CHAIR'S MESSAGE
by Conrad Fung

27 degrees below zero is not so cold if you're prepared for it. My car still starts and I can still get a cup of coffee at my local convenience store. What's remarkable about all this is that none of it is remarkable; it's just a whole lot of people doing what they do every day, and being ready for snags that nature may throw in their way. A lot of people are helping Stat Division "be ready." This Chair's Message will be a report about a lot of their efforts.

The two key projects we announced in the Summer newsletter are done! In October we published an Operating Manual to keep the Division running smoothly. In November some folks from ASQC National and Chairs from other Divisions told us that the Manual would be a model for upgrading their systems. The Manual has even gone international—we've shared it with the American Statistical Association, the Royal Statistical Society in England, and the Swedish Association for Quality. Past chairs Roger Hoerl and Steve Bailey were the authors of this project, and they deserve our applause.

The Division's membership survey was also completed in October under the hand of Chair-Elect Joe Voelkel. The results of the survey are summarized in this Newsletter.

The 1991 Fall Technical Conference in Lexington was a great success. Statistics Division honored the memory of our founder Bill Hunter by presenting the William G. Hunter Award to Dr. Gerald J. Hahn of General Electric for his extraordinary contributions to applied statistics. Statistics Division was also pleased to chair the W. J. Youden Memorial Address delivered by Dr. William H. Lawton of the University of Rochester and Joiner Associates. We're privileged to publish Bill's presentation in this Newsletter.

After the Fall Technical Conference, the Statistics Division Council continued the tactical planning we began in May and which I described in my Summer Chair's Message. Our focus this time was fully on education, especially on integrating the services we offer, each of which has an educational component like the Newsletter, How-To Booklets, conferences, and short courses. The membership survey was vital in guiding our thinking. This is a continuing project, and we'll report on it in more detail as it matures, in the Spring Newsletter.

On November 20, I attended the meeting of the General Technical Council of ASQC in Milwaukee. We learned of very important changes for the Certification exams and the Annual Quality Congress:

The national Certification Committee is starting a major restructuring of the way it manages the content of its exams. The numbers speak to the importance of this: 9500 people are expected to take the CQE exam this year; and 4000 will take the CQA exam. The new plan will be for Statistics Division to have primary ownership of the statistics parts of the exam. This is a step whose time has come—until now there's been no organizational link between expertise and responsibility. Beth Propst will be our liaison with National's certification activities. See Beth's article about Certification in this Newsletter.

The Annual Quality Congress will also have a new structure starting in 1993. To replace the old program format, where individual sessions were sponsored by Divisions rather than organized by topic (with the result that talks about a particular topic might be scattered throughout the program), the new plan is to have sessions aligned by topic rather than by Division. This means a lot more work for the organizers since all the Divisions will have to coordinate with one another in scheduling the program, but hopefully a more rational conference will result. 1993's conference theme will be "Proven Results through Total Quality."

I want to welcome Mike Mazu of Alcoa as Statistics Division's program representative for the 1993 Annual Quality Congress in Boston, and Rick Schleusener of Kodak as Short Course organizer for the 1992 Fall Technical Conference in Philadelphia.

As I said at the beginning, this has been a short report about a lot of people's work to help the Division "be ready." I've been getting even more phone calls recently from members interested in more involvement. Great!

Our next Annual Business Meeting will be held at the Annual Quality Congress in Nashville. A time slot hasn't been assigned to us yet, but we're planning for the late afternoon of May 18. The meeting is open to everyone. Snacks are guaranteed; please come!
About the Statistics Division Logo

The Statistics Division logo is an example of a Central Composite Design, an array of experimental trials for generating data to fit a response surface. The three dimensions of the diagram represent three design factors X1, X2, and X3, whose effects on a response Y it is desired to study. Each ‘dot’ on the diagram is a different combination of levels of X1, X2, and X3. Running the Central Composite Design experiment means measuring a value of the response Y at each of these points. The resulting set of Y’s are the data from the experiment. A quadratic response surface model can be fitted to the data, and this model can be studied to find out what needs to be done to X1, X2, and X3 to maximize or minimize Y, or to achieve a particular desired level for Y.

Central Composite Designs were introduced by Box and Wilson in 1951 in a landmark paper on the experimental attainment of optimum operating conditions. Such designs are particularly nice because they can be run in modules: the core of the design is the well known factorial design (the “cube” part of the logo) which can be run first, together with a few center points (the dot in the middle of the logo). If the information from this first design is sufficient, then the experiment can be stopped. However if the response function shows curvature that needs to be characterized in more detail, additional star points (the six axial points at the end of the “sticks” emanating from the center of the logo) can be run. Combining the factorial points, center points, and star points together, one can fit a full quadratic equation which can be used to understand and optimize the process.

Some references for further reading about Central Composite Designs and Response Surface Methodology are given below. The reference by John Cornell (1990) is an introductory level How-To Booklet published by Statistics Division of ASQC. The reference by Box and Wilson (1951) is the article in which these topics first appeared. The book by Box and Draper (1987) is a textbook at a more advanced level.


Cornell, J. A. (1990), How to Apply Response Surface Methodology, Revised Edition, American Society for Quality Control (Statistics Division), Milwaukee, WI.

Dear Ms. Baxter,

Thank you for your editorial work for the ASQC’s Statistics Division.

While reading through the Fall issue of the newsletter, it occurred to me that my preference would be to have it contain some (more) humor. I got out my file of anecdotes I use to bring across statistical ideas, some of which I’ve enclosed for your pleasure.

Since most originate from the New Yorker, I called them and spoke to the Permissions department representative about copying permission. She told me that to apply for permission from the New Yorker and the cartoonist, one must: 1) Publish no more than one cartoon per newsletter issue; 2)

Continued on page 3
Dear Readers:

Did you notice the “new” name of the newsletter? That’s right, the “new” name is the old name. After careful consideration we decided to keep the name of the newsletter the same. Thanks to Lloyd Nelson, Nashua Corporation and Eleanor Chilson, Security Plastics Inc. for the suggestion. We also thank all the members who participated in the contest. We wanted everyone to have a chance to see all the entries. You’ll find them on page 23.

Jed Heyes, Region 12 councilor, has agreed to take over as Newsletter Editor in July. Jed has been active in the Division for many years and is looking forward to his new role. Submissions for the newsletter should be sent to Jed after June 30, 1992.

The survey has highlighted some topics that readers may want to learn more about. This issue’s Basic Tools column presents one of these techniques (Cause and Effect diagrams). Is there a technique that you’d like to write about or learn about? If you’re planning to send a submission to the newsletter and it was typed on an IBM compatible word processing package, you may be able to save me some steps. Send along a diskette (3 1/2" or 5 1/4", any density) with your submission. Please identify the word processing package you used.

Nancy

STATISTICS DIVISION ANNOUNCEMENTS

• Jed Heyes, currently Region 12 councilor, will become Newsletter Editor in July.
• Mike Mazu has agreed to serve as the 1993 Annual Quality Congress Chair.
• Rick Schleusener, Region 13 councilor, will serve as the FTC Short Course Chair for 1992.
• Joe Troxell, Region 5 councilor, is the Host Committee Chair for the 1992 FTC.

Addresses for Jed, Rick and Joe can be found under Regional Councilors.

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Alcoa Corporation
Building 1
Warwick Operations
Newburgh, Indiana 47630
(812) 853-4893

ADDRESS CHANGES: EDUCATION CHAIR
Beth Propst
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Rockford, IL 61105-4509
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35th Annual Fall Technical Conference

This year’s FTC, held October 24-25 in Lexington, Kentucky was attended by more than 350 people. Along with attendees from the usual diverse locations (35 states and 6 other countries), local colleges and industries were well represented.

The Dean of the College of Engineering at the University of Kentucky presided at the Plenary session. Speakers Joe Pignatelli and John Ramberg presented a David Letterman style “Top Ten Triumphs and Tragedies of Genichi Taguchi.” The technical program consisted of 18 sessions centered around the theme Statistics and Quality: A Winning Combination. These presentations discussed proven strategies and innovative tools for neural networks, robust design, experimental design, quality planning, process control, process improvement and variation analysis. Two sessions were organized by ASQC sponsored journals, Technometrics and Journal of Quality Technology. During one session the Statistics Division White Paper on “Survival Skills for Statisticians” was presented. This year’s Youden Memorial Address, titled “Design, Marketing, and Quality Management: Parts of a Whole” was given by William H. Lawton. (The Address appears elsewhere in the newsletter).

Three awards were presented during the conference. The Shewell Award for the best presentation at the 1990 FTC was given jointly to Steve Bailey, Ken Chatto, Bill Fellner and Chuck Pfeifer for their paper “Giving Your Response Surface A Robust Workout” and to Peter John for his presentation of “Dubious Observations in 2 Factorial Experiments.” Jim Lucas and Mike Saccucci received the Youden Award for the best expository paper in Technometrics during 1990. The Hunter Award, named after the founding chair of the Statistics Division, was presented to Gerald Hahn for his many contributions as a communicator, educator, innovator and integrator of statistics.

Continued on page 5
The Council meeting was held in the Lexington Hyatt Regency, Lexington, Kentucky at 7:30 p.m., Wednesday, October 23, 1991 in conjunction with the Fall Technical Conference. Fourteen Council members and seven other Division members attended the meeting. We were also pleased to have a visitor, Marie Olausson, secretary of the Swedish equivalent of the Statistics Division.

The Division membership is currently 15,981, this does not include members who are late in paying their dues. The balance in the Treasury at the end of September was $116,097.

Reports on current projects were given. The Education Committee is working with ASQC Certification Committee to upgrade the CQE exam. A membership survey was conducted to help provide information for our future efforts. The survey has not completely analyzed, but there was considerable discussion on the preliminary results at the Tactical Planning meeting. (The preliminary results are summarized in another part of this newsletter.)

A major accomplishment of the Division is the completion of the Statistics Division Operating Manual.

The Manual contains:
- the Division's Vision, Mission, and Strategy
- an overview of the Division's organizational structure
- a directory of its officers, committee chairs, and regional councilors
- job descriptions for every position of responsibility
- management systems and procedures
- summaries of long-range planning meetings
- tactical plans for the coming year

The Council expressed a special to Steve Bailey and Roger Hoerl for the work they did in completing the Manual.

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**PUBLICATIONS/STANDARDS**

The Division newsletter will keep the name Statistics Division Newsletter. A new Glossary will be published during the summer of 1992. The Standards Committee is reviewing and providing comments on four standards, and developing three other standards.

**CONFERENCES**

Call for papers for the 1992 FTC is underway. Ralph St John is the Division's 1992 FTC Program chair. Greg Gruska reported on the status of the 1992 AQC program. As a result of Greg's recommendation, the Council voted to recognize the speakers and moderators of the Division sponsored sessions. Beth Propst, Education Committee Chair, has arranged for the Division to sponsor a short course on Designed Experiments at the 1992 AQC. The Council voted to support six students and/or new researchers to attend the 1992 Gordon Research Conference with a total of $2400. The Division contributed $2000 (of which $570.71 was refunded) to the Ott Workshop on Academic Programs in quality, held at RIT July 19-20, 1991. This meeting was a seminal gathering of representatives from the majority of quality-focused academic degree programs in North America.

**REGIONAL COUNCILORS**

Regional councilors activities included organizing sessions at local conferences, contacting new ASQC members, participating in local sections meetings and answering a variety of questions from ASQC members.

Galen Britz and Ed Hansen are preparing a Division Information Package which can be used to make presentations about the Statistics Division. The package is in the form of overhead transparencies.

(A complete copy of the Council Minutes is available from Secretary Galen Britz.)
**HAHN WINS HUNTER AWARD**

Dr. Gerald J. Hahn has been named as the recipient of the 1991 William G. Hunter Award. This award is granted annually by the American Society of Quality Control (ASQC) Statistics Division to honor persons whose qualities mirror those of its founding chairman, Bill Hunter.

Gerry Hahn is manager of the Management Science and Statistics Program at the General Electric Company’s Research and Development Center, where he has worked since 1955. Since 1973, he has led a group responsible for developing, promoting and guiding the proactive and effective use of data-based methodology throughout GE.

He is the author of more than 100 publications and writes the “Random Samplings” column for *Chemtech.* His 1991 book “Statistical Intervals: A Guide for Practitioners,” with Bill Meeker, was published by John Wiley and Sons. He has written two previous books and contributed to eight others. He is a Fellow of the American Statistical Association (ASA) and ASQC and has served both organizations in a variety of leadership positions, including founding leader of ASA’s Committee on Quality and Productivity. He is an elected member of the International Statistics Institute and serves as an adjunct professor at Union College.

Gerry has won ASQC’s Jack Youden Prize (1970), its Shewell Prize (1975, 1990), its Brumbaugh Award (1974, 1980, 1982) and its Wilcoxon Prize (1979, 1989). At the GE R&D Center, Dr. Hahn was recognized in 1984 with a Coolidge Fellowship – the organization’s highest honor – for his “wide-ranging accomplishments in the fields of statistics and quality control.”

This year’s award was presented at the 1991 Fall Technical Conference in Lexington, Kentucky. Gerry is no stranger at this annual event; in particular, he gave the Youden Memorial Address at the 1987 conference.

Nominations for the 1992 Hunter Award will be accepted through June 30, 1992. Nomination forms can be obtained from the Hunter Award Committee Chair:

Peter Jacobs, 3M, 549-2S-03, Statistical Consulting, St. Paul, MN 55144, (612) 733-4257

**ANNUAL QUALITY CONGRESS PREVIEW**

Plans for the 1992 AQC are well underway. The conference will be held May 18-20, at the Opryland Hotel in Nashville, Tennessee. Greg Gruska has been working hard to organize the nine sessions allocated to Statistics Division. The nine sessions include papers in the areas of engineering and statistics, moving averages, education and statistics, Taguchi, probability plots and a Deming panel. Mike Mazu will be the Statistics Division’s representative for the 1993 AQC in Boston. Anyone having suggestions for topics or invited papers should contact Mike (his address appears under Statistics Division Announcements).

The 1993 Technical Program Committee seeks papers for the 47th Annual Quality Congress. Papers must make a significant contribution to the quality field. Previously published material will not be considered for presentation.

Authors must request a Speaker’s Data Packet from: Shirl Furger, ASQC, P.O. Box 3005, Milwaukee, WI, 53201-3005, 800-248-1946. Completed Speaker’s Data Packets must be returned by June 8, 1992. The paper selection process has been revised. All current information will be included in the Speaker’s Data Packet.
Many of you may be familiar with the cause and effect diagram (also called an Ishikawa diagram or a fishbone diagram). Since the diagram is easy to construct and explain, many people use it as a way to generate and display ideas. Often, however, the application of the tool is perfunctory. Because the diagram appears so simple, people are not fully utilizing the process. In addition, there are some useful variations on the diagram that may be of interest.

The cause and effect diagram is used to help organize thinking about the causes of a specified effect. It not only shows the different causes, but their relationship to the effect and each other. It is especially useful when:

- It is desired to get the input of many.
- It is desired to show relationships between causes, sub-causes, and effects.
- The main categories of causes are known.

**ADVANTAGES**

A cause and effect diagram has the following advantages:

- It helps formulate theories about possible cause and effect relationships.
- It shows subordinate relationships.
- It can serve as the basis for an experimental plan or data collection plan.

**LIMITATIONS**

A cause and effect diagram has the following limitations:

- The main categories must be known in advance. If a category is left out, it can limit thinking.
- When there are many ideas and subcategories, the diagram can become cluttered and difficult to read.
- It may be difficult to determine subordinate relationships.
- The diagram itself does not help to evaluate the relative importance of the ideas.
- The diagram cannot substitute for numerical data.

How To Construct A Cause and Effect Diagram

1. **Determine the effect of interest.**

Before writing the effect statement, it is important to clarify thinking on what the effect really is. If the diagram is being done with a team, they must all have a common understanding of the effect, and have reached consensus that this is the effect of interest. It is usually helpful to word the effect as an existing problem – poor quality or bad meetings. Then the ideas are the causes of the problem. When the effect is worded as a desired improvement – good quality or good meetings – the ideas generated tend to be possibilities for future action. This may be a useful exercise, but is not strictly Cause and Effect.

2. **Determine the main cause categories.**

In many situations, the five categories of People, Machines, Methods, Materials, and Environment provide a good basis for starting. In other situations, other categories might be more appropriate. There is no limit to the number of main causes – let the problem dictate what is appropriate.

3. **Draw the diagram.**

When the effect statement has been agreed upon, it can be written at the head of the fish. Each main cause should be written at the end of a bone.

4. **Generate ideas and record on the diagram.**

If the diagram is being done in a group, some type of brainstorming method should be used. (See discussion under Affinity Diagram: Process Variations) Each participant must not only contribute an idea, but also indicate where it fits on the diagram. Continue until all ideas have been captured.

5. **Discuss the diagram.**

This is the time for clarifying ideas. The group can discuss whether the ideas are in the right place, or duplicate ideas exist. They may decide to reword some
Diagram Continued

ideas so they are clearer. If understanding sub-causes is important, the group should treat each idea as an effect and ask again “What causes that?” This can continue for several layers of causes.

6. Plan next steps:
Some appropriate next steps for a cause and effect diagram include:
• Eliminating unlikely causes.
• Developing a data collection plan on the causes.
• Developing an experimental plan to test the causes.
• Rearranging the ideas in a Tree Diagram (another of the Seven Management Tools.)

HAZARDS
Common hazards encountered while constructing a cause and effect diagram include:
• Not having a clear understanding of the effect.
• Participants letting the scribe decide where the ideas belong on the chart.
• Identifying solutions to the problem instead of the causes.
• Voting on the ideas in the diagram and substituting the results of the voting for data.

OTHER USES
• Process Diagram
Instead of using the standard categories of People, Equipment, Material, Methods, and Environment, begin with a flowchart of the process. The causes can then be drawn in to indicate at which step in the process the cause occurs. The steps in the process could also be used as the main categories, but this loses the visual impact of the linear flow.
• Reverse fishbone
A reverse fishbone is used to show the possible effects of a particular action or cause. Usually the diagram is drawn reversed, with the head at the left and the bones slanting to the right. This is especially useful when evaluating the possible effects of a proposed solution to a problem.
• Organizing thoughts
The fishbone shape is useful for organizing thoughts, such as what to include in a speech or a training course. The fishbone can then be used to develop a detailed outline.

Another use for the fishbone is to organize To-Do’s. The categories might be Phone Calls, Correspondence, Meetings, and Projects for example. Note that this is not a cause and effect diagram, although it utilizes the fishbone shape and technique.
• Beginning with Affinity Diagram
Sometimes, the main causes are not known. An affinity diagram (one of the Seven Management Tools) can be used to determine the main causes. The header cards from the affinity become the main bones on the fish. The ideas in each cluster can then be sorted out as causes and sub-causes on the fishbone. Additional idea generation can then take place.
• Using Stickies
It can be effective to use stickie notes for the ideas. This allows for repositioning the ideas during the discussion. If silent brainstorming is used or the cause and effect diagram is based on an affinity diagram, this may be the most efficient way to accomplish the task. It is also a good basis for a living fishbone.
• Living Fishbone
The living fishbone is a good way to get the input of many people not involved in the original fishbone and/or collect ideas on an ongoing basis. It can also be used to show progress in removing causes. The living fishbone is usually drawn on a flipchart page or butcher paper and hung on the wall in an easily visible and accessible location. People can add ideas as they occur. If appropriate, as causes are removed or addressed, they can be crossed off. Since this can be somewhat messy, sometimes stickies and a second fishbone are created for completed ideas. As items are addressed, the stickie is moved from the original diagram to the Completed Item Diagram. This provides a visible picture of progress.

OTHER SOURCES
If you wish to learn more about Cause and Effect Diagrams, two good sources are:
Ishikawa, Kaoru; Guide to Quality Control.
Kume, Hitoshi; Statistical Methods for Quality Improvement.
Both books are available through Quality Press.

Tactical Planning Meeting Highlights

Fourteen Division Council members were present following the FTC for a Tactical Planning meeting, October 25-26. At the start of the meeting, the group reviewed the Vision, Mission, Strategy, Principles, and Meeting Ground Rules. All are still consistent and pertinent for the Division.

The Division Operating Manual was reviewed primarily to assure that the Job Descriptions were complete and correct. The Membership Survey was reviewed by Joe Voelkel, who led the survey committee. Preliminary survey results confirmed that education is of primary interest to our members.

The group developed a model to describe a “process for educational product and service development.” A new tactical plan was established: build a “House of Quality” relating our customers wants/needs to educational material. Don Emerling is heading up this project. This project will be reviewed at the AQC and further tactical planning will center around the findings of this project.

(A complete copy of the Tactical Planning Minutes is available from Secretary Galen Britz.)

MEMBERSHIP SURVEY REPORT

At our annual Tactical Planning meeting in May, one of the key projects identified was a membership survey. The purpose of this survey was to assess our members current and future needs of the Division membership, as defined by the members. This information is vital in directing the Division's customer focused efforts, especially in providing educational services to our primary customer: Division members.

The survey was conducted by a professional survey firm. Five-hundred Division members were randomly selected to participate. Participants responded to questions about their jobs, statistical techniques they used, preferred settings for learning, CQE exams, likes and dislikes about the Division, and knowledge/use of Division activities. The key findings of this survey are summarized here.

Continued on page 8
Survey
Continued from page 7

- A large portion (45%) of respondents classified themselves as quality, quality control or quality assurance managers (Figure 1).

- Control charts, pareto charts and flow charts are being used by respondents. Fewer respondents are familiar with and use cause and effect diagrams, design of experiments, regression and relations and affinity diagrams (Figures 2-13).

FIGURE 1
JOB DESCRIPTION

<table>
<thead>
<tr>
<th>POSITION</th>
<th>PERCENT OF RESPONDENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>QUALITY ENGINEER</td>
<td>21.4%</td>
</tr>
<tr>
<td>QUALITY ASSURANCE MANG.</td>
<td>19.6%</td>
</tr>
<tr>
<td>QUALITY MANAGER</td>
<td>13.4%</td>
</tr>
<tr>
<td>QUALITY CONTROL MANG.</td>
<td>11.6%</td>
</tr>
<tr>
<td>OTHER ENGINEERS</td>
<td>4.2%</td>
</tr>
<tr>
<td>ACADEMIC</td>
<td>3.4%</td>
</tr>
<tr>
<td>LINE SUPERVISOR.</td>
<td>1.0%</td>
</tr>
<tr>
<td>INSPECTOR</td>
<td>1.2%</td>
</tr>
</tbody>
</table>

FIGURE 2
USE CONTROL CHARTS

FIGURE 3
USE PARETO CHARTS

FIGURE 4
USE FLOW CHARTS

FIGURE 5
USE CAUSE AND EFFECT DIAGRAMS

FIGURE 6
USE 2-LEVEL FACTORIAL/FRACTIONAL FACTORIAL DESIGNS

FIGURE 7
USE TAGUCHI EXPERIMENTS

FIGURE 8
USE CENTRAL-COMPOSITE OR BOX-BEHNKEN DESIGNS
• Short courses are the preferred method of learning (Figure 14).
• Eighty percent of respondents had not taken the CQE exam. Of these 50% were planning to study for the exam within the next two years.

Continued on page 18
In a free market economy, the end-users of a product have tremendous power, a power that is largely untapped by American businesses. What I'm going to say today about design, marketing, and Total Quality Management links some existing concepts together in new ways that can show you how to tap into this power of the end-user.

**Total Quality Management**

We start with Total Quality Management which most of us think of as resting on three pillars: (1) **customer-defined quality**, judging a product or service by how well it meets or exceeds **customer needs**, (2) **scientific approach**, a data-oriented statistical approach to problem solving which rests on an understanding of variation, and (3) **all one team**, having all employees working together to reach common, company-wide goals. At Joiner Associates, these elements each form one corner of the Joiner Triangle.

![Joiner Triangle](image)

**Customer-defined Quality**

Customer-defined quality occupies the pinnacle of the triangle because it is absolutely essential for the successful application of total quality. The need for this focus is demonstrated in what we've come to think of as the customer "chain."

**The Customer Chain**

Within a free market economy (a growing phenomenon in the world!), end-users determine a firm's ability to compete by purchasing products based on perceived value for cost. Without continuous improvement in existing products, and the creation of new products, a firm will over time lose out to its competitors because the customer will constantly seek better value for money. If your firm doesn't provide it, your competitors will. We can all think of examples of once dominant and powerful firms that have experienced a gradual eroding of their market share and profitability because they have lost touch with this end-user.

It is the end-user who judges the value of new or improved products, and it's from their purchases that all revenues flow back to the firm. However, the end-user is not the only point of customer focus. In general there's a chain of customers. There are usually other customers between the manufacturer of a product and the end-user. For example, a manufacturer may sell to a distributor, the distributor may sell to a wholesaler, the wholesaler may sell to a retailer, and the retailer will sell to the end-user. How long the chain is varies by country, and by product line.

![Customer Chain Diagram](image)

Now, who is the customer? Technically, they are **all** customers. Yet in many firms, it is often only the direct customer that is viewed as the customer—which can be a very dangerous attitude. And while it's true that the end-user has a particularly important role as the driver of the system, all of the other customers in the chain are also important.

**Defining “Customer”**

So the first step for many companies is to start thinking of other customers in the chain that leads from their work to the end-user. But they can't stop there. The customer chain deals with **current customers**. There are also **potential customers** who are often overlooked: people and companies who buy competing products. Then there are **lost customers**, those who stopped buying your product. In many cases, customers have substituted another firm's products. Very often a customer can find an alternative product that will satisfy their need. For example, a traditional lather razor will serve the same need as an electric razor. But how many companies understand the choices customers make when evaluating and purchasing such alternative products?

Another mistake that companies make, especially technology-driven companies that sell industry to industry, is to develop new, improved products based on what is possible, not what maximizes the end-user's value for cost. The end-users thus end up paying for a lot of features that they don't want.

So identifying and understanding the needs of customers all along the customer chain is critical, as is expanding our thinking to include potential customer segments we've tended to ignore. By broadening our horizons, we open the door to a priceless body of information we can use in developing and producing products.

**Customer Information**

Knowing who our customers and end-users are is a critical step. Next we have to decide what it is we want to know from them, who will gather that information, and how it will be used.

During the development of a product, features are often added or deleted on the basis of manufactur-
Marketing's Role

This question brings us to the second element in the title of the talk—the marketing function. The American Marketing Association's definition of marketing, from 1985, states that "Marketing is the process of planning and executing the conception, pricing, promotion, the distribution of ideas, goods, and services, to create exchanges that satisfy individual and organizational objectives."

Translation: Marketing has the ownership of the processes within the firm that define concepts for products: their pricing, their promotion, and their distribution for an end-user we'd like to satisfy. These are a lot of processes that all have a high impact on the end-user. The Marketing function would, therefore, appear to be a major player in a total quality managed company. Based on this functional definition, the marketing function is a logical channel for the voice of the customer.

So, what are the problems? One problem is that in many, if not most, companies, marketing isn't really marketing, but a sales function. That's not a put-down of the sales function. The sales function involves actual purchase of the product or service and the exchange of cash: obviously a critical function for any company! But in the above definition of marketing, many other processes have taken place before the sale occurred. The sales force receives a product that's already conceived, already priced, and the promotion is probably already in place. Marketing, therefore, encompasses much more than sales.

Another problem is that very good marketing operations are often operating as a chimney of excellence with heavy functional barriers between it, manufacturing and R&D. There is poor cross-functional teamwork. Such companies would claim to be focused on customer needs, but relevant information is not flowing to all the essential players in the firm.

Barriers to Information Flow

In the customer chain, a typical product flow is from manufacturer, to distributor, to wholesaler, to retailer to consumer. The flow of information from the customer about the product, however, is in the reverse direction.

<table>
<thead>
<tr>
<th>Customer</th>
<th>Information Flow</th>
<th>Product Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td></td>
<td>Consumer</td>
</tr>
<tr>
<td>Distributor</td>
<td></td>
<td>Wholesaler</td>
</tr>
<tr>
<td>Wholesaler</td>
<td></td>
<td>Retailer</td>
</tr>
<tr>
<td>Retailer</td>
<td></td>
<td>Customer</td>
</tr>
</tbody>
</table>

A lot of things can happen to customer/end-user information if nothing special is done. Without special processes to capture this information there are significant barriers to this information getting back to the firm. For example:

1. As already noted, the information flow primarily taps current customers; information from lost or potential customers is rarely sought or given.

2. New customers who have switched from another product rarely complain to the new supplier about another manufacturer's products.

3. Information is lost at each interface. Few customers with complaints actually voice them; few happy customers voice their satisfaction. The retailer frequently doesn't pass the information to the wholesaler or the distributor.

4. Even if the information makes it through, it's a little like the old party game of telephone. I tell you a rumor, you tell the next person, and we go around the room. When it gets back to me there is little relationship to what I said.

5. The information is likely to be old, especially if it's a long chain.

6. Finally, while complaint or problem-oriented information is important, it's not enough. It does not, for example, deal with future needs.

Without a serious attempt to capture and utilize the information, we've got major problems. If you have a marketing focus within your company, it would be the logical custodian for information from your customer chain: obtaining it, integrating it, and disseminating it. The information would then become pervasive to the company for development of goods and services.

The House of Quality

How can we gather useful customer information, and where in our processes can it be most valuable? The product development and improvement process is perhaps most critical because it is the basis for the continual improvement of value to the end-user. In a Total Quality Managed company, the product development process should be data-driven and based on a scientific approach. One of the systematic approaches to integrating the customer information and product design is QFD: Quality Function Deployment. QFD seeks to integrate customer needs information with the engineering variables of the manufacturing process.

A useful summary of the Quality Function Deployment approach is illustrated with a graphic referred to as the House of Quality. It incorporates an incredible amount of information relevant to the product development process. (see chart on next page)
Design of Experiments

Typically, when quality function deployment is applied, a cross-functional group (R&D, Manufacturing, Marketing, Finance, etc.) will come together to talk about the process and use their respective expertise to fill in the data for the House of Quality. The relationships between the engineering variables and consumer attributes are usually developed within the team by consensus discussion. While knowledge- and data-driven, this remains essentially a qualitative process.

There are ways, however, to make the link between customer needs and engineering variables more quantitative. One key analytic tool that helps quantify the engineering portion of the product development process is DoE, Design of Experiments, a methodology that has its origins in the 1930s (with Jack Youden being a major contributor).

In DoE, we can deliberately perturb the engineering variables and observe the changes in engineering characteristics and their impact on the customer attributes. In the diagram below, the areas that such a designed experiment quantifies are shaded. This use of DoE does not relate to relative importance, consumer preference or perception, but it does provide data for the attributes and design variables we choose. (see chart below)

Design of Experiments allows the planned manipulation of the key engineering process variables to yield predictive models for attributes important to the customer. We can see which engineering variables most affect customer attributes and can predict the direction and magnitude of impact on these attributes. We have a predictive model. However, the only input we have from the customer is through the selected attributes—and a lot of the attributes that drive product specs may have little or nothing to do with the customer's true basis for choice and evaluation. We must be sure to use those attributes which are truly important to the customer.

Along the top row of the matrix, we have the engineering characteristics, process outputs we can control. Forming the roof of the House we have the interactions between the engineering characteristics: how changing one will affect the others. Along the left column of the matrix are the key product attributes of interest to customers. The next column to its immediate right is the relative importance of these attributes to the customer. At the far right, we have a bit of competitive analysis. This portion of the House plots the perception of performance of our product and our competitor's product with regard to each of the attributes.

At the heart of the House is the core matrix which shows the strength of the relationships between each engineering characteristic and each of the customer attributes. Finally, along the bottom of the matrix, we have engineering characteristics from the competitors' products. It is quite a rich chart.

For the purposes of this talk, it is not important that you understand the details of how the House of Quality is constructed (if interested, see Reference 3). My point is that we have a tool and method that allows us to summarize customer needs, and link those needs to product and process characteristics we can control.
Preference Models and Conjoint Analysis

In the '70s, as the use of Design of Experiments in R&D and manufacturing was spreading, some models from economics and psychology were first applied to problems in marketing. In these models, product attributes replaced engineering variables and DoE was used to develop predictive models for customer preference. This predictive approach to understanding customer preference is called Conjoint Analysis.

Conjoint analysis, when it's used in a firm, has tended to arise in marketing research departments since it involves measurements on the customer chain. Unfortunately, the information from these experiments tends to stay in the marketing function. The detailed product development insights provided by the analyses are not shared with other key functions like Manufacturing and R&D.

In conjoint analysis the customer examines a planned set of alternative products, differing only on key attributes, and is asked to rank these alternative products in order of their preference. What do we do with this data? Using these data and a linear preference model, we can estimate the relative importance, or customer utility, for different levels of each attribute. This approach is "decompositional": instead of asking customers directly what they think is important, we measure importance or utility indirectly as a consequence of customer sorting behavior.

Conjoint analysis allows planned manipulation of product attributes to get a predictive model of customer preference, which provides insight into which attributes are most important to the customer, the direction and magnitude of those attributes' impact on preference, and how end-users trade off among these attributes. In most instances product cost will be one of the key attributes.

Since manufacturing process limitations usually force us to make product attribute tradeoffs during product development, we are always in a position of having to judge what product characteristics can be sacrificed and which have to be maintained in order to achieve customer satisfaction. Usually we make such decisions in a void, knowing only what customers said they wanted without knowing how the customer would make the same choices we are facing. With conjoint techniques you have a predictive model of customer preference to help you assess tradeoffs.

So we’ve provided a quantitative model for another portion of the House of Quality linking customer attributes, perception and customer preference.

Conjoint techniques have been used very extensively for the last 20 years. There’s a large body of literature (see references at the end). These are not new or untried methodologies, but, like any design of experiments, they have some important assumptions and cautions.

Customer Driven Design

The next step is to put together these two predictive models.

In the engineering space, we’ve got a model from a designed experiment, that lets us take engineering variables to customer attributes. In the customer space we’ve done some planned experimenting, and it allows us to take customer attribute levels all the way to customer preference. To the degree that those two models are adequate for prediction, we have a way to go from engineering variables to customer preference. Now we can begin to ask questions about how to turn the knobs on the engineering process to get the highest customer preference. Not the warmest feeling in our heart, not the greatest in technology, not the cheapest product, but the one with highest value for cost in the eyes of the customer.

By merging traditional engineering design of experiments with predictive models that come out of preference modeling, we’ve created a house of quality that is quantifiable. Actually it turns out that QFD, as usually applied in a qualitative
sense, and the technology here, doing the quantitative work, are a natural progression. Qualitative work first, followed by a quantitative analysis. The kinds of team discussion that would let you fill in a qualitative QFD chart are the important pre-work prior to designing engineering space and customer space experiments.

Since the combined model allows us to set engineering variables that cover the likely range of manufacturing processes values and predict the resulting overall customer preference (customer value for cost) for the resulting "product," we can then seek the engineering design parameters that maximize the customer's preference.

**Designing a Coffee Pot**

A simple, yet realistic, example could be the design of a coffee pot. We have a basic design concept. Water is put in a vessel that is surrounded by a heater to warm the water. At a certain temperature, a valve opens and the water flows down into another vessel that has coffee in it. From there the liquid, which is now coffee, flows into the pot that sits next to another heater which keeps it hot. The two important engineering variables are capacity (in cups of water) and heater size (BTU/minute).

The engineering team has probably heard, through the grapevine, that marketing says that brewing time and cup capacity are important to the customer. What does this information mean to engineering? Well, we can get brewing time down by heating the water faster, but if we increase the capacity we'll have more water to heat and will have to increase the heater capacity. The more water, the bigger the heater needed for timely heating and the higher the manufacturing cost. There are going to have to be some tradeoffs here.

So how do we design the coffee pot? If we go to our marketing community, we might find they have done some focus group discussions on coffee pots. We might have transcripts and videos of people saying things like:

"We forget to set the coffee pot, and when I get up in the morning I'm only thinking about that cup of coffee, and the darn thing isn't set, it isn't going, and I've gotta get coffee made, and I want it quick." Or:

"You know, they've got these great little coffee makers in the room that make one cup of coffee, just enough to get you awake so you want another one, but you can't make it because it doesn't have enough capacity to do it."

We might also find other variables, like the strength of the coffee, the temperature it is when it comes out of the coffee maker, or the price. (That's the one that often doesn't make it into the bundle when we talk about quality. Quality involves value for money.)

Based on our customer research, let's say that the customer's key coffee pot attributes and their desired levels are:

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Desired Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brewing time = BT</td>
<td>Short time</td>
</tr>
<tr>
<td>Cup capacity = C</td>
<td>High capacity</td>
</tr>
<tr>
<td>Strength = S</td>
<td>Capable of strong flavor</td>
</tr>
<tr>
<td>Temperature = T</td>
<td>High temperature</td>
</tr>
<tr>
<td>Price = P</td>
<td>Low</td>
</tr>
</tbody>
</table>

We can now develop a simple experimental design to explore the relationship of our engineering variables to key product attributes.

First of all, let's simplify our task by defining brewing time as the time it takes to make a target strength and target temperature. The three remaining variables are brewing time, cup capacity and price.

We will then use DoE to model the relationship between the heater power and cup capacity.

- The heater, measured in BTUs per minute, will be run at three levels: a heater of nominal capacity, a heater of half nominal capacity and a heater of twice nominal capacity. Smaller heaters are cheaper, larger heaters are quite a bit more expensive and require higher cost wiring and materials.
- Cup capacity will be run at four levels: four cups, eight cups, ten cups and twelve cups—the range that we think is of interest to the consumer.

This gives us three times four factor levels or twelve runs (if we don't replicate—multiples of twelve if we do) for a full factorial experiment.

The experiment gives us the following results. (See next page for table)

The table summarizes the experimental design and the associated values of the three critical attributes of the product. Down near the bottom we have engineering designs that give us a short brewing time and high capacity—four or five minutes for ten or twelve cups—but the price is very high. Up at the top, with the small heaters, we have some nice prices and some brewing times that aren't bad, but the cup capacity is low.

In many firms the decision at this point would be: Powerful heaters cost a lot. We want to keep the product cost low and heaters are the most expensive part, so we'll go with the smaller heat capacity. That will keep the price low but the brewing time high. We can either have a low brewing time or a high capacity. The cheapest is the high capacity so we go with it.

But what if we turn to conjoint analysis and with it the voice of the customer? For conjoint analysis, we want a model based on our three attribute variables: brewing time, capacity, and price. The range of the attributes in the customer space experiment must cover my engineering space. From the engineering design table above, we know what price, brewing time, and capacity range must be covered. It doesn't have to be the identical levels, but must cover the range.

So we will choose to put together hypothetical products that have brewing times that cover the range from 2 to 14 minutes, cup capacities that vary from 4 to 12 cups, and at...
prices ranging from $17 to $30. In particular, let us select an experiment with 2, 6, 9, or 12 minutes Brewing Time; cup capacity of 4, 8, or 12 cups; at prices of 17, 22, or 32 dollars. That's the structure of the design; again we'll show it as a design matrix. A portion of this matrix is shown below.

With two of the factors at 3 levels and one at 4 levels, there are 36 possible products that you can get out of these combinations; the first 15 are shown above. For example, the first product configuration has the $18 price, 4 cup capacity, and 3 minute brewing time. Each of the configurations would be printed on a card. For example, the card for this product would say "4 cup coffee maker with 3 minute brewing time, cost $18." Another one, would be "12 cup coffee maker with 3 minute brewing time, cost $30." There would be another 34 of these cards.

If I ask you to choose between those two cards listed above, which would you pick? Clearly a rational person would choose the second card. But what if I said: "4 cup coffee maker, 3 minute brewing time, $18", or "12 cup coffee maker, 3 minute brewing time, $30"? Tougher question. In an actual experiment the customer has all the cards on the table, and is asked to sort them: the extreme ones first, then working on the middle. As expected, there's going to be noise in the ranking among things that are very close, while other choices are going to stay very distinct.

But the output of this sort is then 36 ranks. These ranks are shown in the far right column of the design matrix above. The biggest rank goes with the most preferred, which happens to be the $18 coffee maker with a maximum capacity and minimum brewing time. Big surprise! That was obvious.

Through ANOVA or dummy-variable linear regression we can estimate the "utility" or "value" the customers have associated with each level of our three attributes. These customer utilities for this experiment are summarized in three plots.

The first plot shows the utility or value to the customer on the vertical or y-axis and brewing time (2, 4, 6, 8, 10, 12) on the horizontal or x-axis. There are comparable graphs for capacity and price. The most preferred, or highest utility for the customer, is a two-minute brewing time, 12 cup capacity, at the lowest price of $18. That doesn't tell you anything new. So what's the new information here? What do you notice about brewing time? The utility curve flattens out on the top! In other words, the customer perceives little loss of utility between two and six minute brewing times—in other words, it doesn't signifi-
cantly impact their perception of value. Even on the price, the utility loss between $18 and $22 is not bad. But what do you notice about the utility plot for capacity? The customer's utility is very sensitive to any changes in capacity: big range, linear; important all the way.

What's typically been done, then, in marketing organizations, is to look at these pictures and say, "Well, we've got some latitude in brewing time, and price. Let's inch up on price, inch up on brewing time, in order to get the best capacity we can get." And that's not bad. That information goes back to engineering, and says we need a $22, 12 or 10 cup, at a brewing time of no more than 6 minutes. That's an order of magnitude of improvement over not using conjoint input for the engineering tradeoffs. But you can do better.

Now we can go back to the results of our engineering design (see earlier) and use the conjoint utility model to compute the overall utilities for each set of attribute values. These overall preference or utility values are shown in the far right column in the figure below. Higher utility means higher preference.

I've circled the two highest numbers. Notice they're not right next to each other. The two highest utilities, the products the customer sees as best value for money, are among the most expensive product concepts. Because what the consumer is getting for that cost is worth it to them. And what you've got here is a 12 cup coffee maker that gives you your coffee in 8 minutes or 5 minutes (a 3-minute difference) at a price range of $25.20 to $31.20. For about $6 you're going to gain 3 minutes in brewing time. What would you do in that case? Well, a lot of things come into play outside of the data we have here. If you're a company with a high-end image, you tend to have a high price premium; you may want to do the highest price model of the two. If you're a company that's known as a really good value for money and sort of moderate, you might take the 8-minute $25.20 model.

But notice that the cheap model coffee makers, all of these inexpensive things that we might have been led to produce in classic American business are all things with low customer utility! Companies tend not to think this way. Especially when they do pricing.

Now there's one more plot that I would like to introduce. This is a plot of overall customer utility versus the engineering space; the data in the above figure. This plot is shown at right.

Notice that this is a fairly smooth surface, in that the low-capacity, low-heater range is sort of parabolic. At the high heater, it's virtually a linear rise. It makes you ask some interesting questions. Why is that parabolic? Kind of interesting. Think about it. We've got low heater capacity, so you can get short brewing time if you keep capacity small. If you start raising capacity, for a little bit you can trade off, because remember, brewing time wasn't too sensitive for a while; you actually get an increase in utility; but if you go too far, you've got so much water to heat, and the heater's kind of small, if you get into very long brewing times, you get into disutility, or a loss of utility.

Notice also that the utility surface reaches its peak value at the edge of our design. In terms of future experiments, what would that suggest? It makes looking at the circled area awfully interesting.

Two final comments. First, ranking 36 cards is tough work. And that's for three attributes at 3, 3, and 4 levels. What can we do to make that task a little easier, especially if we want to move to more attributes? Well, the same old approach, fractional factorials! After all, we're using a linear additive model, a main effects model. We can get by with much smaller experiments, if indeed there are no interactions present. So in fact, very often, latin square techniques and other fractional factorials are used.

Second, consider the concept of two-level screening designs. This is important when you're trying to work your way through too many attributes. You want to at least get some order of magnitude understanding of what you should be looking at. So what happens, bottom line, is all the stuff we've used so effectively to produce useful design strategies in engineering, are almost all portable to the customer space work.

In conclusion, Quality Management requires a quantitative approach to customer information processes. The marketing function of the firm, if it exists, is a logical driver of such customer information processes. And finally, linking, or blending, of experiment-based engineering models and quantitative preference models gives you a way to truly achieve a customer-driven product development.

Continued on page 17
Quarterly Newsletter
Division activities, information on upcoming events, technical and non-technical papers, and useful information for the application of statistical concepts are published in the newsletter quarterly.

"How To" Series
Statistics Division sponsors the publication of the ASQC Basic References in Quality Control: Statistical Techniques. This "How To" series introduces a straightforward manner a variety of statistical techniques.

Co-Sponsorship of Fall Technical Conference
Representatives from government, industry, and academia learn new tools and explore opportunities for applications of statistics and quality technology.

1992 FTC -
Philadelphia, PA Oct. 8-9

Sponsorship of AQC
Sessions Technical sessions are sponsored at the Annual Quality Congress. Highlights in recent years have included panels on Deming and Taguchi.
46th AQC -
Nashville, TN May 18-20, 1992
47th AQC -
Boston, MA May 24-26, 1993

Co-Sponsorship of Annual Conference on Applied Statistics
This conference presents new techniques and statistical applications in the biological-pharmaceutical and quality control fields.

Youden Address Continued

Background References


The lead article in the February 1992 issue of Technometrics is "Zero Inflated Poisson Regression, With an Application to Defects in Manufacturing" by Diane Lambert.

The quality of some manufactured items can be measured in two ways: the fraction of items with defects and the average number of defects per item. Improved manufacturing may decrease one of these parameters but have little, if any, effect on the other. For example, a change in materials may reduce the average number of defects per item without increasing the fraction of defect-free items. Unfortunately, the Poisson distribution, which is the standard model for counts of defects for reliable manufacturing processes, has only one parameter and does not allow the fraction of items with defects and the average number of defects per item to be modeled separately.

Zero inflated Poisson (ZIP) regression allows the fraction of defect-free items to be larger than would be predicted from the number of defects on items with defects. That is, ZIP regression is a model for count data with excess zeros. It assumes that with probability p the only possible observation is zero and with probability 1 - p a Poisson (λ) random variable is observed. For example, when manufacturing equipment is properly aligned, defects may be so rare that they are impossible for all practical purposes. But when it is misaligned, defects may occur according to a Poisson distribution. Both the probability p of the perfect, zero-defect state and the mean defect rate λ in the imperfect state may depend on covariates or experimental design factors. Sometimes p and λ are unrelated; other times p may be taken to be a simple function of λ. In either case, as this paper shows, ZIP regression models are easy to fit, maximum likelihood estimators are well-behaved and likelihood ratio confidence intervals are trustworthy.

ZIP regression models can lead to more refined analyses of the quality of manufacturing processes, as the motivating application to soldering defects on printed wiring boards shows. Two sets of conditions may give about the same number of defects, but the perfect, defect-free state may be more likely under one set of conditions and the mean number of defects in the imperfect state may be smaller in the other. That is, ZIP regression can show not only which conditions give lower mean number of defects but also why the means are lower.

ZIP regression can also be inter-

Continued on page 22
1992 FALL TECHNICAL CONFERENCE CALL FOR PAPERS

A Call for Papers has been issued for the 36th Annual Fall Technical Conference to be held October 8-9, 1992 in Philadelphia, PA. The conference is co-sponsored by the Chemical and Process Industries Division and Statistics Division of the American Society for Quality Control, and the Section on Physical and Engineering Sciences of the American Statistical Association. The theme for the 1992 conference is "Competitiveness Through Continuous Improvement: A Nation Waking Up".

Applied or expository papers are needed for Statistics, Quality Control, and Tutorial/Case Study sessions. Statistics papers should be at or below the level of Technometrics, while Quality Control and Tutorial/Case Study papers should be at or below the level of Journal of Quality Technology.

Please send the title, one-page abstract, and one-page outline of your paper by January 24, 1992 to Greg Piepel, Battelle-Northwest, P.O. Box 999, Richland, WA 99352. For more information contact any of the program chairs: Greg Piepel of the Section on Physical and Engineering Sciences (509-375-6911), Kymberly Hockman of the Chemical and Process Industries Division (302-999-6634), or Ralph St. John of the Statistics Division (419-372-8098).

Survey
Continued from page 9

FIGURE 15

- Respondents are aware of and use the Newsletter. Respondents were aware of other Division activities but used them to a lesser degree (Figure 15).

We are still reviewing the verbatim comments and will be using all the information obtained from the survey to help guide future activities of the Division. To all those members who participated in the survey, we thank you for your valuable input. If you have suggestions or comments regarding Division activities, please contact one of the Division officers.
FALL TECHNICAL CONFERENCE

Conrad Fung presents the Hunter Award to Gerry Hahn.

Joe Voelkel and Conrad Fung with Youden Address presenter Bill Lawton.

Tactical Planning Meeting: Council members discussing Statistics Division operating manual.

At Left: Statistics Division Officers: (R to L) Conrad Fung, Rick Lewis, and Galen Britz.

Below: Fall Technical Conference Session: Jim Lucas, Speaker.

Fall Technical Conference Session: Jeff Hooper, Speaker.

Fall Technical Conference Session: Roger Hoerl, Speaker.

Tactical Planning Meeting: Galen Britz and Beth Propst.
APPLICATION OF CONTROL CHARTING TO WEIBULL DATA

Paul Stephens, General Electric Company, Building 2, Room 637, One River Road, Schenectady, NY 12345

Introduction: Weibull probability plots have long been used by reliability engineers to gain insight into the distribution of component lifetimes. Additionally, the Weibull statistical technique has been used to describe the strength of brittle materials such as the crush strength of aspirin tablets. Occasionally, anecdotal remarks are heard to the effect that Weibull statistics are useful in quality control. Exactly what is done with these statistics is never discussed. The purpose of this paper is to present, by example, one possible use for lot type data.

For Weibull distributed data, the maximum likelihood (ML) estimates of the Weibull characteristic value (CV) and the shape parameter (β) are jointly normally distributed [1] for large samples. This fact can be used to construct familiar statistical process control charts that can be used to monitor process stability.

**MONTE CARLO SIMULATED DATA FOR A HYPOTHETICAL QUALITY CHARACTERISTIC**

**TABLE 1**

<table>
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<tr>
<th>LOT</th>
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<td>3</td>
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<td>4</td>
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<td>3.36437</td>
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<td>5</td>
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<td>6</td>
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</table>

**NOTE:**

ALL DATA OBTAINED BY MONTE CARLO SIMULATION USING SAMPLE SIZE 100.

**Example:** Table 1 contains the ML estimates (CV, B) for 20 sets of Monte Carlo (MC) generated observations from a hypothetical quality characteristic that has a Weibull distribution with CV=40 arbitrary units and =2.8. The sample size used for the ML estimate of CV and B was 100. These data represent the "in-control" data that are used to establish the control charts. Figures 1 and 2 are normal probability plots of CV and B. A modified Wilk-Shapiro Test [2] for goodness of fit, based on the linear correlation coefficient, indicates the normal hypothesis for CV and B cannot be rejected. This gives reasonable comfort as to using the assumption of normality for CV and B, but normality should be checked each time this technique is used to give assurance that the lot size is sufficiently large.

**Table 2** contains the ML estimates of CV and B for 16 Monte Carlo simulations of sample size 100 which simulates a uniform drift in B of the quality characteristic toward more variability in the process while CV is held constant at 40 arbitrary units. These are the "out of control" data that form sequential lots 21 through 36.

**TABLE 2**

<table>
<thead>
<tr>
<th>LOT</th>
<th>CV</th>
<th>B</th>
</tr>
</thead>
<tbody>
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<td>1</td>
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**Continued on page 21**
**MINI PAPER FIGURES**

**FIGURE 1**
- Characteristic Value (CV) vs Normal Scores for In-Control Data
- Correlation of CV and Normal Scores = 0.995

**FIGURE 2**
- Weibull Shape Factor (β) vs Normal Scores for In-Control Data
- Correlation of Beta and Normal Scores = 0.940

**FIGURE 3**
- Individuals Chart for Characteristic Value (CV)
- Moving Range Chart for Characteristic Value (CV)

**FIGURE 4**
- Individuals Chart for Weibull Shape Factor (β)
- Moving Range Chart for Weibull Shape Factor (β)

**FIGURE 5**
- Time Series Plot of Hotelling's T**2** Statistic for All Data

**FIGURE 6**
- Moving Average Chart for T**2** For a Sample Size of 2

**DIAGNOSTICS:**
- TEST 1. One point beyond zone A.
  - Test failed at points: 4 25 29 32 33 36
- TEST 2. Nine points in a row in Zone C or beyond (on one side of CL).
  - Test failed at points: 30 31 32 33 34 35 36
- TEST 3. Six points in a row all increasing or all decreasing.
  - Test failed at points: 29
- TEST 5. Two of 3 points in a row in Zone A or beyond (on one side of CL).
  - Test failed at points: 25 26 27 28 29 30 31 32 33 34 35 36
- TEST 6. Four of 5 points in a row in Zone B or beyond (on one side of CL).
  - Test failed at points: 26 27 28 29 30 31 32 33 34 35 36
- TEST 8. Eight points in a row beyond Zones C (above and below CL).
  - Test failed at points: 30 31 32 33 34 35 36
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Weibull Data
Continued from page 21

Weibull process and the "drifting" Weibull process were accomplished using the "WeibullSMITH" Program [5]. The maximum likelihood estimates of the $\alpha$ and $\beta$ parameters were also made using Weibull Smith.

The statistical processing of the $\alpha$ and $\beta$ data in Tables 1 and 2 to produce the control charts were made using the Minitab Data Analysis Software [6]. A copy of the Minitab macro for making these calculations is available from the author.


Technometrics
Continued from page 17

interpreted as a robust design model for count data. As Taguchi has demonstrated, minimizing variability is just as important for quality improvement as optimizing mean performance. ZIP regression accomplishes this by modeling $p$ and $\lambda$ as a function of design(control) factors and choosing their settings to minimize both the fraction of defective items and the mean number of defects.
The ASQC Statistics Division Newsletter is a publication of the statistics Division of the American Society for Quality Control.

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