector, in services, health care, government and educational systems. The tools and concepts of industrial statistics have to be viewed in the context of their applications. These applications are greatly affected by management style and organizational culture. We begin by describing key aspects of the industrial setting in order to lay out the foundations for the book.

Industrial organizations typically include units dedicated to product development, manufacturing, marketing, finance, human resources, purchasing, sales, quality assurance and after-sales support. Industrial statistics is used to resolve problems in each one of these functional units. Marketing personnel determine customer requirements and measure levels of customer satisfaction using surveys and focus groups. Sales are responsible for providing forecasts to purchasing and manufacturing. Purchasing specialists analyze world trends in quality and prices of raw materials so that they can optimize costs and delivery time. Budgets are prepared by the finance department using forecasts that are validated periodically. Accounting experts rely on auditing and sampling methods to ascertain inventory levels and integrity of databases. Human resources personnel track data on absenteeism, turnover, overtime and training needs. They also conduct employee surveys and deploy performance appraisal systems. The quality departments commonly perform audits and quality tests, to determine and ensure the quality and reliability of products and services. Research and development engineers perform experiments to solve problems and improve products and processes. Finally, manufacturing personnel and process engineers design process controls for production operations using control charts and automation.

These are only a few examples of problem areas where the tools of industrial statistics are used within modern industrial and service organizations. In order to provide more specific examples we first take a closer look at a variety of industries. Later we discuss examples from these types of industries.

There are basically three types of production systems: (1) continuous flow production; (2) job shops; and (3) discrete mass production. Examples of continuous flow production include steel, glass and paper making, thermal power generation and chemical transformations. Such processes typically involve expensive equipment that is very large in size, operates around the clock and requires very rigid manufacturing steps. Continuous flow industries are both capital-intensive and highly dependent on the quality of the purchased raw materials. Rapid customizing of products in a continuous flow process is virtually impossible and new products are introduced using complex scale-up procedures.

Modern Industrial Statistics: with applications in R, MINITAB and JMP, Second Edition. Ron S. Kenett and Shelemyahu Zacks.

Companion website: www.wiley.com/go/modern_industrial_statistics

Job shops are in many respects exactly the opposite. Examples of job shops include metal-working of parts or call centers where customers who call in are given individual attention by non-specialized attendants. Such operations permit production of custom-made products and are very labor-intensive. Job shops can be supported by special purpose machinery which remains idle in periods of low demand.

Discrete mass production systems can be similar to continuous flow production if a standard product is produced in large quantities. When flexible manufacturing is achieved, mass production can handle batches of size 1, and, in that sense, appears similar to a job shop operation. Service centers with call routing for screening calls by areas of specialization are such an example.

Machine tool automation began in the 1950s with the development of numerical control operations. In these automatic or semi-automatic machines, tools are positioned for a desired cutting effect through computer commands. Today's hardware and software capabilities make a job-shop manufacturing facility as much automated as a continuous-flow enterprise. Computer-integrated manufacturing (CIM) is the integration of computer-aided design (CAD) with computer-aided manufacturing (CAM). The development of CAD has its origins in the evolution of computer graphics and computer-aided drawing and drafting, often called (CADD). As an example of how these systems are used, we follow the creation of an automobile suspension system designed on a computer using CAD. The new system must meet testing requirements under a battery of specific road conditions. After coming up with an initial design concept, design engineers use computer animation to show the damping effects of the new suspension design on various road conditions. The design is then iteratively improved on the basis of simulation results and established customer requirements. In parallel to the suspension system, design purchasing specialists and industrial engineers proceed with specifying and ordering the necessary raw materials, setting up the manufacturing processes, and scheduling production quantities. Throughout the manufacturing of the suspension system, several tests provide the necessary production controls. Of particular importance are dimension measurements performed by coordinate measuring machines (CMM). Modern systems upload CMM data automatically and provide the ability to perform multivariate statistical process control and integrate data from subcontractors on all five continents (see, e.g., www.spclive365.com). Ultimately the objective is to minimize the costly impact of failures in a product after delivery to the customer.

Statistical methods are employed throughout the design, manufacturing and servicing stages of the product. The incoming raw materials have often to be inspected, by sampling, to ensure adherence to quality standards (see Chapters 6–7 in Part II). Statistical process control is employed at various stages of manufacturing and service operations to identify and correct deviations from process capabilities (see Chapters 8–10 in Part III). Methods for the statistical design of experiments are used to optimize the design of a system or process (see Chapters 11–13 in Part IV). Finally, tracking and analyzing field failures of the product are carried out to assess the reliability of a system and provide early warnings of product deterioration (see Chapters 14–15 in Part V).

CAD systems provide an inexpensive environment to test and improve design concepts. Chapter 13 is dedicated to computer experiments and special methods for both the design and the analysis of such experiments. CMM systems capture the data necessary for process control. Chapter 10 covers methods of multivariate statistical process control that can fully exploit such data. Web technology offers opportunities to set up such systems without the deployment of costly computer infrastructures. Computerized field failures tracking systems and sales forecasting are very common. Predictive analytics and operational business intelligence systems like eCRM tag customers that are likely to drop and allow for churn prevention initiatives. The application of industrial statistics within such computerized environments allows us to concentrate on statistical analysis that infers the predictive behavior of the process and generates insights on associations between measured variables, as opposed to repetitive numerical computations.

Service organization can be either independent or complementary to manufacturing type operations. For example, a provider of communication systems typically also supports installation and after-sales services to its customers. The service takes the form of installing the communication system, programming the system's database with an appropriate numbering plan, and responding to service calls. The delivery of services differs from manufacturing in many ways. The output of a service system is generally intangible. In many cases the service is delivered directly to the customer without an opportunity to store or fix "defective" transactions. Some services involve very large number of transactions. Federal Express, for example, handles 1.5 million shipments per day, to 127 countries, at 1650 sites. The opportunities for error are many, and process error levels must be of only a few defective parts per million. Operating at such low defect levels might appear at first highly expensive to maintain and therefore economically unsound. In the next section we deal with the apparent contradiction between maintaining low error levels and reducing costs and operating expenses.

1.2 The quality-productivity dilemma

In order to reach World War II production goals for ammunitions, airplanes, tanks, ships and other military materiel, American industry had to restructure and raise its productivity while adhering to strict quality standards. This was partially achieved through large-scale applications of statistical methods following the pioneering work of a group of industrial scientists at Bell Laboratories. Two prominent members of this group were Walter A. Shewhart, who developed the tools and concepts of statistical process control, and Harold F. Dodge, who laid the foundations for statistical sampling techniques. Their ideas and methods were instrumental in the transformation of American industry in the 1940s, which had to deliver high quality and high productivity. During those years, many engineers were trained in industrial statistics throughout the United States.

After the war, a number of Americans were asked to help Japan rebuild its devastated industrial infrastructure. Two of these consultants, W. Edwards Deming and Joseph M. Juran, distinguished themselves as effective and influential teachers. Both Drs. Deming and Juran witnessed the impact of Walter Shewhart's new concepts. In the 1950s they taught the Japanese the ideas of process control and process improvements, emphasizing the role of management and employee involvement.

The Japanese were quick to learn the basic quantitative tools for identifying and realizing improvement opportunities and for controlling processes. By improving blue-collar and white-collar processes throughout their organizations, the Japanese were able to reduce waste and rework, thus producing better products at a lower price. These changes occurred over a period of several years leading eventually to significant increases in the market share for Japanese products.

In contrast, American industry had no need for improvements in quality after World War II. There was an infinite market demand for American goods and the emphasis shifted to high productivity, without necessarily assuring high quality. This was reinforced by the Taylor approach splitting the responsibility for quality and productivity between the quality and production departments. Many managers in the US industry did not believe that high quality and high productivity could be achieved simultaneously. The Quality-Productivity Dilemma was born and managers apparently had to make a choice. By focusing attention on productivity, managers often sacrificed quality, which in turn had a negative effect on productivity. Increasing emphasis on meeting schedules and quotas made the situation even worse.

On the other hand, Japanese industrialists proved to themselves that by implementing industrial statistics tools, managers can improve process quality and, simultaneously, increase productivity. This was shown to apply in every industrial organization and thus universally resolve the Quality-Productivity Dilemma. In the 1970s, several American companies began applying the methods taught by Deming and Juran and by the mid-1980s there were many companies in the US reporting outstanding successes. Quality improvements generate higher productivity since they permit the shipment of higher quality products, faster. The result was better products at lower costs–an unbeatable formula for success. The key to this achievement was the implementation of Quality Management and the application of industrial statistics, which includes analyzing data, understanding variability, controlling processes, designing experiments, and making forecasts. The approach was further developed in the 1980s by Motorola who launched its famous Six Sigma initiative. A striking testimonial of such achievements is provided by Robert W. Galvin, the former chairman of the executive committee of Motorola Inc.:

> At Motorola we use statistical methods daily throughout all of our disciplines to synthesize an abundance of data to derive concrete actions ... How has the use of statistical methods within Motorola Six Sigma initiative, across disciplines, contributed to our growth? Over the past decade we have reduced in-process defects by over 300-fold, which has resulted in a cumulative manufacturing cost savings of over 11 billion dollars. Employee productivity measured in sales dollars per employee has increased three fold or an average 12.2 percent per year over the same period. Our product reliability as seen by our customers has increased between 5 and 10 times.

Source: Forword to *Modern Industrial Statistics: Design and Control of Quality and Reliability* (Kenett and Zacks, 1998).

The effective implementation of industrial statistics depends on the management approach practiced in the organization. We characterize different styles of management, by a **Quality Ladder**, which is presented in Figure 1.1. Management's response to the rhetorical question: "How do you handle the inconvenience of customer complaints?" determines the position of an organization on the ladder. Some managers respond by describing an approach based on reactively waiting for complaints to be filed before initiating any corrective actions. Some try to achieve quality by extensive inspections

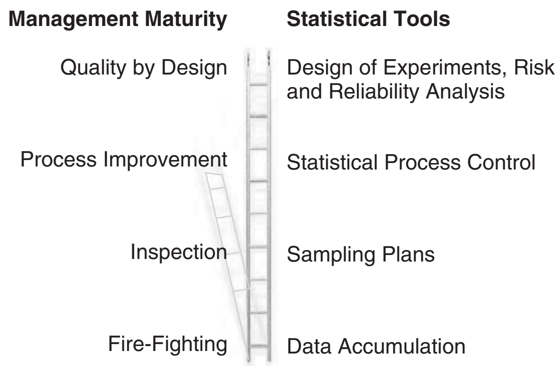

Figure 1.1 *The quality ladder*

and implement strict supervision of every activity in the organization, having several signatures of approval on every document. Others take a more proactive approach and invest in process improvement and quality by design.

The four management styles we identify are: (i) reactive fire-fighting; (ii) inspection and traditional supervision; (iii) processes control and improvement and (iv) quality by design. Industrial statistics tools can have an impact only on the top three steps in the quality ladder. Levels (iii) and (iv) are more proactive than (ii). When management's style consists exclusively of fire fighting, there is typically no use for methods of industrial statistics and data is simply accumulated.

The Quality Ladder is matching management maturity level with appropriate statistical tools. Kenett *et al*. (2008) formulated and tested with 21 case studies, the **Statistical Efficiency Conjecture** which states that organizations higher up on the Quality Ladder are more efficient at solving problems with increased returns on investments. This provides an economic incentive for investments in efforts to increase the management maturity of organizations.

1.3 Fire-fighting

Fire fighters specialize in putting down fires. Their main goal is to get to the scene of a fire as quickly as possible. In order to meet this goal, they activate sirens and flashing lights and have their equipment organized for immediate use, at a moment's notice. Fire-fighting is also characteristic of a particular management approach that focuses on heroic efforts to resolve problems and unexpected crisis. The seeds of these problems are often planted by the same managers, who work the extra hours required to fix them. Fire-fighting has been characterized as an approach where there is never enough time to do things right the first time, but always sufficient time for rework and fixing problems once customers are complaining and threaten to leave. This reactive approach of management is rarely conducive to serious improvements which rely on data and teamwork. Industrial statistics tools are rarely used under fire-fighting management. As a consequence, decisions in such organizations are often made without investigation of the causes for failures or proactive process improvement initiatives.

In Chapters 2–5 of Part I we study the structure of random phenomena and present statistical tools used to describe and analyze such structures. The basic philosophy of statistical thinking is the realization that variation occurs in all work processes, and the understanding that reducing variation is essential to quality improvement. Failure to recognize the impact of randomness leads to unnecessary and harmful decisions. One example of the failure to understand randomness is the common practice of adjusting production quotas for the following month by relying on the current month's sales. Without appropriate tools, managers have no way of knowing whether the current month's sales are within the common variation range or not. Common variation implies that nothing significant has happened since last month and therefore no quota adjustments should be made. Under such circumstances changes in production quotas create unnecessary, self-inflicted problems. Fire-fighting management, in many cases, is responsible for avoidable costs and quick temporary fixes with negative effects on the future of the organization. Moreover, in such cases, data is usually accumulated and archived without lessons learned or proactive initiatives. Some managers in such an environment will attempt to prevent "fires" from occurring. One approach to prevent such fires is to rely on massive inspection and traditional supervision as opposed to leadership and personal example. The next section provides some historical background on the methods of inspection.

1.4 Inspection of products

In medieval Europe, most families and social groups made their own goods such as cloth, utensils and other household items. The only saleable cloth was woven by peasants who paid their taxes in kind to their feudal lords. The ownership of barons or monasteries was identified through marks put on the fabric which were also an indication of quality. Since no feudal lord would accept payment in shoddy goods, the products were carefully inspected prior to the inscribing of the mark. Surviving late medieval documents indicate that bales of cloth frequently changed hands repeatedly without being opened, simply because the marks they bore were regarded everywhere as guarantees of quality. In the new towns, fabrics were made by craftsmen who went in for specialization and division of labor. Chinese records of the same period indicate that silks made for export were also subjected to official quality inspections. In Ypres, the center of the Flemish wool cloth industry, weavers' regulations were put down in writing as early as 1281. These regulations stipulated the length and width as well as the number of warp ends and the quality of the wool to be used in each cloth. A fabric had to be of the same thickness throughout. All fabric was inspected in the draper's hall by municipal officials. Heavy fines were levied for defective workmanship, and the quality of fabrics which passed inspection was guaranteed by affixing the town seal. Similar regulations existed elsewhere in France, Italy, Germany, England and Eastern Europe. Trademarks as a guarantee of quality used by the modern textile industry originated in Britain. They first found general acceptance in the wholesale trade and then, from the end of the 19th century onward, among consumers. For a time manufacturers still relied on in-plant inspections of their products by technicians and merchants, but eventually technological advances introduced machines and processes which ensured the maintenance of certain standards independently of human inspectors and their know-how. Industrial statistics played an important role in the textile industry. In fact, it was the first large industry which analyzed its data statistically. Simple production figures including percentages of defective products were already compiled in British cotton mills early in the 19th century. The basic approach, during the pre-industrial and post-industrial period, was to guarantee quality by proper inspection of the cloth (Juran, 1995). In the early 1900s, researchers at Bell Laboratories in New Jersey developed statistical sampling methods that provided an effective alternative to 100% inspection (Dodge and Romig, 1929). Their techniques, labeled "Sampling Inspection," eventually led to the famous MIL-STD-105 system of acceptance sampling procedures used throughout the defense industry and elsewhere. These techniques implement statistical tests of hypotheses, in order to determine if a certain production lot or manufacturing batch is meeting Acceptable Quality Levels. Such sampling techniques are focused on the product, as opposed to the process that makes the product. Details of the implementation and theory of sampling inspection are provided in Part II (Chapters 6 and 7) that is dedicated to acceptance sampling topics. The next section introduces the approach of process control that focuses on the performance of processes throughout the organization.

1.5 Process control

In a memorandum to his superior at Bell Laboratories Walter Shewhart documented, in 1924, a new approach to statistical process control (Godfrey, 1986; Godfrey and Kenett, 2007). The document dated May 16th describes a technique designed to track process quality levels over time, which Shewhart labeled a "Control Chart." The technique was further developed and more publications followed two years later (Shewhart, 1926). Shewhart realized that any manufacturing process can be controlled using basic engineering ideas. Control charts are a straightforward application of engineering feedback loops to the control of work-processes. The successful implementation of control charts requires management to focus on process performance, with emphasis on process control and process improvements. When a process is found capable of producing products that meet customer requirements and a system of process controls is subsequently employed, one no longer needs to enforce product inspection. Industry can deliver its products without time-consuming and costly inspection, thereby providing higher quality at reduced costs. These are prerequisites for Just-In-Time deliveries and increased customer satisfaction. Achieving quality by not relying on inspection implies quicker deliveries, less testing and therefore reduced costs. Shewhart's ideas are therefore essential for organizations seeking improvements in their competitive position. As mentioned earlier, W. Edwards Deming and Joseph M. Juran were instrumental in bringing this approach to Japan in the 1950s. Deming emphasized the use of statistical methods, and Juran created a comprehensive management system including the concepts of management breakthroughs, the quality trilogy of planning, improvement and control and the strategic planning of quality. Both were awarded a medal by the Japanese emperor for their contributions to the rebuilding of Japan's industrial infrastructure. Japan's national industrial award, called the Deming Prize, has been awarded every year since the early 1950s. The United States National Quality Award and the European Quality Award have been presented, since the early 1990s, to companies in the US and Europe that can serve as role models to others. Notable winners include Motorola, Xerox, Milliken, Globe Metallurgical, AT&T Universal Cards and the Ritz Carlton. Similar awards exist in Australia, Israel, Mexico and many other countries. Part III (Chapters 8–10) deals with implementation and theoretical issues of process control techniques. The next part of the book takes the ideas of process control one step further and covers the design and analysis of experiments and reliability analysis. These require management initiatives we generally label as Quality by Design. Quality by Design is an approach relying on a proactive management style, where problems are sought out and products and processes are designed with "built in" quality.

1.6 Quality by design

The design of a manufactured product or a service begins with an idea and continues through a series of development and testing phases until production begins and the product is made available to the customer. Process design involves the planning and design of the physical facilities, and the information and control systems required to manufacture a products or deliver a service. The design of the product, and the associated manufacturing process, determine its ultimate performance and value. Design decisions influence the sensitivity of a product to variation in raw materials and work conditions, which in turn affects manufacturing costs. General Electric, for example, has found that 75% of failure costs in its products are determined by the design. In a series of bold design decisions in the late 1990s, IBM developed the Proprinter so that all parts and sub-assemblies were built to snap together during final assembly without the use of fasteners. Such initiatives resulted in major cost reductions and quality improvements. These are only a few examples demonstrating how design decisions affect manufacturing capabilities with an eventual positive impact on the cost and quality of the product. Reducing the number of parts is also formulated as a statistical problem that involves clustering and grouping of similar parts. Take, for example, a basic mechanical part such as aluminum bolts. Many organizations find themselves purchasing hundreds of different types of bolts for very similar applications. Multivariate statistical techniques can be used to group together similar bolts, thereby reducing the number of different purchased parts, eliminating potential mistakes and lowering costs.

In the design of manufactured products, technical specifications can be precisely defined. In the design of a service process, quantitative standards may be difficult to determine. In service processes, the physical facilities, procedures, people's behavior and professional judgment affect the quality of service. Quantitative measures in the service industry typically consist of data from periodical customer surveys and information from internal feedback loops such as waiting time in hotels' front desks or supermarket cash registers. The design of products and processes, both in service and manufacturing, involves quantitative performance measurements.

A major contributor to modern quality engineering has been Genichi Taguchi, formerly of the Japanese Electronic Communications Laboratories. Since the 1950s Taguchi has advocated the use of statistically designed experiments in industry. Already in 1959 the Japanese company NEC ran 402 planned experiments. In 1976, Nippon Denso, which is a 20,000-employee company producing electronic parts for automobiles, is reported to have run 2700 designed experiments. In the summer of 1980, Taguchi came to the United States to "repay the debt" of the Japanese to Shewhart, Deming and Juran and delivered a series of workshops at Bell Laboratories in Holmdel, New Jersey. His methods slowly gained acceptance in the US. Companies like ITT, Ford and Xerox have been using Taguchi methods since the mid-1980s with impressive results. For example, an ITT electrical cable and wire plant reported reduced product variability by a factor of 10. ITT Avionic Division developed, over a period of 30 years, a comprehensive approach to quality engineering, including an economic model for optimization of products and processes. Another application domain which has seen a dramatic improvement in the maturity of management is the area of system and software development. The Software

Engineering Institute (SEI) was established in 1987 to improve the methods used by industry in the development of systems and software. SEI, among other things, designed a five-level capability maturity model integrated (CMMI) which represents various levels of implementation of Process Areas. The tools and techniques of Quality by Design are applied by level 5 organizations which are, in fact, at the top of the quality ladder. For more on CMMI and systems and software development, see Kenett and Baker (2010).

A particular industry where such initiatives are driven by regulators and industrial best practices is the pharmaceutical industry. In August 2002, the Food and Drug Administration (FDA) launched the pharmaceutical current Good Manufacturing Practices (cGMP) for the 21st-century initiative. In that announcement, the FDA explained the agency's intent to integrate quality systems and risk management approaches into existing quality programs with the goal of encouraging the industry to adopt modern and innovative manufacturing technologies. The cGMP initiative was spurred by the fact that since 1978, when the last major revision of the cGMP regulations was published, there have been many advances in design and manufacturing technologies and in the understanding of quality systems. This initiative created several international guidance documents that operationalized this new vision of ensuring product quality through "a harmonized pharmaceutical quality system applicable across the life cycle of the product emphasizing an integrated approach to quality risk management and science." This new approach is encouraging the implementation of *Quality by Design* (QbD) and hence, de facto, encouraging the pharmaceutical industry to move up the **Quality Ladder**. Chapter 12 covers several examples of Quality by Design initiatives in the Pharmaceutical industry using statistically designed experiments. For a broad treatment of statistical methods in healthcare, see Faltin *et al*. (2012).

Parts IV and V present a comprehensive treatment of the principal methods of design and analysis of experiments and reliability analysis used in Quality by Design. An essential component of Quality by Design is *Quality Planning*. Planning, in general, is a basic engineering and management activity. It involves deciding, in advance, what to do, how to do it, when to do it, and who is to do it. Quality Planning is the process used in the design of any new product or process. In 1987, General Motors cars averaged 130 assembly defects per 100 cars. In fact, this was planned that way. A cause and effect analysis of car assembly defects pointed out causes for this poor quality that ranged from production facilities, suppliers of purchased material, manufacturing equipment, engineering tools, etc. Better choices of suppliers, different manufacturing facilities and alternative engineering tools produced a lower number of assembly defects. Planning usually requires careful analysis, experience, imagination, foresight, and creativity. Planning for quality has been formalized by Joseph M. Juran as a series of steps (Juran and Gryna, 1988). These are:

1. Identify who are the customers of the new product or process.
2. Determine the needs of those customers.
3. Translate the needs into technical terms.
4. Develop a product or process that can respond to those needs.
5. Optimize the product of process so that it meets the needs of the customers including economic and performance goals.
6. Develop the process required to actually produce the new product or to install the new process.
7. Optimize that process.
8. Begin production or implement the new process.

1.7 Information quality and practical statistical efficiency

Statistics in general, and Industrial Statistics in particular, is focused on extracting knowledge from data. Kenett and Shmueli (2013) define information quality as an approach to assess the level of knowledge generated by analyzing data with specific methods, given specific goals. Formally, let:

- g = a specific analysis goal
- X = the available dataset
- f = an empirical analysis method
- U = a utility measure

A goal could be, for example, to keep a process under control. The available data can be a rational sample of size 5 collected every 15 minutes, the analysis methods an Xbar-R control chart and the utility being the economic value of achieving high production yield. Information quality (**InfoQ**) is defined as: $InfoQ(f,X,g) = U(f(X|g))$, that is, the utility derived by conducting an analysis f, on a given dataset X, conditioned on the goal g. In terms of our example, it is the economic value derived from applying an Xbar-R chart on the sample data in order to keep the process under control.

To achieve high InfoQ, Kenett and Shmueli (2013) map eight dimensions:

1. Data resolution: This is determined by measurement scale, measurement uncertainty and level of data aggregation, relative to the task at hand. The concept of rational sample is such an example.
2. Data structure: This relates to the data sources available for the specific analysis. Comprehensive data sources combine structured quantitative data with unstructured, semantic based data.
3. Data integration: Properly combining data sources is not a trivial task. Information system experts apply ETL (Extract-Transform-Load) technologies to integrate data sources with aliased nomenclature and varying time stamps.
4. Temporal relevance: A data set contains information collected during a certain time window. The degree of relevance of the data in that time window to the current goal at hand must be assessed. Data collected a year ago might no longer be relevant in characterizing process capability.
5. Generalizability: Statistical generalizability refers to inferring from a sample to a target population. Proper sampling of a batch implies that decisions based on the sample apply to the whole batch.
6. Chronology of data and goal: This is obvious. If a control chart is updated once a month, proper responsive process control cannot be conducted.
7. Construct operationalization: Findings derived from analyzing data need to be translated into terms that can drive concrete actions, and vice versa. Quoting W. Edwards Deming, "An operational definition is a procedure agreed upon for translation of a concept into measurement of some kind."
8. Communication: If the information does not reach the right person at the right time, then the quality of information is necessarily poor. Data visualization is directly related to the quality of information. Poor visualization of findings can lead to degradation of the information quality contained in the analysis performed on the data.

These dimensions can then be individually scored to derive an *overall InfoQ score*. In considering the various tools and methods of Industrial Statistics presented in this book, one should keep in mind that the ultimate objective is achieving high information quality or InfoQ. Achieving high infoQ is, however, necessary but not sufficient to make the application of industrial statistics both effective and efficient. InfoQ is about using statistical and analytic methods effectively so that they generate the required knowledge. Efficiency is related to the concrete organizational impact of the methods used. We next present an assessment of efficiency called practical statistical efficiency.

The idea of adding a practical perspective to the classical mathematical definition of statistical efficiency is based on a suggestion by Churchill Eisenhart who, in a 1978 informal "Beer and Statistics" seminar in the Shorewood Hills house of George Box in Madison Wisconsin, proposed a new definition of statistical efficiency. Later, Bruce Hoadley from Bell Laboratories, picked up where Eisenhart left off and added his version nicknamed "Vador." Blan Godfrey, former head of the quality technologies department at Bell Laboratories and, later, CEO of the Juran Institute, used this concept in his 1988 Youden Address on "Statistics, Quality and the Bottom Line" at the Fall Technical Conference of the American Society for Quality Control. Kenett, Coleman and Stewardson (2003) further expanded this idea adding an additional component, the value of the data actually collected, and defined practical statistical efficiency (**PSE**) in an operational way. The PSE formula accounts for eight components and is computed as:

$$PSE = V\{D\} \cdot V\{M\} \cdot V\{P\} \cdot V\{PS\} \cdot P\{S\} \cdot P\{I\} \cdot T\{I\} \cdot E\{R\},$$

where:

- $V\{D\}$ = value of the data actually collected.
- $V\{M\}$ = value of the statistical method employed.
- $V\{P\}$ = value of the problem to be solved.
- $V\{PS\}$ = value of the problem actually solved.
- $P\{S\}$ = probability level that the problem actually gets solved.

- $P\{I\}$ = probability level that the solution is actually implemented.
- $T\{I\}$ = time the solution stays implemented.
- $E\{R\}$ = expected number of replications.

These components can be assessed qualitatively, using expert opinions, or quantitatively, if the relevant data exists. A straightforward approach to evaluate PSE is to use a scale of "1" for not very good to "5" for excellent. This method of scoring can be applied uniformly for all PSE components. Some of the PSE components can be also assessed quantitatively. P(S) and P(I) are probability levels, TI can be measured in months, V(P) and V(PS) can be evaluated in euros, dollars or pounds. V(PS) is the value of the problem actually solved, as a fraction of the problem to be solved. If this is evaluated qualitatively, a large portion would be "4" or "5," a small portion "1" or "2." V(D) is the value of the data actually collected for the goal to be considered. Whether PSE terms are evaluated quantitatively or qualitatively, PSE is a conceptual measure rather than a numerically precise one. A more elaborated approach to PSE evaluation can include differential weighing of the PSE components and/or non-linear assessments.

1.8 Chapter highlights

The effective use of industrial statistics tools requires organizations to climb up the quality ladder presented in Figure 1.1. As the use of data is gradually integrated into the decision process, both at the short-term operational level, and at the long-term strategic level, different tools are needed. The ability to plan and forecast successfully is a result of accumulated experience and proper techniques. Modern industrial organizations (manufacturing or services) are described and classified in this introductory chapter. Different functional areas of a typical business are presented with typical problems for each area. The potential benefits of industrial statistics methods are then introduced in the context of these problems. The main theme here is that the apparent conflict between high productivity and high quality can be resolved through improvements in work processes, by introducing statistical methods and concepts. The contributions of Shewhart, Deming and Juran to industries seeking a more competitive position are outlined. Different approaches to the management of industrial organizations are summarized and classified using a **Quality Ladder**. Industrial statistics methods are then categorized according to the steps of the ladder. These consist of Fire-Fighting, Inspection, Process Control and Quality by Design. The chapter discusses how to match a specific set of statistical methods to the management approach and how to assess information quality (**InfoQ**) and practical statistical efficiency (**PSE**) to ensure that industrial statistics methods are used effectively and efficiently in organization and application areas. It is designed to provide a general background to the application of industrial statistics.

The following chapters provide a comprehensive exposition of the tools and methods of modern industrial statistics. In this chapter we refer to the need to develop the maturity of the management approach, to ensure high InfoQ in data analysis and to plan for high PSE in order to achieve high impact. These aspects are complementary to the methods and tools presented in the next 14 chapters.

The main terms and concepts introduced in this first chapter include:

- Continuous Flow Production
- Job Shops
- Mass Production Systems
- The Quality-Productivity Dilemma
- Quality Management
- The Quality Ladder
- Fire-Fighting as a Management Approach
- Inspection as a Management Approach
- Process Control and Improvement as a Management Approach
- Quality by Design as a Management Approach
- Information Quality (InfoQ)
- Practical Statistical Efficiency (PSE)

1.9 Exercises

1.1 Describe three work environments where quality is assured by 100% inspection.

1.2 Search periodicals, such as *Business Week*, *Fortune*, *Time* and *Newsweek* and newspapers such as the *New York Times* and the *Wall Street Journal* for information on quality initiatives in service, healthcare, governmental and industrial organizations.

1.3 Provide examples of the three types of production systems.
(i) continuous flow production.
(ii) job shops.
(iii) discrete mass production.

1.4 What management approach cannot work with continuous flow production?

1.5 What management approach characterizes
(i) a school system?
(ii) a military unit?
(iii) a football team?

1.6 Provide examples of how you, personally, apply the four management approaches
(i) as a student.
(ii) in your parents' house.
(iii) with your friends.

1.7 Evaluate the InfoQ dimensions of following case study on predicting days with unhealthy air quality in Washington, DC. Several tour companies' revenues depend heavily on favorable weather conditions. This study looks at air quality advisories, during which people are advised to stay indoors, within the context of a tour company in Washington, DC. http://galitshmueli.com/content/tourism-insurance-predicting-days-unhealthy-air-quality-washington-dc.

1.8 Evaluate the InfoQ dimensions of following case study on quality-of-care factors in U.S. nursing homes Thousands of Americans reside in nursing homes across the US, with facilities spanning a wide range. This study looks at the quality of care in nursing homes in the United States. http://galitshmueli.com/content/quality-care-factors-us-nursing-homes.

1.9 Evaluate the InfoQ dimensions of a case study provided by your instructor.

1.10 Evaluate the practical statistical efficiency (PSE) of a case study provided by your instructor.