J. Webster (ed.), *Wiley Encyclopedia of Electrical and Electronics Engineering*

QUALITY CONTROL

What is Tqm?

Total quality management (*TQM*) is a collection of principles, concepts, tools, and processes, all designed to promote quality within an organization and its functions, as well as in interactions with its customers, suppliers, and the environment. The word *total* emphasizes the all-encompassing nature of TQM (all processes, functions, and people). The word *management* adds organizational and behavioral components to the technical scope of quality, emphasizing its business focus.

There is no universal agreement on the definition of quality. However, a number of leaders in the quality movement have provided definitions that have a common focus on the customer's needs, requirements, and expectations. Feigenbaum (1) defines quality as "[t]he total composite of product and service characteristics of marketing, engineering, manufacturing, and maintenance through which the product and service in use will meet the expectations of the customer." Other definitions of quality include: "conformance to requirements," (2) and "fitness for use" (3).

The quality movement has its origin in the industrial revolution, which replaced craftsmen's pride in the quality of their work, with industrial workers focused on one aspect of production and removed from the quality of the final product. The first systematic attempt in increasing quality was the scientific management theory, pioneered by Fredrick Winslow Taylor (4). In this theory, production was considered a closed system, which was to be improved by scientific and technical methods.

The human behavior movement started with a series of studies (mostly performed at Western Electric's Hawthorne plant), which showed that the supervisors' special attention to workers increased their productivity (5). This was called the *Hawthorne effect* and introduced a behavioral approach to management.

The attention to quality of industrial production coincided with the development of modern statistical theory, pioneered by Sir Ronald A. Fisher, a British statistician working at the turn of century. In the early 1920s, Walter A. Shewhart, a physicist at AT&T Bell Laboratories, used Fisher's work to develop control charts for controlling quality. As statistics grew in theory and found more applications in business and economics, the use of statistics in management decisions, including quality control, took a firm hold. The development and application of mathematical models (such as linear programming and optimization) for logistic decisions in World War II increased the use of quantitative methods in management decision processes.

It was in this historical context that W. Edwards Deming, a physicist and later a statistician, began his advocacy for the use of statistics in the service of the industry and humanity (6). As a graduate student, Deming worked at the Hawthorne plant (10 years earlier than the Hawthorne experiments) and saw the impact of the industrial division of labor (7). In 1938, he invited Shewhart to deliver a lecture series on the use of statistical methods for quality control, and worked with Shewhart in the aiding the war effort (8). After the war, Deming and later Juran contributed extensively to the revival of Japan's economy by advising Japanese industry on the total quality approach, which began the global quality movement.

In 1956, Feigenbaum (another TQM guru) introduced the concept of the cost of quality, which rejects the idea that higher quality means a higher cost. He advocated the development of measures and the collection of data for the cost of quality. In 1962, Kaoru Ishikawa, a professor at Tokyo University, started quality circles in Japan, which consisted of small, voluntary teams of workers who developed and monitored quality-control activities in their units, as a part of a company-wide quality program. Quality circles were the forerunners of TQM's quality team concept.

Quality Principles

Quality gurus, Deming, Juran, Crosby, Feigenbaum, and Taguchi, each advocated a set of principles in promoting quality. Deming emphasized Seven Deadly Diseases in the U.S. quality crisis as (1) lack of constancy of purpose, (2) emphasis on short-term profits, (3) evaluation of people by rating and annual review, thus destroying teamwork and creating rivalry and fear, (4) management mobility, leading to inadequate understanding of how the organization works and lack of incentive for long-range planning, (5) managing organizations by visible numbers only, (6) excessive employee health-care costs, and (7) excessive warranty costs, encouraged by lawyers.

To counter these problems, Deming proposed a 14-point solution. (1) Create constancy of purpose; (2) adopt quality and customer orientation philosophy; (3) cease dependence on inspection to achieve quality; (4) end the practice of rewarding business on the basis of price tag; (5) improve constantly and forever; (6) institute training; (7) institute leadership; (8) drive out fear; (9) break down barriers between departments; (10) eliminate slogans, exhortations, and arbitrary numerical goals; (11) eliminate numerical quotas; (12) remove barriers that rob employees of their pride of workmanship; (13) institute a vigorous program of education and self-improvement; and (14) take action to accomplish the transformation.

Juran advocated managing quality in three parts (9): planning, control, and improvement. He recommended seven breakthrough sequences: (1) breakthrough attitude, (2) identify the few vital projects, (3) organize for breakthrough in knowledge, (4) conduct analysis, (5) determine how to overcome resistance to change, (6) institute the change, and (7) institute controls.

Crosby has a 14-point set of principles (10). Feigenbaum was first to coin the term *total quality control* and identified 10 benchmarks for controlling quality (1,11). Taguchi emphasized quality, robustness, and minimum variation in product design (12).

Quality Awards

After the Japanese success with TQM, various agencies have taken initiatives to encourage and promote quality. Among them are the Deming Prize, the Malcolm Baldrige Award, and the European Quality Award.

The Deming Prize is a Japanese award, instituted in 1951 by the Japanese Union of Scientists and Engineers (*JUSE*) for companies dedicated to quality. This prize has an extensive application process. The Malcolm Baldrige Award was created in the United States in 1987, named after a Reagan Administration's Commerce Secretary. The purpose of this annual award is to raise US industry's awareness of the significance of quality in the global market. The European Quality Award was created in 1988 by 14 European companies, which formed the European Foundation for Quality Management. This award is the European equivalent of the Malcolm Baldrige Award in the United States.

Quality Standards

Quality standards were developed before the popularity of TQM. The US airforce in World War II recognized the need for quality standards, and initiated quality assurance programs that led to the military quality-assurance standard MIL-Q-9858, and later revised as MIL-Q-9858A in 1963. This standard was adopted by NATO in 1968 (AQAP-1). Its European version (DEF STAN 05-21), created in 1970, was the basis of the Britain's standards (BS 5750).

Europe's standard-setting body (European Committee for Standardization) commissioned a private organization [International Standards Organization (*ISO*)] to develop quality-assurance standards. ISO used the previously developed US and NATO standards to develop the ISO 9000 series (13).

ISO 9000 consists of a series of quality-assurance guidelines for companies engaged in different phases and types of production of goods and services. ISO 9000 is a general guideline. ISO 9001 provides guidelines for companies engaged in design, development, production, installation, and servicing functions. ISO 9002 has guidelines for companies engaged in production and installation functions only. ISO 9003 is developed for companies engaged in final inspection and testing functions. ISO 9004 describes the elements of a quality-management system. ISO 9000-2 is a guideline for selected service industries, and ISO9000-3 provides guidelines for applying ISO 9001 to software companies (14).

Various countries have adopted ISO 9000 standards and applied their own codes. An example of the British adoption of ISO 9000 is BS 5760; in the United States it is called ANSI/ASQC Q90; European Community knows it as EN 29000, Australia as AS 3900, and Japan as JIS Z 9900. Brazil, Denmark, France, Germany, Portugal, and Spain also have their own code names for ISO 9000 quality-management standards. In 1993, ISO established a committee to develop the ISO 14000 series for environmental management systems.

In 1994, the US auto manufacturers (Chrysler, Ford, and General Motors) combined their company-wide quality management standards under the Quality Systems Requirements QS 9000 standard, which is based on the ISO 9000 series, especially on ISO 9001 guidelines.

The difference between ISO 9000 and the US quality-management guidelines (such as Q90 or QS 9000) is that the ISO 9000 series is used for the certification process, which is required for dealing with European Common Market countries, while the US guidelines are voluntary standards of quality assurance. The ISO 9000 certificates are used as the mark of a company's commitment to quality. However, there are concerns that the certification process does not deal with process inefficiencies and customer-related issues.

Components of TQM

There is no single or uniform approach to implementing TQM in organizations. Quality pioneers have their own principles and points of emphasis. However, one can categorize and glean common themes from the vast array of available principles and recommendations. The components of TQM approach include: leadership, organizational structure, principles, methodologies, and metrics. Awards and standards discussed above form another component of TQM. These areas are discussed both in a general context and in the context of their application to quality information systems.

Leadership. A culture of quality requires the creation of a shared vision to promote the constancy of purpose and the uniformity of direction in the organization's activities. A *vision* is defined as the desired or ideal state of the unit. The leadership of the organization develops the vision through a participatory process, which includes the organization's stakeholders, consisting of employees, stockholders, managers and, in some cases, even the representatives of internal and external customers. The vision of an information systems unit is derived from the organization's vision and applies specifically to information technology. An example of IT vision is: "an integrated and reliable information technology that meets its customers' requirements for timely, accurate, and on-demand information" (13).

There are a number of related concepts that make the vision tangible and operational. These are mission, values and principles, goals, strategies, plans, and tactics. While vision describes *what* the desired state is, a mission describes *how* the organization should move toward its vision. Values and principles are the core beliefs under which the organization operates. Goals are defined in terms of measures (often numerical) that

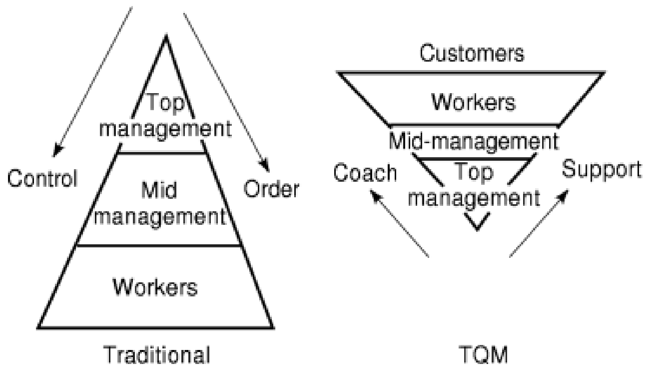

Fig. 1. Traditional versus TQM structure.

lead the organization toward its vision. Strategies, plans, and tactics constitute road maps of actions leading to the vision.

TQM requires strong leadership, which starts with developing a clear vision for the organization that is shared by its members. It has now evolved into the *leadership system,* which is defined as creating clear values that (1) respect stakeholder capabilities and improve performance, (2) build loyalty and teamwork for the pursuit of the shared vision, (3) support initiatives and avoids long chains of command, and (4) include mechanisms for the leader's self-examination, receipt of feedback, and improvement (15).

Organizational Structure. TQM requires a particular organizational structure. The hierarchy of the organization is more flat and upside-down, in that customers and workers who come in contact with customers are on the top of the organizational pyramid (Fig. 1). The managerial approach is coaching and supporting employees. Workers are empowered to make decisions. Cross-functional teams are the hallmark of quality organizations. The organizational culture is one of openness and communication. The performance of workers and managers is evaluated by their internal and external customers, and this evaluation forms the basis of their reward systems. In this scheme, workers are the managers' internal customers. Managers are rewarded on the basis of their ability to provide support for workers to achieve their best. Problems in such organizations are considered opportunities for continuous improvement. A worker believed to be responsible for the problem should be involved in finding ways to ensure that the process is improved and that the problem will not occur again.

Continuous Improvement. Continuous improvement has its origin in the Japanese concept of *kaizen,* which means "ongoing improvement involving everyone—top management, managers, and workers" (16). In the United States, the idea of the continuous improvement cycle was developed by Shewhart and popularized by Deming. The cycle has four components: plan, do, check, and act (Fig. 2). This cycle is continuously implemented in order to improve quality in the processes and outcomes. Applied to information systems, the concept of continuous improvement provides a third option to maintenance and innovation by creating new systems. Figure 3 shows the process of change in information systems.

Benchmarking. Benchmarking is based on the concept of finding the best industry practices and applying them in the continuous quest for improvement. Benchmarking has a long history in China and Japan. The Japanese word *dantosu* (the best of the best) embodies the idea of benchmarking. In the United States, Juran in his book *Management Breakthrough* posed the question: "What is it that organizations do that gets results much better than ours?" The first known comprehensive benchmarking in the United States was carried out by Xerox in 1979 (17) and later by Motorola in early 1980s.

Benchmarking is a part of the continuous-improvement process. It requires: (1) self-evaluation, (2) identification of weak spots, (3) definition of metrics, and (4) identification of processes, policies, and structures

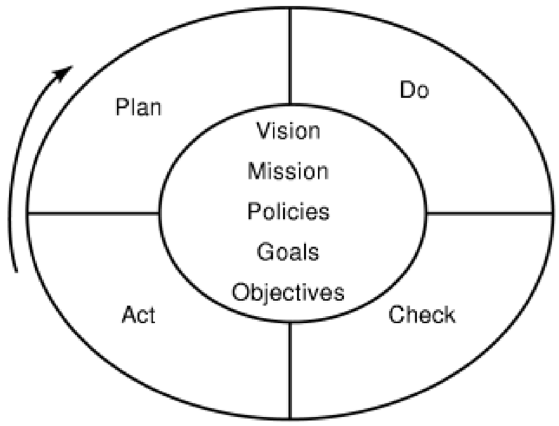

Fig. 2. Shewhart–Deming cycle.

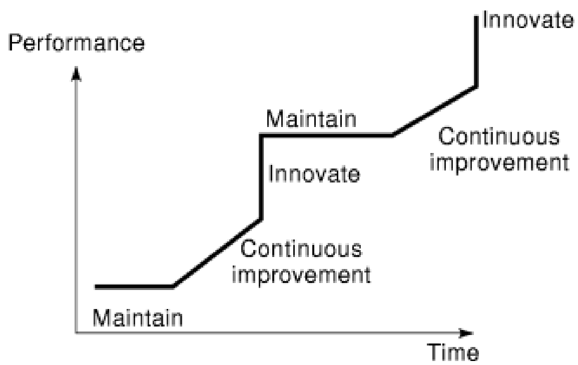

Fig. 3. Information systems changes.

of interest. These steps provide focus and purpose for benchmarking activities. Benchmarking requires the identification of benchmarking partner(s), planning, information collection, analysis, goal setting, and implementation. These steps are discussed in detail in (13).

To select the appropriate benchmarking partner, one needs to select the appropriate type of benchmarking: internal, competitive, functional, or generic. In locating the benchmarking partner, one can use a number of resources such as: internal experts, internal functional areas, professional associations, journals, external experts, and consultants.

There are a number of issues that should be addressed: obtaining the benchmarking partner's consent, forming benchmarking teams, selecting methods of benchmarking (such observations, interviews, questionnaires, site visits, telephone surveys, and mail surveys), analyzing the results, communicating the recommendations, and implementing them. In successful cases of benchmarking, companies could continue the benchmarking partnership or make benchmarking an integral part of the continuous-improvement process.

Benchmarking is particularly valuable for information systems. The speed of change in the technology and the relative paucity of information regarding the innovative use of information technology make benchmarking a requirement for creating quality information systems. Since business-process reengineering often requires the integration of information systems in the new process, benchmarking the use of information technology in business processes is extremely useful.

Reengineering. Continuous improvement emphasizes relatively small changes, while business-process reengineering focuses on sweeping changes at the corporation or functional level. Hammer and Champy (18) defined reengineering as "[t]he fundamental rethinking and radical design of business processes to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service, and speed." Based on their observations of reengineering efforts in major corporations, they have found that reengineering has the following characteristics—focused on process, sweeping and extensive, rule-breaking, and reliant on the innovative use of information systems. The common features in business-process reengineering are: combining jobs, empowering employees as decision-makers, creating multitrack processes, placing the work in a natural and commonsense way, reducing costly controls and checks, reducing the number of external-contact points, creating one contact point through a case manager, and using a combination of centralized and decentralized structures.

Quality Information Systems

Information technology is one of the most important tools an organization can use to facilitate continuous improvement, business-process reengineering, creativity, and innovation within an organization. One can use information technology in quality-management functions, such as making quality guidelines and processes accessible to all workers through company intranets, automated collection and analysis of quality-management data (in order to identify improvement opportunities in the Shewhart–Deming cycle), or computerized suggestion boxes for collecting and analyzing innovative ideas from workers.

While information technology can contribute substantially to the organization's TQM undertakings, using the principles of TQM to develop and operate information systems (*IS*) can substantially improve the organization's IS. Systems built based on TQM are called quality information systems (*QIS*) (13). These systems have a customer focus, and the development process is based on the early determination of systems customers (such as internal and external, developers and users, direct users and indirect users, and people impacted by the system). The principles of zero defects and designing quality into the system are incorporated in these systems. The management of QIS is based on collecting quality and reliability data on the system and using them to set up early-warning signals (19). The operation of QIS includes recovery plans (rather than fire-fighting) and is based on continuous improvement cycles.

Data and Information Quality

One of the important aspects of using information technology in TQM, as well as creating and operating QIS, is the quality of data and information used in these systems. Strong, Lee, and Wang (20) report that 50% to 80% of criminal records in the United States contain poor-quality data; and that low data quality has a social and economic cost in the billions of dollars. Redman (21) discusses far-reaching impacts of low data quality on operational, tactical, and strategic decisions within an organization.

One approach for improving data quality is to view the creation, storage, and use of data as a manufacturing process (22). The application of the TQM principles to data and information manufacturing process is called total data quality management (TDQM). Wang (22) defines the TDQM's continuous-improvement cycle as: define, measure, analyze, and improve, similar to the Shewhart-Deming cycle. Orr (23) suggests a systems-theory approach to data quality, in which customers and users of data are a significant part of the continuous-improvement feedback loop. In this approach, data quality is defined on the basis of the use of data, and is improved by users' feedback.

Although TDQM is relatively new, a number of researchers are working on developing theories and methodologies for dealing with data and information quality within the context of TDQM.

Quality Tools

In the early 1900s, quality efforts were concentrated mostly on controlling the end-products and, subsequently, on inspecting the quality of input materials. These early quality-control efforts relied heavily on statistical sampling techniques and on control charts for controlling the quality of inputs, machine operations, and outputs. With the TQM movement, quality concerns moved upstream from the end-product to design and requirements analysis. The philosophy of control management shifted from discovering errors after they are made and “fire-fighting,” to preventing errors from happening.

Concepts of designing quality into the product, such as Taguchi methods and zero-defect concepts, became popular. Taguchi developed methods for designing quality into the system or product with the goal of minimizing any variation from the design targets (24). This design philosophy makes it possible to have the goal of zero defects in the final output.

To this end, quality tools also evolved to include methods for collecting, organizing, and analyzing ideas, incorporating customer preferences into the design of products and systems, identifying root-causes of problems, and designing for zero defects. With the increased popularity of TQM and business-process reengineering, and their applications to various areas, the list of available tools is expanding (25). Here some of the original TQM tools are briefly reviewed, and quality information systems are used to provide a context for the description of these tools.

Group Idea Generation Tools. The employee-empowerment and team approach in TQM requires tools and methods for generating ideas and consensus in groups. Early TQM tools for this purpose included questioning, brainstorming, mental mapping, and affinity diagram.

Questioning stimulates group members to identify the nature of the outcome of the group’s activity and its internal and external customers. Examples of questions for developing a vision statement are: What is the most desirable outcome of our work? What is the value of the outcome for us and for others? Who are our external customers? Who are our internal customers?

Brainstorming was developed by Osborne in the 1930s (26) and is used extensively by TQM teams to generate ideas. The philosophy in brainstorming is to generate a large set of ideas by a number of individuals in a short period of time (27). It has four phases: (1) idea generation, (2) categorization of generated ideas, (3) discussion, and (4) selection. The selection phase involves rating the ideas based on a number of criteria (determined by the team). Brainstorming requires a facilitator who conducts the meeting, has no stake in the outcome, and does not take part in the process. The meetings should be facilitated on the basis of principles that encourage participation and cross-fertilization of ideas (13).

Mental mapping is a method of aiding the creative process and unblocking mental barriers. Its purpose is to use unorganized and sometimes seemingly illogical associations in order to tap mental creativity. Mental mapping starts with a core idea. One group member draws branches from the core, and other group members join in to generate a mental picture of all issues related to the core questions. Figure 4 shows an example of a partial mental map for the core questions of “What is our information-systems vision?”

The affinity diagram is another tool for collecting information (such as ideas, issues, proposals, and concepts) and organizing them in a creative fashion. The affinity diagram is based on the JK Method, developed in the 1960s by Jiro Kawasha, a Japanese anthropologist. This tool is helpful when the problem is complex and has no apparent logical structure. This method has the following steps: (1) assemble the team, (2) pose the central question, (3) generate ideas, (4) group ideas, and (5) assign headers. Generating ideas is done in complete silence on small cards. In grouping ideas, members group the cards based on similarity of ideas with no discussion. The grouping would continue until nobody wants to move any card. The assignment of headers is either from a card within a stack of grouped cards or by the suggestions of the members. The headers then may be put into a hierarchical structure.

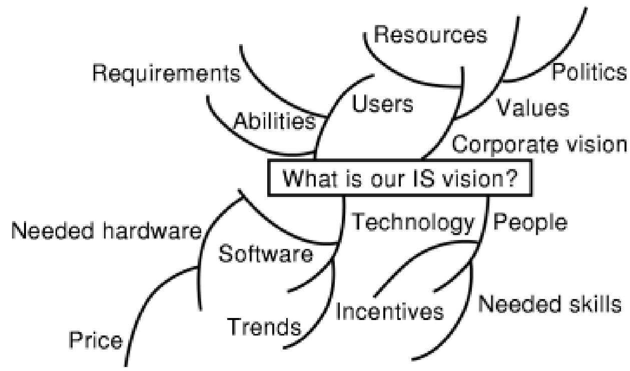

Fig. 4. An example of mental map.

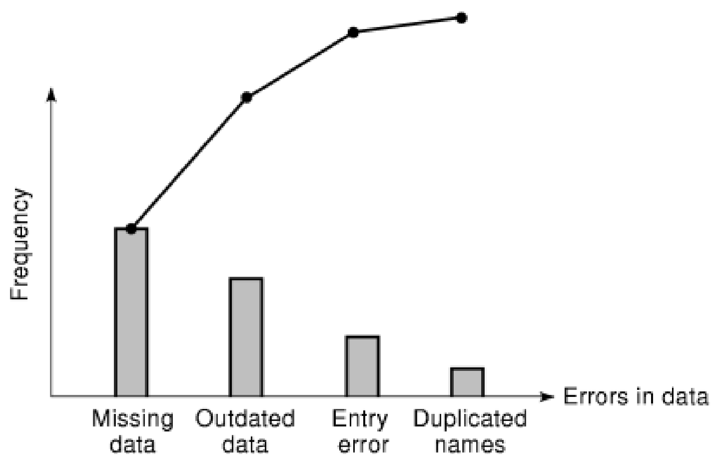

Fig. 5. An example of Pareto chart.

Hoshin Planning. Organization-wide policies, goals, objectives, strategies, and tactics, collectively form a master plan for the organization. *Hoshin karni* or policy deployment is the choice of focus areas for implementation. The identification and selection of hoshins is a team effort and an integral part of the planning process. The hoshins guide the choices in the continuous-improvement process and focus on the root causes of problems.

Tools for Problem Identification. A number of tools are used in problem identification for the continuous-improvement process, which include the Pareto chart, cause-and-effect diagram, and tree hierarchy process.

A Pareto chart is a simple tool for identifying the value (normally in the form of relative frequency) of the item that has the highest contribution to the problem under study. It is a bar chart of relative frequencies, sorted in descending order of frequency values. The cumulative frequency values are also shown on the chart. Using a Pareto chart requires that one already has determined the metric for identifying the problem and the sources of problems. For example, in Fig. 5, sources of errors in information systems and the frequencies are identified. The bar with the highest frequency should be the focus of the continuous improvement process.

The cause-and-effect diagram, also known as the Fishbone diagram, was first developed by Ishikawa, and is used for determining the root causes of problems and their constraints. The diagram starts with a straight

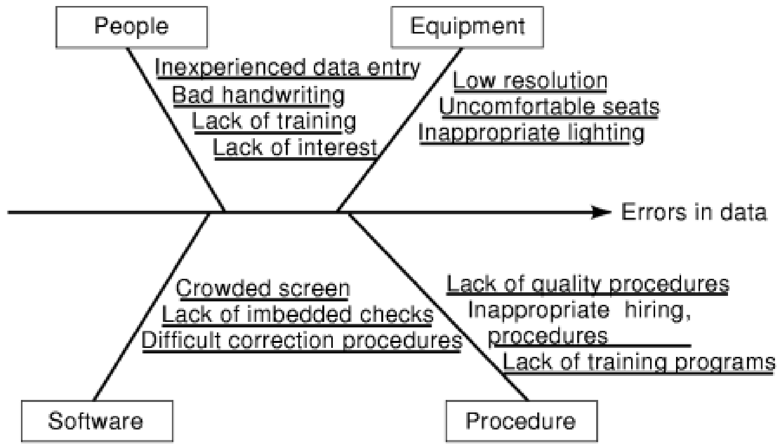

Fig. 6. An example of cause-and-effect diagram.

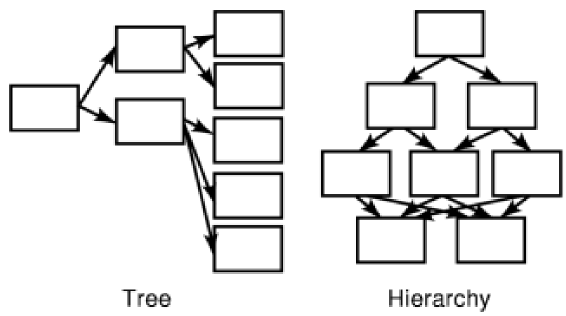

Fig. 7. Hierarchy and tree.

line, at the end of which is the problem, such as *Errors in data* in Fig. 6. The team members add sources of problems, such as people, equipment, software, procedures, and more specific details are added to the diagram.

The tree and hierarchy diagrams are tools for organizing a sequence of ideas, tasks, or attributes, starting from the most general level, and gradually breaking down into more detail. They are tools for organizing complex structures into manageable and comprehensible forms. A tree diagram starts at the left-hand side of the page with the most abstract or general concept and moves to the right. A hierarchy for a similar structure starts from the top and moves down the page. Hierarchy could be more general by allowing a lower-level concept to have more than one parent in the upper level (and hence become a network), as shown in Fig. 7.

Process Analysis Tools. There are a growing number of tools for process analysis, due to the popularity of business-process reengineering (25). However, two older tools have remained popular—data flow diagrams and flowcharts. A data flow diagram consists of: (1) data flows, (2) external and internal entities, (3) data storage, (4) processes or actions, and (5) labeled, directed arrows. Each component has its own symbol and is used to show the flow of data in and out of processes, data storage, and internal and external entities. Processes in a data flow diagram are called “actions” to avoid confusion with the business processes that are more general.

A flowchart is used to show the details of an action or computation. It has symbols for: (1) action, (2) comparison or decision, (3) labeled, directed arrows, (4) start and end, and (5) connectors.

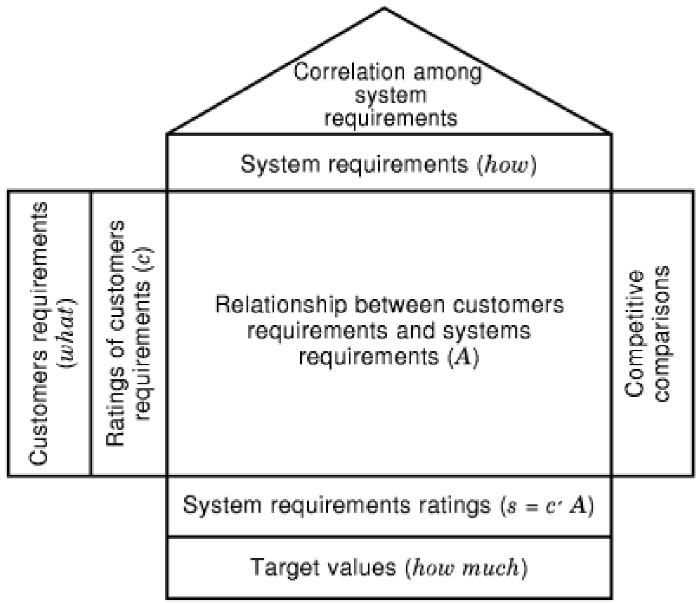

Fig. 8. House of quality.

Data flow diagrams and flowcharts differ in a number of ways: (1) A data flow diagram focuses on the flow of data and does not imply a time sequence, in that many flows may take place simultaneously or at different times. A flowchart documents a sequence of actions and implies a time sequence. (2) The data flow diagram does not show repetitions, conditions, and choices (such as if, while, and for structures), whereas a flowchart documents these structures. (3) The data flow diagram shows the sources and destinations of data, whereas the flowchart does not document the external and internal sources of data. (4) The data flow diagram shows the overall picture of a process with its organizational and environmental links, whereas the flowchart provides a detailed documentation for a given action or computation (13).

Requirements Analysis and Design Tools. Trees and hierarchies, discussed above, are used also in requirements analysis and design in TQM. However, the major tool for connecting the requirements of customers to the design of products, systems, or services is quality function deployment (*QFD*).

QFD consists of a series of interrelated houses of quality. The first house of quality captures customers' requirements and connects them to the functional or technical requirements of the product or system. The subsequent houses of quality break down the requirements and translate them into general and then specific design components. The first house of quality is used for planning, and has the components shown in Fig. 8.

The left side of the house contains the customers' requirements and their relative rating of each requirement, determined by customers. This part of the house determines *what* is to be created. It may be structured in a tree or hierarchical form. The flat top part of the house contains the system requirement. (If used for product development, then "system" should be replaced by "product" in this discussion.) The top determines *how* the system should be created. The roof of the house shows the degree of interdependencies among various parts of the system. The main part of the house documents the extent of the relationship among customers' requirements and systems requirements. The right side of the house compares the performance of major competitors in each category of customers' requirements and rates them in each category on a scale (c). The lower part of the house shows the relative rating of the systems requirements, determined by multiplying the relationship values (in the main part of the house: A) by the customers'-requirements rating (on the left part of the house:

c), and summed ($s = c'A$), where c' is the transpose of c. The outcome of the first house of quality is a rated list of systems requirements and their degree of interdependencies.

The next house of quality has on its left side the systems requirements and their relative ratings (which are the outcomes of the first house of quality), and on the top has general design components. The outcome of the second house of quality is the list of general design components with their relative importance ratings. This becomes the input (left side) of the third house of quality, in which the detailed design components and their relative ratings would be determined. This process continues until the required specificity for design or even implementation is satisfied. Using QFD connects the design of the system's components and their relative importance in the project with the customers' requirements. To create the hierarchy of the customers' requirements and to have them assign relative weights to their requirements, one can use the analytic hierarchy process (*AHP*) approach as described in (13).

Other Quality Tools. Other quality-analysis tools include: interrelationship digraph, prioritization matrix, matrix diagram, process-decision program charts, and activity-network diagrams. A brief review of these tools can be found in Zahedi (13), and details are discussed in Brassard (28,29). The origin of these quality tools is the work by a committee of Japan's Society for QC Technique Development, published in 1979 as Seven Quality Tools for Managers and Staff (30). Brassard (28,29) brought these tools to the United States. Affinity diagrams, Pareto charts, the cause-and-effect diagrams, tree and hierarchy diagrams, and data flow diagrams are also part of the seven quality tools.

Quality Metrics

In order to evaluate quality objectively, one needs to define metrics that formalize and quantify quality. The handbook on metrics published by the US Air Force (31) defines a metric as a combination of measures designed for depicting an attribute of a system or entity. The handbook lists the characteristics of a good quality metric: (1) meaningful to customers, (2) containing organizational goals, (3) simple, understandable, logical, and repeatable, (4) unambiguously defined, (5) capable of showing trends, (6) economical in data collection, (7) driving appropriate action, and (8) timely.

Metrics could be categorized in two dimensions: organization-customers versus processes-results, thus generating four types of metrics: (1) organization-process focus, (2) customer-process focus, (3) organization-result focus, and (4) customer-result focus. Zahedi (13,19) discusses in detail design, reliability, implementation, and operations metrics for information systems, as well team-management quality metrics.

Analysis of Quality Metrics

Statistical quality control (*SQC*) and control charts are the main methods for analyzing quality metrics. In SQC, the observed values of quality metrics, like most business data, have random elements. Therefore, the deviation of quality metrics from their target values could have two sources: (1) random or chance elements that have the same probability distribution for all observed values of the quality metric (common cause), and (2) a shift in performance, which causes the metric to deviate from its target value (special cause). Statistical analysis offers the capability to distinguish between the two causes and to identify the early signals for a change of conditions. Two types of statistics are commonly computed for summarizing data: (1) measures of central tendency (mean, median, or mode) and (2) measures of dispersion or variation (standard deviation, range, or mean-absolute deviation). For a given sample, the common test in SQC is to test the hypothesis that the metric's mean (or any other statistics) has deviated from its desired level.

Control charts graphically show the SCQ test. Control charts could be categorized into Shewhart type and non-Shewhart type. A Shewhart-type control chart has a central line that indicates the target value of the metric, with two warning lines (one upper and one lower with the central line in the middle), and two lines farther out (one upper and one lower) showing control limits. There are a number of Shewhart-type control charts, such as *x* chart, *c* chart, *np* chart, *p* chart, *u* chart, *x-bar* chart, *m* chart, *r* chart, *s* chart, and more. Non-Shewhart charts require more complex methods of establishing control limits. Examples of this type are *MOSUM* (moving sum of sample statistics), *EWMA* (exponentially weighted moving average), *CUSUM* (cumulative sum), and modified Shewhart charts [see, e.g., Zahedi (13) for a brief description of each].

The purpose of control charts is to discover variations caused by special circumstances and to take appropriate actions. The data on quality metrics should be collected regularly and the sample statistics (mostly the mean) are plotted on the control charts. Any regular pattern or movement outside the warning lines and control limits are signals for activating the Shewhart–Deming cycle of continuous-improvement actions.

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