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Statistical Thinking and Its Contribution to Total Quality

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1. WE MUST RESPOND TO OUR CHANGING WORLD

Much of American business has begun to respond to the new economic era in which we live. This response takes many forms. Much of it is aimed at improving the quality of everything we do. Many of us call this effort *total quality*. By aiming at total quality, our businesses will be competitive in global markets, the United States will continue to be a world leader, and we will continue to enjoy a high standard of living.

This attention to total quality has brought with it a renewed emphasis on statistics, and in particular, on *statistical thinking*. The purpose of this article is to emphasize our need for acquiring greater understanding of statistical thinking and its role in total quality. It is my view that this understanding is not adequately developed today and, as a result, we cannot successfully respond to our changing world and the need for total quality. I will present some ideas on how statistical thinking can be used to help achieve total quality.

2. A MODEL OF TOTAL QUALITY

Total quality is a difficult concept to understand because it is so broad and complex. I have been working on a model of total quality to aid my understanding and implementation (Snee 1986). The model I have developed (Fig. 1) has three segments that relate to levels of activity in an organization:

- Strategic—where the organization needs to direct its efforts in order to achieve total quality
- Managerial—systems that align the organization's operational activities with its strategic direction
- Operational—specific activities an organization engages in to pursue total quality.

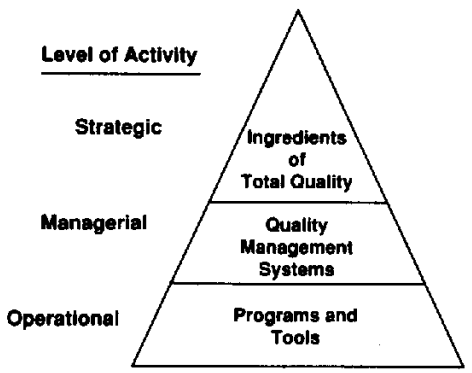

Figure 1. A Model of Total Quality.

Each part of an organization has its own views as to the meaning of total quality. Therefore, any model for total quality must help each part determine where the organization should direct its efforts. Each can focus on its own segment—for example, top management on strategic direction. Each person using the model must understand the whole model, however, in order to see how his or her part fits into the whole.

I emphasize that this model is generic and must be adapted to suit the needs of the organization that uses it. This is a key step; for as the organization adapts the model, it becomes "its own" and a part of how the organization does its business.

An overview of this model is given in the following sections. The objective is not to give a detailed description but to show the wholeness of total quality. It is important to note the linkage between the strategic and managerial segments of the model and similarly between the managerial and operational segments. This overview will enable us to see where statistical thinking plays its role.

Ingredients of Total Quality. The strategic segment of the model tells the organization what is required to achieve total quality. In Figure 2 we see that total quality has four key ingredients: management leadership, product quality and care of customers, people and teamwork, and constant improvement and innovation. The work of Deming (1986), Peters and Austin (1985), Joiner (1985), and Watson (1962) (also see Pascale and Athos 1981) indicates that these four key ingredients will move an enterprise most rapidly toward total quality.

It is critical that an organization work on all four ingredients. Total quality cannot be achieved without active programs that assure that each of the ingredients is given its proper attention. It is in this sense that I find the model most useful. I use it to evaluate the activities of any total-quality effort to see if all of the ingredients are being worked on and if greater emphasis may be needed.

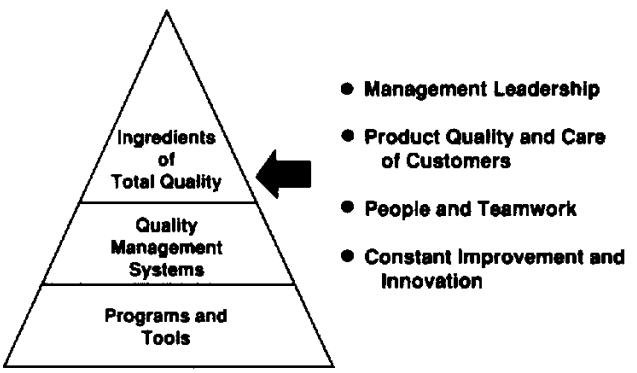

Figure 2. A Model of Total Quality.

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Quality Management Systems. The managerial segment of the model (Fig. 3) describes the quality-management systems that must be in place to pursue the four ingredients of total quality. A management system and associated programs must be in place for each. The management system is the aligning link between the strategic direction and its related operational activities. Without this link, operations will not be working in an effective way toward achieving the ingredients of total quality.

The 12 elements shown in the model can serve as a starting point to help an organization develop its quality-management systems. Each organization should customize the systems to suit its own particular needs. Each element will likely encompass several programs.

Programs and Tools. The operational segment consists of the programs specified by the quality-management systems and their associated implementation tools (Fig. 4). This is where the role of statistics is most evident. Note, for example, that *statistical control* is the program associated with the *process control* element of the quality-management system aimed at product quality and care of customers. Similarly, *design of experiments* and *product and process ruggedness* are the programs and tools associated with, respectively, the quality-improvement and quality-by-design quality-system elements of constant improvement and innovation.

My objective is not to present a detailed discussion here but to note the clear role of statistics in the programs and tools of total quality. This comes as no surprise, for this is where statisticians have focused their efforts for years. Our experience with total quality has pointed out that we must move on from our focus on tools and problem solving to the development of systems for achieving total quality, systems that involve several statistical tools, and other concepts and methodologies (Pfeifer, Marquardt, and Snee 1988).

3. STATISTICAL THINKING

The world has changed and so must our view of the role of statistics in total quality. The key to making this transition is to focus on statistical thinking rather than statistical tools. Though it may not be readily apparent, statistical thinking permeates all aspects of total quality. Some of us understand this and many of us believe it, but the concept is not clear; many, many more do not understand it or believe it. H. G. Wells told us that "statistical thinking will one day be as necessary for efficient citizenship as the ability to read and write." That day has arrived for those of us who are pursuing total quality.

If we are to make effective use of statistical thinking, we must define what we mean by the term. It is my experience that many of us talk about statistical thinking but rarely

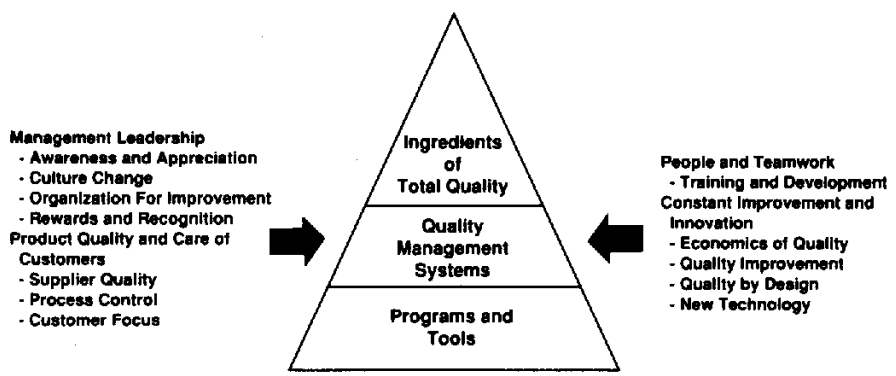

Figure 3. A Model of Total Quality.

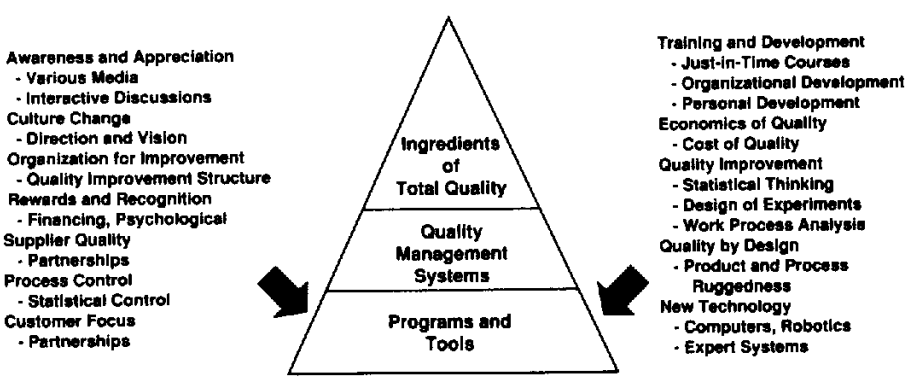

Figure 4. A Model of Total Quality.

define it. The result is that there is confusion and lack of agreement over what statistical thinking is.

Statistical Thinking in Quality Improvement. I define statistical thinking as *thought processes*, which recognize that variation is all around us and present in everything we do, all work is a series of interconnected processes, and identifying, characterizing, quantifying, controlling, and reducing variation provide opportunities for improvement. This definition, shown schematically in Figure 5, integrates the ideas of processes, variation, analysis, developing knowledge, taking action, and quality improvement.

Reducing Variation. The importance of statistical thinking derives from the fundamental principle of quality put forth by W. Edwards Deming: Reduce variation and you improve quality.

Customers value products that have consistent performance. Employees enjoy working with managers whose behavior and actions are consistent. Suppliers enjoy working with customers who consistently define their needs.

Indeed, consistency is often more important than satisfying all of the requirements. It is much easier to interact with and serve a person, process, or organization that is predictable and consistently in a given place than one that is inconsistent and unpredictable. A study of Deming's 14 points shows that many of them are aimed directly at reducing variation and creating consistency.

Deming points out that we can reduce variation and improve quality in two key ways:

- Eliminate the *special* causes of variation and bring the process into a state of statistical control.
- Improve the system by reducing the *common* causes of variation—those causes of variation that still exist when a process is in statistical control.

Special-cause and common-cause variation are illustrated in Figure 6. We generally treat special-cause variation by finding its cause and developing solutions to prevent its recurrence. This approach was outlined by Shewhart (1931) and Deming (1986) and relies on the use of problem-solving

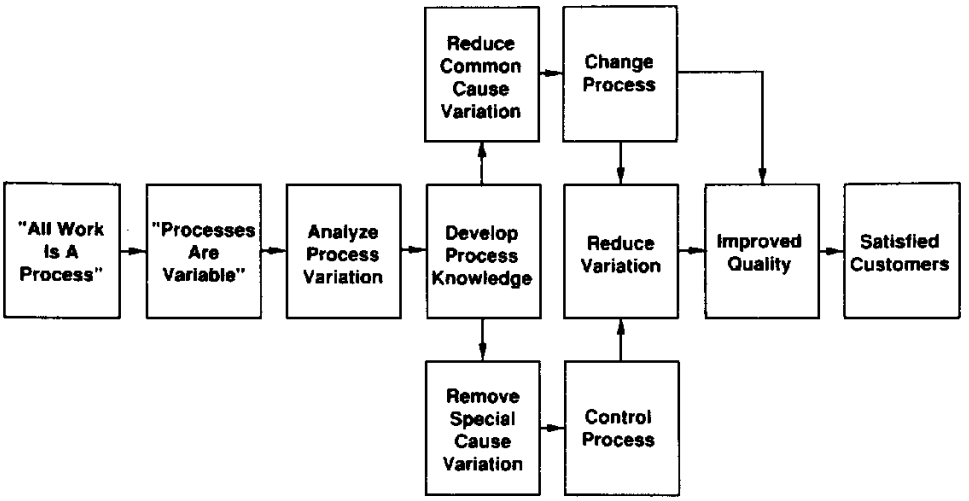

Figure 5. Statistical Thinking in Quality Improvement.

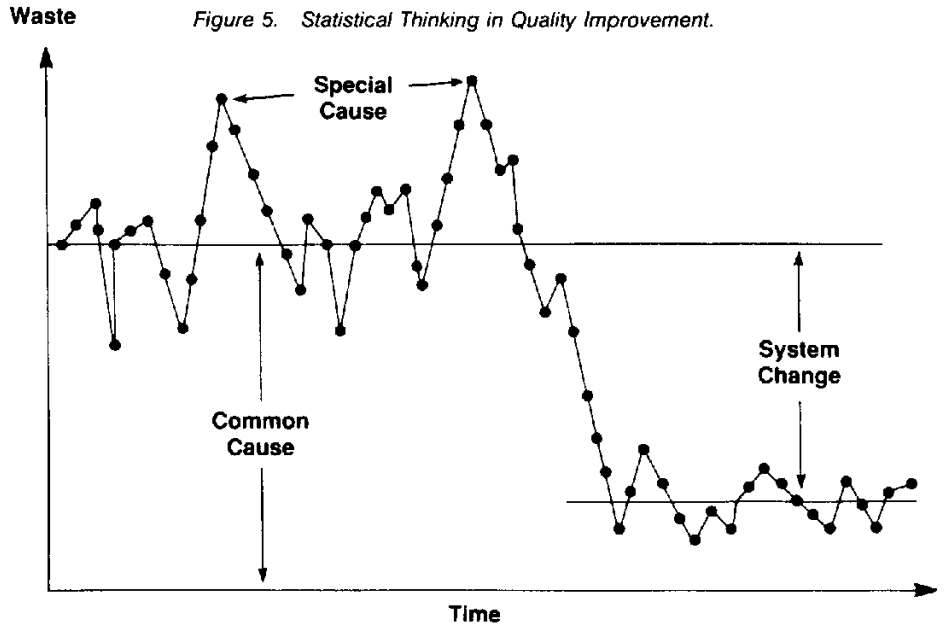

Figure 6. Special-Cause and Common-Cause Variation.

tools.

The reduction of common-cause variation, on the other hand, focuses on improving the system. This typically requires first developing knowledge of the system through extensive study and then getting management involved in order to make required changes.

Distinguishing between special-cause and common-cause variation is the key to reducing variation effectively so that the associated problems do not appear again. We must understand that different types of actions, particularly on the part of management, are needed to deal effectively with common-cause and special-cause variation.

I have also found it helpful to think of statistical thinking at different levels of activity similar to those used in the model for total quality discussed earlier. Figure 7 lists some concepts, systems, and tools associated with statistical thinking. Concepts, systems, and tools play a role in the model for statistical thinking similar to that of the strategic, managerial, and operational levels of the total quality model (Fig. 1). An illustration of the use of Figure 7 would be an improvement in the quality of a product produced by a series of interconnected processes (concept), through the development of a statistical process control procedure (system), which brings together several statistical tools (e.g., control charts, nested sampling studies, graphical displays, and the "Magnificent 7") to reduce special-cause variation.

At Strategic Level, Concepts:

- **Variation is present in all processes.**
- **All work is a series of interconnected processes.**
- **Reducing variation improves quality.**

At Managerial Level, Systems:

- **Statistical process control**
- **Strategy of experimentation**
- **Ruggedness of product and process design**

At Operational Level, Tools:

- **Control Charts**
- **Factorial Designs**
- **Statistical Methods**
- **Magnificent "7"**
- **Response Surface Designs**
- **Screening Designs**
- **Mixture Designs**
- **Graphical Displays**
- **Nested Sampling Designs**

Figure 7. Statistical Thinking at Different Levels of Activity.

Our study of Figure 7 reminds us, once again, that the statistics community tends to view statistical thinking from a "tool" viewpoint with little focus at the concept level. It is only recently that we have begun to consider statistical thinking from a "systems" viewpoint, that is, specifically developing systems that bring together several statistical tools and other methodologies to perform a certain activity (Pfeifer et al. 1988). Broad understanding of statistical thinking at the concept, systems, and tool levels is essential to maximizing the contribution of statistical thinking to total quality.

Ruggedness of Product and Process Design. A third way to reduce variation is to *anticipate variation* and build products and processes that are insensitive to and not affected by unknown or uncontrollable sources of variation. Such products and processes are said to be *rugged* or *robust* (Taguchi and Wu 1980). I prefer the term *rugged*, as it is already used in some fields (Wernimont 1977; Youden 1967), and I have found *ruggedness* easier for people to understand. (Youden introduced the concept of ruggedness tests for analytical procedures.) It was noted earlier that a focus on ruggedness was one of the programs we could use to gain quality by design, thereby helping us achieve the constant improvement and innovation ingredient of total quality (Fig. 4).

A rugged product or process reduces variation because it is insensitive to variations in components of manufacture, type of use, and conditions of use. The output of a rugged process would not be affected by variations in raw materials or product components, ambient temperature and humidity, the work force operating the process, and so forth. A rugged product should be a high-quality product. Ruggedness is a generic concept that can be used in both manufacturing and nonmanufacturing environments.

We should pay more attention to ruggedness, because it is difficult to predict how customers will use or abuse products. A good example is the response of one major manufacturer to complaints about its washing machines. On investigation, the manufacturer discovered that the tops were caving in, not because they were inadequate for their intended function, but because their owners were standing on them to reach cabinets above. Obviously, the manufacturer had to strengthen the top if the washing machines were to keep their reputation for quality.

There are many other examples of ruggedness that demonstrate the usefulness of the concept. User-friendly computers and software, low-maintenance automobiles, five-mile-an-hour auto bumpers, and medical instruments that patients can use in their homes are good examples. They fit the concept of ruggedness because they produce the expected results under many different conditions. In the case of user-friendly software or home-operated medical instruments, the product is rugged with respect to the inexperience of the user as well as with respect to physical misuse.

Customers view rugged products and procedures as having high quality. Ruggedness must be designed into the product and the process that produces it. Even 100% inspection cannot produce a rugged product.

4. USE OF STATISTICAL THINKING BY MANAGEMENT

One of the most difficult challenges we face is to figure out how to use statistical thinking to help the management of American business do a better job. By focusing on Deming's principle that reducing variation improves quality, we see that there are many actions managers can take that will reduce variation. Figure 8 reminds us that managers can reduce variation by maintaining a constant purpose for their employees to pursue, by enabling employees to manage themselves and not interfering with their work programs unless special-cause or common-cause variation has been identified, by providing needed training in a consistent fashion, and by helping all groups work toward a common goal. Figure 9 shows that reduced variation is the link between supplier partnerships and improved quality.

Management can also reduce variation by designing their

- **Maintaining Constancy of purpose**
- **Enabling people to self-manage**
- **Reducing the number of suppliers**
- **Breaking down barriers between departments**
- **Providing training for workers**
- **Basing decisions on facts, not emotions**
- **Active involvement in planning**
- **Promotion of teamwork**

Figure 8. Management Actions That Reduce Variation and Improve Quality.

actions and systems to be rugged. Figure 10 lists some examples. Ruggedness is not a new concept to managers. I have heard managers refer to a system as "fragile" when it did not perform as desired if small changes were made. Though the ruggedness concept is not new, it does need to be understood more broadly so that its benefit can be more fully realized.

The concept of special-cause versus common-cause variation is also useful for managers. Deming and his colleagues point out that managers typically treat all problems as due to special-cause variation (i.e., a problem to be fixed) when, in fact, more than 85% of problems are due to defects in a system (common-cause variation), which only management can change. The result is that management spends too much time "fire-fighting," solving the same problem again and again because the system was not changed. These situations are not likely to improve without the use of statistical thinking.

5. INTEGRATING STATISTICAL THINKING AND TOTAL QUALITY

Reflecting on the model for total quality (Figs. 1–4) and the discussion of statistical thinking, I see a broadening role for statistical thinking. At first encounter, it is clear that statistical thinking plays a role in product quality and care of customers through statistical process control, customer surveys, process capability and calibration studies, the development of supplier and customer partnerships, and so forth. The value of statistical design of experiments, distinguishing between special-cause and common-cause variation, work process analysis, and ruggedness of product and process design to constant improvement and innovation is also clear.

If we accept that all work is a process, all processes are variable, and that there is a relationship between management actions and quality, we see that statistical thinking is essential to attaining *all* of the ingredients of total quality. The use of statistical thinking in the areas of management leadership and people and teamwork is admittedly less clear, but nonetheless important. At this time the value of statistical thinking is understood only at the concept level (e.g., management's leadership by developing constancy of purpose and the associated culture change). We have few, if any, statistical tools to help management develop corporate direction, to enable people to interact more effectively, to promote teamwork, and so forth. The concept that "reducing variation improves quality" applies as well in these areas as to the other two ingredients of total quality.

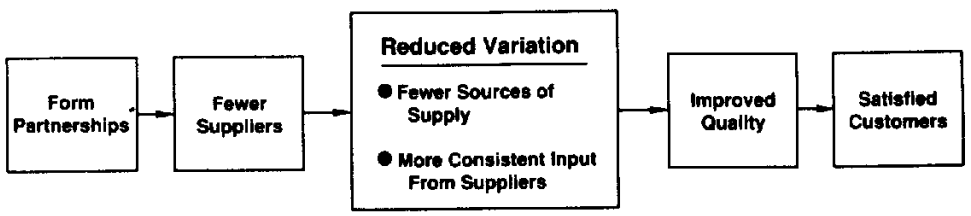

Figure 9. Supplier Partnerships Improve Quality.

- **Adopting business portfolio and strategies that are insensitive to business trends and cycles.**
- **Using a project management system whose performance is not affected by project changes, personnel changes, etc.**
- **Enabling personnel to rapidly adapt to changing business conditions.**
- **Ensuring that meeting effectiveness is not dependent on facilities, equipment, or participants.**

Figure 10. Ruggedness in Management.

6. OUR CHALLENGE

Statistical thinking has a role to play in all aspects of total quality. The use of statistical methods has a long history of successful use in both research and development and manufacturing environments. They have almost always been used at the operational level, with little attention paid to the needs of management or the organization as a whole. We have done little thinking about statistics at the "concept" and "systems" levels. Our challenge is to understand the concepts, systems, and tools of statistical thinking and how statistical thinking is used in all parts of the organization.

Statistical thinking is not the only field of knowledge one needs to understand in order to achieve total quality. A good example is organizational development, which deals with the behavioral aspects of how we direct our businesses and interact with each other [Bennis (1969) and French and Bell (1978)]. Box (1988) emphasized that achieving total quality requires knowledge of statistical thinking, engineering, management, psychology, sociology, and anthropology. A knowledge of organizational development will not only help us do a better job of achieving the management leadership and people and teamwork ingredients of total quality, but it should also enhance our ability to improve product quality and care of customers and achieve constant improvement and innovation.

We will achieve total quality more rapidly when we integrate the concepts, systems, and tools of statistical thinking and organizational development. I believe that Deming's principle of reducing variation to improve quality is fundamental. It is the theme that will enable the integration.

7. CONCLUSION

I began this discussion by noting the tremendous changes now affecting American business and society. Statistical thinking is also at a juncture in its history. Broader use of statistical thinking is essential to the successful pursuit of total quality. It is not clear where this will lead, but it is clear that we have no choice. The journey can be challenging and rewarding.

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EDUCATION COMMITTEE UPDATE

Education was one of the topics discussed at the Strategic Planning Meeting held in conjunction with the Fall Technical Conference. Representatives from ASA Quality & Productivity Section participated in this part of the meeting. This is part of the ongoing effort to work jointly with ASA Q&P.

Four additional directives were identified for the Education Committee. These are long term goals. The four new directives are:

1) Sponsor short courses at AQC, FTC (currently done by the Division) or other places.

A list of potential topics was developed. We are looking for meetings or other places where we could sponsor these courses. Co-sponsorship of courses with other divisions of ASQC, sections or other societies was discussed. If you have ideas for co-sponsorship for 1992 or later, we would be interested in hearing from you.

2) Train statisticians in non-statistical areas to enable them to perform better in the "real world".

Roger Hoerl is chairing an effort to develop a white paper on what skills are necessary. When the white paper has been completed (target date is mid-summer), we will consider developing a short course around these skills.

3) Develop short course material on statistical topics that can be delivered by a wide variety of people. These could be used by individuals to deliver short courses using a consistent approach.

George Marrah (James Madison University) is developing a draft list of topics that statisticians and other practioners need and are considered to be of enduring usefulness. We will try to look at those topics which are either not currently being addressed or are not being addressed adequately.

4) Develop and provide to sections a process that they could use to educate others not currently aware of the value of statistical methods.

No action is currently being taken on this item.

If you are interested in helping with the Education Committee, please contact:

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