The 1999 ASA Quality and Productivity Research Conference Presentation Abstracts

Wednesday Keynote Address

Six Sigma: From Strategic Deployment to Bottom-line Results

A. Blanton Godfrey, Joseph A. DeFeo and Richard Chua
Juran Institute, Inc.

There are many challenges in creating a strong, competitive position today. They start with creating the right strategic direction for the organization and developing an aggressive, yet realistic strategic plan. But the plan is only a starting point. Without deployment, the strategic planning process is just another non-valued-added activity. In the last few years a small number of companies have used the emerging ideas, concepts and tools of Six Sigma to develop deployment plans leading to stunning results. We shall review some of the successful approaches - and some of the failed ones - and share lessons learned from a number of case studies.

Six Sigma Implementation I

Applying Six Sigma in an Innovative R&D Organization

Jane C. Li, James Rockwell and Anne Raich
UOP LLC

UOP has a proud history of innovation as a world leader in development and commercialization of new technologies for petroleum refining and petrochemical process industries. Two years after successful introduction of Six Sigma to manufacturing in 1995, over 250 UOP engineers, scientists and managers began participation in an accelerated in-house customized Six Sigma program. Long-term success through new product and process design is emphasized with a broad training approach. A culture change has begun toward aligning complex technical and business issues, providing a fresh view of catalysis, material, and process research and development, and improving testing efficiency. Six Sigma has led to disciplined, quantitative problem solving and decision making, linking customer needs to product and process requirements, developing robust manufacturing recipes, and improving cycle time, quality and margins, at over $50MM cumulative savings. Examples of the use of Six Sigma tools for research and development at UOP are given.

Six Sigma at Eastman Kodak Company

Stanley H. Gabel
Eastman Kodak Company

At Eastman Kodak Company, the Six Sigma philosophy and methodology have been adopted as key drivers towards achieving total customer satisfaction. This talk will describe the evolution of the Six Sigma Program at Kodak and focus on the three corporate training and certification programs for building Six Sigma capability in the company - the Quality Improvement Facilitator Program, the Black Belt program, and the Management Black Belt Program. Since its inception two years ago, certified graduates from these programs have recorded process and product improvements valued at over $50M. We will highlight the unique features of the overall program, as well as the key learnings we have gained from this endeavor.

Control Charts I

Control Charts for Means with Limits Obtained by Bootstrap Methods

Thomas J. Boardman and C. Richard Gumina
Colorado State University

One tool used by organizations engaged in the Six Sigma philosophy is the classic Shewhart control chart for subgroup means. Although it is well known that subgroup averages are often well monitored by setting the control chart limits at the usual +/- 3 sigma limits, there are situations in which these limits may lead to erroneous conclusions concerning the process. After encountering several of these situations, the authors prepared a macro for the Minitab statistical package to obtain bootstrap upper and lower control chart limits. For many situations these limits are not close to being symmetric about the overall mean. However, the limits can ensure equivalent coverage. We will present some empirical and Monte Carlo results on the use of bootstrap control chart limits as well as demonstrate the macro on several processes.

Multivariate Control Charts for Process Dispersion

M. Raghavachari
Rensselaer Polytechnic Institute

George C. Runger
Arizona State University

Johann Surtihadi
Lifescan, Inc.

The multivariate extension of control charts for process dispersion is not as straightforward as that for the process mean. A general model with techniques that would encompass a wide range of problems encountered in practice is not currently available. In most cases, particular problems need to be handled in a specific manner. We consider several special cases of a process displacement affecting the covariance matrix, and we develop control charts (both Shewhart-type and CUSUM) to detect these process changes.

PEZ 1.4 - A General Purpose DFSS Software Tool

Don Beeson, Hannah Bond, Don Carpenter and Kristy Gau
GE

PEZ is a general purpose software tool developed at Aircraft Engines which is currently being used by more than 250 engineers for Design for Six Sigma (DFSS) analysis. Version 1.4 of this tool has a new analytical method for fast probabilistic integration (AURORA) as well as a new capability for distributed, parallel processing (ASCEND). These additions extend the existing PEZ capabilities for linking simulation codes with analysis drivers for automated design of experiments, Monte Carlo simulations, and optimization studies. AURORA provides an efficient alternative to the Monte Carlo method of dealing with random variables, greatly reducing the number of runs to achieve a desired level of confidence. By distributing DFSS studies to many machines with free computing cycles, ASCEND mitigates the large increase in demand for computing resources due to a growing number of DFSS studies. This paper will give a general overview of PEZ V1.4 and will use GEAE examples to illustrate how using fast probabilistic integration and distributed computing can significantly reduce design cycle time and computer costs.

Demonstrating The Equivalence of Two Process Means

Jeff Stein, GE CRD

Demonstrating an equivalence of two process means requires an approach different from that found in standard statistical textbooks. In this talk, I will present a revised formulation of the classical statistical hypothesis of "no difference" between two process means and discuss sample size considerations. A case study will be presented to demonstrate the methodology.

Design for Six Sigma Experiences

DFSS on Feasibility of High-Flux Industrial CT Tube

Subhasish Roy Choudhury
GE

DFSS based approach was used to study the feasibility of enhancing the throughput for an existing micro-focus stationary industrial CT Tube. In order to increase the throughput, the effort was directed towards enhancing an existing design, concentrating on two design concepts. The first one involved electron beam sweep, while the second one involved enhancing the current cooling methodology. Based on prior experience and engineering judgment, 3 CTQ's, namely temperatures of target track, braze joint and copper base with clearly defined Upper Spec Limits were chosen. A DoE using face-centered central composite design was performed to capture expected non-linear behavior based on the physics of the problem. Physics-based transformation of design variables led towards excellent fit for all 3 response surfaces. Optimization were performed with a goal to maximize the throughput or heat flux, resulting in a maximum power setting of 2.85 kW, while maintaining 6σ performance.

Predictive Design and Extrusion Line Simulation – An Initial Application To Process Control

Don Ellington and Necip Doganaksoy
GE

Feeder capabilities for an extrusion line at one GE Plastics site have been verified and captured in a Monte-Carlo simulation, using Microsoft Excel and the Crystal Ball tool. The simulation allows the user to produce lots of a flame retardant polymer product on extrusion compounding lines. The resultant Critical To Quality (CTQ's) can be predicted from the output of the model. Transfer functions for UL94 flame performance and product composition have been developed and encoded into the model. The significant aspects of the model are the inclusion of feeder capability and Gage R&R effects from QA testing. A cross functional team has successfully used the model to eliminate selected "end-of-the-pipe" QA testing at one GE Plastics site as well as identifying the critical control points in manufacturing, through the use of sensitivity analysis. Future uses of the simulation will include product reformulations, based on better process understanding, resulting in significant raw material productivity.

The Six Sigma Initiative: Lessons Learned

Gerald J. Hahn
GE CRD

Six Sigma was launched by top GE management as a key Company initiative about three and a half years ago, and has resulted in some significant "bottom-line" results. This personal perspective examines some of the lessons learned in start-up, implementation, and tools application. The role of statisticians in the new environment — in which all employees have some training in statistics — is also briefly discussed, and some key issues are examined. In summary, the news is good — but many important challenges remain!

Real World Methods

Physical Layout Statistical Analysis

G. Forman, E. Kaminsky, D. Shaddock, K. Ma, A. Johnson, L. Douglas
GE

CAD generated physical layout for electronic circuit boards, flex circuits and assemblies has been generally treated as custom artwork (highly unique) or correct by construction (using CAD tool built in error checking) and has rarely been treated with post layout statistical analysis for design rule checks and pre-fabrication checks for comparisons to process capabilities. In this presentation, we introduce a physical layout analysis methodology and tool suite that is based on over 200 audits and statistical analysis for PCB/PWB artwork and factory manufacturing files for defects, design for manufacturability, design for assembly and electrical rules checking. Additionally, we propose design for reliability checking as part of a comprehensive physical layout analysis element of an overall Electronics DFSS Design Methodology. GE procures circuit board assemblies at a cost of over $200M per year primarily from suppliers and contract assemblers, and this tool suite can aid in the preparation of error free design databases and in the selection of an optimum or a group of potential suppliers.

The Application of Statistical Modeling in Engineering

George Dyson
GE

Statistical tools and data mining techniques have become part of the GE Six Sigma culture in all facets of the business. Statistical models are needed to extract meaningful information from certain types of data that require more rigorous analysis: e.g. time ordered data are analyzed differently than data from a designed experiment. In general, a model of a response variable has two basic components: a deterministic component and its error. This paper addresses both the Linear Model, such as Regression/DoE, and the Stochastic Model involving Time Series Analysis, each with quite different error structures. Understanding the error structure of the data, is key to model building. This paper will examine the basic Statistical Model and how it was applied to several industrial examples and a brief look at stock market forecasting- a personal hobby.

Defect Rate Estimation using Imperfect Zero-Defect Sampling with Rectification

Neerja Wadhwa
Mitchell Madison Group

An important aspect of any quality control program is estimation of the quality of outgoing products. This paper applies Acceptance Sampling with rectification to the problem of quality assurance when the inspection procedure is imperfect. The objective is to develop effective rectification sampling plans and estimators based on these plans without making the assumption of a perfect inspection procedure. We develop estimators, under two different sampling plans, for the number of undetected defects remaining after a set of lots has been passed. We compare, by extensive simulation, the proposed estimators with existing ones in terms of Root Mean Squared Error (RMSE). One of our estimators, an empirical Bayes estimator, is seen to consistently obtain substantially lower RMSE overall.

Process Capability Indices

A Simple Graphical Hypothesis Testing Procedure for C*pm* Goals

N. F. Hubele, L. Zimmer, S. Kunjurananthram, Arizona State University
M. Dumitrescu, Bucharest University

Setting a goal capability indices, such as C*pm*>2.0, is common practice within the Six Sigma philosophy. The challenges for the practitioner is to find a simple, understandable procedure for testing conformance to such a goal. In this paper, such a simple graphical procedure for C*pm* is presented. Sample sizes, process target values and C*pm* threshold values, together with acceptable risk levels, can be negotiated and translated into these simple graphical displays. The proposed decision making tool is a graph of acceptance and rejection regions on the (*x, s*) - plane. The user merely plots the process sample mean and standard deviation on the graph and is able to make a statistically sound, valid assessment of conformance to the C*pm* goal. Furthermore, this graphical aid can alert the user to the source of non-conformance derived from either poor process centering or excessive process dispersion.

Process Capability Indexes: Confidence Intervals and Sample Size Requirements

John S. Ramberg
University of Arizona

Michael Scussel
Valenite Corporation

Process capability indexes continue to play an increasingly important role in six sigma quality initiatives. Awareness that their estimators are subject variability is sometimes lacking. In this presentation, methods for determining the sample size requirements for estimating capability indexes are given. These resulting sample sizes ensure, with 100(1-a)% confidence, that the estimated value of the capability index will be within a user specified P % of the true value of the index. Assumptions underlying these results are described, as well as their evaluation. In addition, some simple, easy to calculate, confidence interval estimates are given.

Process Indices for Certain Non-Stable Processes

Joseph O. Voelkel
Rochester Institute of Technology

The *Cpk* index has been widely used to summarize how well a process is running relative to its specification limits. This measure is only reasonable to use when the process being studied is stable. Unfortunately, most processes are not stable, but the need to create process summaries often means that a *Cpk* is still calculated, even though it is incorrect and frequently misleading. We discuss under what conditions it is reasonable to calculate a process index for a non-stable process. We show how the *Cpk*, and the *Ppk*, indices can be naturally generalized to these types of non-stable processes. We also show how confidence intervals may be constructed for these indices by solving an optimization problem based on tolerance-interval ideas. We recommend that these generalized indices be used to replace the current ones for such non-stable processes.

Wednesday After Dinner Speaker

Statistics and the Pursuit of Quality

J. Stuart Hunter
Princeton University (Emeritus)

Quality is a Polyscience. It entrains the social arts of management, commerce, service and consumer satisfaction along with the technical arts of product design, process planning, distribution, and, of course, statistics. The words Statistics and Quality were first introduced together formally by Walter Shewhart in his 1925 paper in JASA "The application of statistics in maintaining the quality of a manufactured product". Today entire journals are devoted to the subject area and everyday conversations employ such phrases as "Six Sigma" and "Statistical Thinking". A brief appraisal will be attempted along with some prognostications.

Thursday Invited Speaker

Accelerated Reliability Testing - Applications and Pitfalls

William Q. Meeker
Iowa State University

Accelerated tests are commonly used to obtain timely information on product life. Test units are used more frequently than usual or are subjected to higher-than-usual levels of accelerating variables like stress, temperature, or voltage. Then the results are used, through an appropriate physically-based statistical model, to make predictions about product life at the more moderate use conditions. The extrapolative predictions inherent in the use of accelerated testing raise serious concerns, and use of accelerated testing has a number of dangerous pitfalls. The purpose of this talk is provide an overview of accelerated test applications and methods and to warn potential users about some possible pitfalls.

Six Sigma Implementation II

Getting Statistics Off the Shelf – The Culture Change Challenge

William A. Berezowitz and Bradley J. Whittaker
GE

Harnessing quality improvement as a competitive advantage is being recognized more and more, especially through the work being done at General Electric, AlliedSignal, and a few others. Most of the people working in industry do not understand simple statistics, let alone the huge untapped power of analyzing variation over time and under various imposed conditions. When experts enter an organization to foster change they can quickly overwhelm and alienate the less technically inclined. The technical practitioner may also dismiss the Six Sigma methods as 'nice to do' and miss the real power of the process. This paper and presentation explores the pitfalls associated with Six Sigma deployment (generically - any quality improvement program introduction) and presents a framework for avoidance. Special emphasis is placed on making a connection to the organization through the "CTQ Life Cycle Concept".

Institutionalizing Six Sigma in Large Corporations: A Leadership Roadmap

Stephen A. Zinkgraf and Ronald D. Snee
Sigma Breakthrough Technologies, Inc.

Recently, many large corporations have implemented Six Sigma - with varying degrees of success. Noteworthy successes have been Motorola, AlliedSignal and General Electric. This paper addresses the general success factors associated with successful large-scale implementations of Six Sigma. One major success factor is that each company had a core of statisticians that were actively involved in the culture change. A proposed Six Sigma leadership roadmap consists of five steps: (1) Select the right projects; (2) Select and train the right people; (3) Develop and implement improvement plans; (4) Manage for excellence and (5) Sustain the gains. We will present the role of the statistician as a leader in implementing large scale change programs for each of the steps. Clearly the role of statisticians in Six Sigma companies move from that of an instructor and internal consultant to that of a leader of change focused more on implementation and skills deployment than facilitating technical applications.

Measurement

Why And When Should One Calibrate A Measurement System

Raghu Kacker
National Institute of Standards and Technology

A measurement without its uncertainty is not adequate. The stated uncertainty ceases to be valid when the measurement system goes out of calibration. A conventional re-calibration interval may not be optimal for all usage conditions. The cost of re-calibration may be viewed as unnecessary expense when there is no indication that the system is out of calibration. We propose that the system should be checked at regular intervals in real-time. Then we provide a simple, generic, and widely applicable formula for the checking interval. The formula is illustrated with application to coordinate measuring machines.

Between Rockwell Hardness And Six Sigma

Walter Liggett
National Institute of Standards and Technology

Rockwell hardness is a widely-used measurement that, along with others of its type, presents substantial challenges to six sigma methodology. Measurements of this type might better be called test methods or indicators to distinguish them from scientifically conceived measurements. In manufacturing, test methods may be the only option for gauging some product properties. One challenge is experimental determination of test method validity and of the specification limits needed to judge measurement capability. Another challenge is comparison among measurements from different facilities as required when the same part comes from different suppliers. At least in the case of Rockwell C scale hardness, achieving comparable measurements involves more than just assuring that each facility follows the same test protocol. Although Rockwell hardness was invented 80 years ago, one can imagine new test methods with the same challenges. Test method development might be spurred, for example, by the decreasing prices of continuous sensors.

Control Charts II

A Control Chart for an Improvement Metric

Stephen J. Caffrey and Barbara Pociatek
Eastman Kodak Company

A common metric tracked within Eastman Kodak Company is “Defects per Unit” (DPU). On a monthly basis manufacturing departments summarize the total DPU for their key products. It is expected the department’s improvement projects will cause this metric to systematically decrease over time. As with all processes, there is random variability associated with this metric. The plant manager requested control charts to monitor this process, thereby reducing incorrect reactions to monthly fluctuations. A traditional control chart (constant mean) was not a workable solution as the metric was decreasing due to improvement projects. Using the principles of control charts for tool wear and an assumption about the distributional nature of DPU, a chart was created with a sloping centerline and upper and lower control limits that converge toward the centerline. The use of this chart has greatly improved the monthly review and management’s reactions to the DPU metric.

Statistical Process Control using Run Sums

Thomas R. Willemain
Rensselaer Polytechnic Institute

George C. Runger
Arizona State University

We develop a novel and effective way to monitor quality using the large volumes of positively autocorrelated data produced by high-frequency sampling of a process. We regard the process as a sequence of runs above and below the mean. The sums of the observations in these runs behave as independent random variables suitable for charting. Using simulated data, we show that the average run length performance of charts based on run sums compares favorably to that of alternative charts based on ARMA residuals, while avoiding the need for ARMA modeling. Furthermore, we obtained the same relative performance results for i.i.d data. Thus, run sum charts provide a powerful and comprehensive method for SPC in data-rich environments.

Reliability and DOE Applications

UR Power Supply Analysis for Reliability Prediction

Lester Harrison
GE

The Universal Relay Power Supply has already been designed and is now analyzed for predicted defect reduction and improved reliability. The Berryman scorecards for parts and performance are used as a predictive tool and for highlighting areas for design improvement. Process capability data collected from the vendors for quality (dpmo) and the Bellcore model used for reliability parameters. All defect and reliability data will now reside in a standard parts list database that allows for easy retrieval for future designs. With PSPICE being purchased by OrCad and our schematics created in OrCad, we decided that PSPICE would be the choice of tool for analyzing our circuits for optimization. PSPICE allows us to see the effect that component variation has on our circuits by performing Monte Carlo, and sensitivity/worst-case analyses. Method 1 of the Bellcore Reliability Model is used for predicting the reliability of the circuit. The failure rate for each component is calculated based on a generic failure rate as well as it's quality, temperature and stress factors. The specified environment condition to which the power supply can be subject is then factored in for the final predicted failure rate.

Reliability Analysis for a Brake Hub Isolator

Marcia Brey
GE

As of 1998, the engineers for the washing machine at GE Appliances started to use Probabilistic Mechanical Design (PMD) methods to analyze designs. One application of the PMD theory was in the design of a new isolator that was developed to reduce noise in the washer. Noise knock in spin in the washer continues to be a problem in both customer complaints and factory rejects. Lab tests indicate that this washer rattle is a wear out failure mode that tends to get worse with the life of the machine. The brake hub isolator is a new plastic insert that was added to the system to eliminate objectionable rattle in the washer. The rattle is a function of the amount of clearance between a hub and a tube; the greater the clearance, the greater the potential for the rattle. The isolator provides an interference fit between the hub and tube to keep the hub from moving relative to the tube. The isolator must provide enough holding force to prevent washer rattle but not too much force to prevent the hub/tube from functioning properly. This paper focuses on the reliability analysis of the isolator starting with the initial design stage and continuing through the final production phase. Probabilistic mechanical design theory was used to predict the 10-year reliability. This prediction was continually updated as the design progressed. The final isolator prediction for the rattle failure mode at a 10-year life or 5,500 wash cycles is 0.9992. In addition, several groups of isolators were put on life test in the evaluation lab to validate the model. The reliability for the test washers was calculated using a Weibull model to be 0.9968 at 10-years' life.

Statistical Design Of Experiments Applied To A Rocket Thrust Chamber Brazing Process

Daksha Chokshi
Pratt & Whitney

Statistical Design of Experiments (DOX) was applied to a rocket thrust chamber brazing process. The configuration of the thrust chamber makes it very difficult to achieve 100% braze coverage at all of the several thousand braze joints. However, the acceptable braze coverage is required for structural and fuel flow path integrity. Lack of braze coverage in the braze joints not only causes an excessive amount of manual braze repairs, but effects the overall cost, quality and schedule of the engine, as well as increases the risk of part damage. This paper shows how statistical DOX identified major contributing drivers of the band-to-tube braze coverage and minimized amount of manual braze required. The study resulted in significant savings in cost, quality, and schedule of a rocket thrust chamber brazing process. Manufacturing management has recognized the value of the statistical DOX and has requested additional DOX be utilized on other manufacturing processes.

Design of Experiments I

Enhancing The "Design" Process In Design Of Experiments

T. N. Goh
National University of Singapore

Design of experiments is a core element in the Six Sigma methodology. Many Six Sigma projects are carried out by people who have learned design of experiments from Six Sigma training rather than formal statistics courses. As a result, when it comes to designing an experiment, they tend to refer to examples or standard designs found in the Six Sigma training material. While this practice has the advantage of getting projects off the ground quickly, the design used may not be the best from the point of view of the objectives and practical constraints faced during the study. For example, variations of experimental design are called for depending on whether the investigator is in need of quick results such as in a troubleshooting situation, or prefers to have knowledge of process variability, or wants of know if there is non-linearity in process behavior, or aims to avoid certain confounding situations right from the beginning, and so on. In fact, with given finite time and budget, hence the maximum number of experimental runs, there can be many options of evolving an experimental design to suit specific needs and concerns. In this presentation it will be illustrated, in a non-mathematical manner, how one may use appropriate reasoning to make design of experiments a truly "design" process, i.e. how to evolve appropriate designs to meet different Six Sigma priorities. With such insights, industry practitioners will find themselves in an even better position to fully utilize the power of experimental design in the face of specific project requirements and possible operational constraints.

Random Run Order Without Resetting Factors For Efficient Six-Sigma Experiments

James M. Lucas
J. M. Lucas and Associates

Many experiments are run using a random run order yet if successive runs have the same level of a factor, that factor is not reset. Therefore (complete) randomization is not achieved, and the errors will not be independent. We discuss important practical issues such as how experiments should be run to minimize the variance or the cost of information. We also mention technical issues such as the expected covariance matrix, and the expected bias for significance tests in such experiments. Advantages and disadvantages of using a random run order instead of complete randomization are discussed. In many cases it is appropriate to use a random run order instead of (completely) randomizing the experiment.

Combinatorial Search and Experimental Design Techniques

James Cawse, Necip Doganaksoy, Carl Hansen, Robert Mattheyses, Chandrasekha Pisupati,
Tom Repoff, Christopher Stanard, and William Tucker
GE

The new field of combinatorics has revolutionized the chemical discovery process, reducing the time for discovery of useful chemical compounds by orders of magnitude and greatly increasing both the competition and the stakes for companies in the chemical arena. Furthermore, combinatorics has great potential for use in many other areas beside chemistry. We will explore combinatorial computation algorithms, experimental design methods, and analysis with applications to Six Sigma Statistics.

Non-Normal Data

Comparison of Edgeworth and Burr's Methods in Evaluation of Non-Normal Process Capability Indices (note: paper withdrawn and not presented; replaced by Willemain & Runger – See "Program Change")

Hassan A. Mohsen
Ford Motor Company

Ethem Cekecek
Wayne State University

Under assumption of normality, the spread of a distribution is assessed using an estimate of 6 sigma, which covers 99.73% of the distribution when centered. However, the standard interpretation of capability indices becomes invalid when the assumption of normality of the underlying process is violated. Modified Burr's Method was introduced previously. We will use Edgeworth expansion to estimate process capability indices under assumption of non-normality. The performance of the proposed method will be compared with Modified Burr's Method's.

Using the Beta Distribution on Confidence Intervals for Proportions

Jim Rutledge
Data Vision

Brad Warner
United States Air Force Academy

Most introductory texts on statistics include approximate methods for finding confidence intervals for proportions. As a result, these normal based approximation methods have become part of most 6-sigma training programs. Rules of thumb are often given for when the approximation method is valid. However, in many processes, the proportion of defectives is so small that it is impractical to comply with the rules of thumb. This presentation will discuss an easily applied exact method for calculating confidence intervals for proportions. The method is implemented using Microsoft EXCEL's built in BETAINV function. In addition, this methodology can be used to help determine the appropriate sample size needed with pass/fail type of data. Easily programmed (one liners) Microsoft EXCEL commands will be discussed. The authors will make available a copy of their spreadsheet that implements the methods presented for both one-sided and two-sided confidence intervals.

The Normal Distribution with Six Sigma Projects

Amir Shaiegan and Bill Wunderlin
GE

The normal distribution plays a critical role in the traditional approach to Six Sigma projects, because the normal distribution is used to translate the average and standard deviation into the proportion of defects. However, few (or no) populations of real data follow a normal distribution. Some statistical procedures to test for normality will be discussed. We often encounter "rounded" data, where the gage does not have a large number of significant digits. Adding a random digit to the end of the number often allows these data to "pass" a test of normality. This helps to distinguish between data that are truly not normal, and data that "failed" the normality test merely because of rounding. Simulations were run to evaluate the level of significance for the normality test when using the method of adding a random digit, and to demonstrate the effectiveness of adding the random digit in allowing normal, but rounded, data to pass a test of normality.

The Impact Of Six Sigma: Today And In The Future

Ronald D. Snee
Management Consultant

Six Sigma, created by Motorola and developed into a major corporate initiative by AlliedSignal and General Electric, is now being utilized by many different companies. The primary focus of all of these efforts is the identification and completion of process improvement projects that produces bottom line results ($). This is a key use of Six Sigma but more is possible. This presentation explores the next phase of Six Sigma and addresses such questions as: How do we integrate Six Sigma tools and methods into the work we do daily to serve our customers? How do we integrate Six Sigma into our management systems and other improvement approaches such as Baldridge assessments and ISO 9000? How do we use Six Sigma as a foundation for an organizational improvement process that is an integral part of how we do business? What new career opportunities will a focus on Six Sigma provide? Answers to these questions and others will be discussed, as we explore the impact of Six Sigma today and in the future.

Engineering Applications

Random and Fixed Factors in Measurement System Studies

Thomas A. Early and Radu Neagu
GE

In any quality program, it is important to be able to distinguish between product and measurement variation to be sure that the noise in the measurement system is always less that the random variation of the product. A gauge study, a design of experiments, is usually performed to characterize variation in the measurement system due to reproducibility and repeatability (R&R) sources. The application of the proper ANOVA model is critical in being able to make conclusions and inferences from the gauge study. In particular, the choice of random, fixed or mixed factor models will have a large impact on the calculation of the measurement system noise from a gauge study. These important details can be lost in a process oriented quality program. This work will re-introduce random and fixed factor ANOVA modeling to gauge R&R studies.

Six Sigma Electronics Tool Box

Ahmed Elasser, Sriram Ramakrishnan, Ljubisa Stevanovic, Charles Korman
GE

The presentation discusses the use of six sigma methodology in electronic applications. In addition to the statistical tools, specific tools such as Electronic Design Automation (EDA) tools, Finite Element (FEA) tools, Optimization tools are needed to successfully apply the DFSS and six sigma methodology for electronic designs. Through application of DFSS on electronic applications, we have developed methods and tools to harvest the benefits of six sigma. Tools such as Saber (System Level Simulation Tool), ANSOFT (Finite Element Tool), iSIGHT (Optimization Tool) are effectively used in conjunction with DFSS techniques to achieve a six sigma design. Applications highlighted in this presentation include a ballast circuit, a circuit breaker and low profile power magnetics.

Six Sigma in the Engineering Design Process: Improving the Quality of the Engineering Product

Gavin A. Finn
Prescient Technologies, Inc.

By applying Six Sigma techniques to the engineering design process, enterprise benefits are realized. Six Sigma applied to engineering allows for the formal capture and measurement of quality metrics that affect both the quality of the engineering product, and the final manufactured product. The use of three-dimensional computer-aided design and manufacturing software tools has forged a new process within engineering, and the dimensions of which provide the framework for a comprehensive Six Sigma program. Characterizing the digital product model from the perspective of the capability indices is possible because each model consists of features and attributes. These features and attributes have both general characteristics (from which the baseline statistical data are derived) and unique values (against which the specifications are measured.) The results of this kind of analysis include measurements and specific actions for process improvement in engineering. Using Six Sigma we can now "measure" quality in the engineering process.

Design of Experiments II

Understanding the Influence of Several Factors on a Cylindrical Response

C. M. Anderson-Cook
Virginia Tech

Understanding the influence of several input factors on the relationship between bivariate responses with one directional and one linear component is an important part of some industrial applications. These applications include the analysis of rotating parts, common in the engine components; defect detection on circular or cylindrical parts; and orientation problems associated with magnetic fields. A model based on a linearized form of this directional data is presented for factorial designs with a cylindrical response. It allows the standard linear regression framework to be used to analyze this directional data. A strategy adapted from backwards stepwise regression is also given for obtaining a parsimonious model to highlight numerically and graphically the individual effect of both main and interaction effects. The method proposed is demonstrated by analyzing data from an experiment involving the balancing of automotive flywheels.

The Confounding Relationship of Location and Dispersion Effects in Unreplicated Fractional Factorials

Richard N. McGrath and Dennis K. J. Lin
Pennsylvania State University

When studying both location and dispersion effects in unreplicated fractional factorial designs, a ”standard'' procedure is to identify location effects using ordinary least squares analysis, fit a model, then identify dispersion effects by analyzing the residuals. In this paper, we show that if the model in the above procedure does not include all active location effects, then null dispersion effects may be mistakenly be identified as active. We derive an exact relationship between location and dispersion effects.

Central Composite Response Surface and Analysis

Paul Cadima
GE

Designed experiments play an important role in product development. They are used to model physical systems, using regression with empirical data, when the theory is undeveloped or not fully understood. While the simplest and most popular DOE is the two level factorial, systems with curvature in the response require higher ordered approximations. An advance experiment design called a Response Surface is commonly used to capture curved responses. This paper gives an example of central response surface experiment used for a Six-Sigma project, highlighting its successes and pitfalls. Clues giving insight as to the best model are discussed. Finally, various regression techniques and models are investigated to find a model fitting the data better and more consistent with the physics of the system. Regression techniques used to model the system include: full-quadratic fit including interactions, linear + quadratic terms, and piecewise linear techniques.

Probabilistic Modeling

Improving Performance for Engines Using Sensitivity Information

Kristy Gau and Liping Wang
GE

PEZ is a general purpose software tool developed at Aircraft Engines that is currently being used by over 250 engineers for DFSS activities. Compare to the traditional Monte Carlo approach which tends to be time consuming, AURORA, a new capability in PEZ, can significantly reduce computer CPU time and design cycle, at the same time, provide more probabilistic information including probability density function (PDF), cumulative distribution function and sensitivity information. This paper will demonstrate how to apply known sensitivity information obtained from AURORA to improve the performance and meet the requirements without extra runs. In general, the system's performance may fall short and requires some changes to achieve the goal. One way to do that is using sensitivity information to provide guidance for design engineers to 1. determine what features are importance, 2. identify the key design or noise variables, 3. change the response's CDF shape, and 4. minimize variations.

Fast Probability Integration and Its Applications to DFSS

L. Wang, K. Gau, H. Bond, J. Vishnauski, D. Beeson, D. Carpenter, B. Striebich
GE

Fast Probabilisty Integration (FPI) is a new mathematical tool that has the potential for wide application to many types of DFSS problems. In comparison with traditional Monte Carlo methods, FPI requires significantly fewer analysis runs to provide an accurate approximation of a function's probability. We will: 1) explain what FPI is and how it can be used to avoid large Monte Carlo runs, 2) describe the accuracy of FPI, 3) discuss the implementation of FPI at GE Aircraft Engines through the DFSS software tool PEZ, and 4) describe the benefits of using FPI, as demonstrated by several applications at GE Aircraft Engines.

Planning An Accelerated Degradation Test

Peter Morse
GE

With short product development schedules, reliability tests are subject to severe time constraints. In high reliability applications, traditional life tests often result in few or no failures. When degradation data can be collected on a unit and there is a relationship between degradation and unit failure, degradation can be used to estimate a time-to-failure distribution. Degradation tests can sometimes be "accelerated" by testing at conditions more severe than normal use conditions. A physical model is used to describe the effect that acceleration has on the degradation rate.

This talk discusses methods for using simulation to plan an accelerated degradation test (ADT). ADT experiments are simulated and a nonlinear, mixed-effect degradation model is fit to the data from the simulated experiment using approximate maximum likelihood estimation. Repeated simulation allows assessment of test-plan properties. Varying test plan parameters (e.g., levels of acceleration and allocation of units to these levels) allows one to obtain an optimal test plan. Optimizing under practical constraints provides useful "compromise" test plans.

Thursday Invited Speaker

Six Sigma and Beyond: Technical Challenges

Michèle Boulanger
Motorola

Six Sigma is an initiative that was pioneered by Motorola about ten years ago by a visionary group charged to improve Motorola's productivity. Its rapid adoption throughout the company was attributable to its ability to span the full range of company processes. It is based on the assumption that, if a product were the result of a process, then any "6 sigma" process would deliver products at a quality and cost level that would always be satisfactory to both customer and supplier. This presentation explores successes of the Six Sigma initiative and reviews its challenges from a technical, standardization, and quality management points of view. These perspectives suggest a roadmap for subsequent initiatives.

Friday Invited Speaker

Six Sigma-The AlliedSignal Experience

William Hill
AlliedSignal

The speaker will address the major impact that Six Sigma deployment has had in AlliedSignal, Inc., a large diversified company that makes products ranging from aircraft engines, automotive oil filters, to fluorocarbon substitutes. Customer focused and process driven, the AlliedSignal Six Sigma approach has dramatically reduced costs, increased capacity, and significantly improved quality with $1.5 billion in documented savings over the past four and half years. Some of the factors and experiences will be discussed that have driven a very successful deployment of the Six Sigma strategy.

Experimental Design

Problem Solving Using Shainin Methodology and Philosophy: A Case Study

Michael J. Hayes
GE

John Zaczyk
Shainin Consultants

This paper discusses the application of a problem solving methodology in the resolution of a costly reliability problem concerning water accumulation in the oil of a railroad locomotive's air compressor. The paper briefly discusses the history of the problem and proceeds to describe how the problem was focused and its root cause pursued. The Shainin approach is to analyze the pattern of a problem with tools that rapidly surface the root cause. The approach is statistically valid, universally applicable, incredibly powerful, and remarkably straightforward. The approach ensured that the details pursued had both statistical significance and, just as importantly, practical significance. The problem, which other teams had attempted to solve on several previous occasions, was eliminated with a slight design modification and validated with both laboratory and field data. The problem was completely eliminated.

Utilizing Classical DOE to Enhance a Component Search Strategy

George R. Johnson
The Foxboro Company

The component search strategy is a simple technique popularized by Dorian Shainin often used to isolate a small number of independent factors which have resulted in a degraded product output characteristic. The primary weakness in the strategy typically involves the interpretation of a number of test treatments for statistical significance. Traditionally, a graphical approach is taken with the use of Shewhart style control limits to test each of the individual treatments for significance. Utilizing this approach, the analysis is typically constrained by inadequate sample size with a corresponding elevated Beta Risk. This paper demonstrates the use of traditional Design of Experiment (DOE) techniques to improve the test precision and simplify the interpretation of a component search strategy. Examples are given.

Improving Measured Fuel Flow Accuracy in Jet Engine Test Cells

Dan Bergsten, Jon Robertson and David Rumpf
GE

Jet engine test cells provide real time data to confirm that each production engine meets or exceeds customer requirements. Fuel flow at various power settings are essential for fuel consumption and related efficiency calculations. The proposed paper will describe: 1. the fuel flow measurement system, 2.the problems with data accuracy and variation which existed at the start of the six sigma project, 3. the tools used to determine major sources of variation in the data, 4. the process used to reduce the observed variation The improved situation including control plan, 5. future improvement plans. The fuel flow project is an excellent example of the benefit derived from a creative application of six sigma tools using the Measure-Analyze-Improve-Control approach. The approach resolved a process problem which has caused periodic engine shipment delays for over 10 years. The paper will include discussion of team involvement and buy-in.

Optimization

Quality Economics

Soren Bisgaard
University of St. Gallen

A key obstacle to long-term managerial support for quality has been our poor understanding of the economic benefits of quality management. We have not been successful in convincing executives that quality is a winning strategy. Cost of quality, an integral part of Six Sigma initiatives and many other programs, goes part way to justify quality initiatives. Such calculations should certainly be part of the wider economic evaluation but we need to consider the wider economic implications of quality improvement. In this presentation we will outline a wider economic perspective of quality. We will also discuss the classical idea of cost optimal quality levels which has been a mental stumbling block for understanding the economic benefits of never-ending quality improvement. Examples will be used to demonstrate the economic effect of upstream quality improvement. As a conclusion, the case will be made that the economic benefits of quality improvement are far greater than what has previously been understood.

Improvements Through Process Adjustments

Carlos W. Moreno
Ultramax Corporation

One way to decrease variation in key production processes is by improved adjustments of their control inputs. “Dynamic Optimization” does this and more: It can be applied by an engineer/black-belt “by hand”; and can be integrated with DCS/SCADA systems for on-line automatic performance optimization as conditions and objectives change. It can simultaneously address multiple (measurable) objectives, such as several measures of variation, yields, production rates, product characteristics to be maximized/minimized such as strength and impurities, consumption, losses, safety, emissions. It uses sequential modeling and optimization. Given a set of objectives, adjustment of control inputs such as temperatures, pressures, flows, depth of cut, cycle times, etc. are optimized in usually 30-80 readjustments without requiring prior data or prior models. A run with each adjustment is usually 0.25 to 2 hours for continuous processes, or the normal batch time. Typically in the last ten years, the bottom-line gains have been several $100K/year per application, a payback of a few months. Using this tool can increase the profitability impact of Six Sigma programs.

Optimal Adjustment for Processes with Run-to-Run Variation

Pasquale Sullo
Rensselaer Polytechnic Institute

Mark VanDeven
Nabisco Research Institute

As short manufacturing runs become more common, run-to-run variation such as that induced by set-up error has greater potential to affect product quality. While efforts should be made to eliminate such variation, some will always be present. Consequently, a within-run adjustment may improve process capability. We shall review our investigations of optimal adjustment strategies under two quality loss functions: a 0-1 loss criterion related to the Cp and Cpk process capability indices and a quadratic loss criterion equivalent to the Taguchi loss function. The procedure consists of (perhaps) making a single within-run adjustment early in the run that depends on within and across run variability, adjustment error, run size, and adjustment and sampling costs. The solution specifies the adjustment amount, if any, and the optimal decision point within a run at which to adjust or not. Examples will be given that relate the adjustment strategy to Six Sigma process criteria.

Eclectics

The Power Of Synergy: Using Survival Analysis For Business Forecasting

Ai-Chu Wu
Ai-Chu Wu Teaching & Consulting Services

Mike Adair and Jeff Gould
Hewlett-Packard

Our company sells a huge variety of custom systems to many different customers. Capacity planning relies on accurately forecasting the timing and dollar volume of orders. The current method relies on individual project managers to predict the probability of success for each active deal, and consistently overestimates actual results. This paper describes how a Statistician's expertise, a Financial Manager's experience, and a Manufacturing Manager's sponsorship are combined to develop an improved approach. We describe the survival analysis approach, and show the significantly better results to the current practice. We also point out problems in the current data and opportunities for improving future data.

Advanced Methods in Statistical Reliability: Quantifying Business Risk

John Hershey and Brock Osborn,
GE

As we discussed in our earlier workshop, the analysis of reliability data is essential for delivering quality products to our customers in an environment of high customer expectation, strong competition, and an increasing emphasis on service. In this talk we will discuss how these statistical methodologies have been used to identify and quantify risk faced by manufacturing and service organizations and how the resulting knowledge can be leveraged to increase profits.

Statistics in the Real World - What I've Learnt in My First Two Years in Industry

Rekha Agrawal,
GE CRD

It's been two years since I graduated with my Ph.D. in statistics. Since then, I've been working in at GE Corporate Research and Development, in the Applied Statistics program. In this talk, I'll discuss my experiences in industry, what I've been doing in that time, and some of the surprises I've had.

Stand-By Paper

Statistical Issues in the Consumer Credit Life Cycle

Tim Keyes,
GE CRD

We will discuss issues pertaining to consumer credit card life cycle management. Each phase of the life cycle presents enormous statistical opportunities. We will shed light on what solutions issuers are employing to stay profitable in this very dynamic industry.

PROGRAM CHANGE: Session on Non-Normal Data (10:45 am Thursday, May 20)

Presentation by Mohsen and Cekecek withdrawn; replaced by

Designing Control Charts Using an Empirical Reference Distribution

Th0omas R. Willemain
Rensealaer Polytechnic Institute

George C. Runger
Arizona State University

We address a problem of increasing practical interest: control charting in the absence of an assumed normal distribution. We analyze the sampling uncertainties inherent in selecting control limits from the empirical distribution of a large sample of whatever statistic is to be charted. We then related selections of the number of preliminary observations and control limits to chart performance measures. The methodology is nonparametric, requiring only that the plotted statistics be independent and come from the same distribution.

Closing Panel Discussion

M. Boulanger
Motorola

B. Godfrey
Juran Institute

W. Hill
AlliedSignal

J. S. Hunter
Princeton University (Emeritus)

W. Meeker
Iowa State University

R. Snee
Management Consultant

Posters/Exhibitors
(5:15-6:15 Thursday, May 20, 1999; GE CRD Upper Atrium)

Posters

Name	Affiliation	Poster
JaiWoo Baik, JinGyu Hwang, & MokYong Jung	Korea National Open University, Samsumg Electronics Co., Ltd, & Samsung Display Devices Co., Ltd.	6 Sigma Activities in Korea
S. K. Bagepalli, L. A. DeRose, D. F. Townsend	GE CRD	DMAIC for Material Substitution Process within the ESR Business
Kathryn Dudding	GE CRD	A Technique for Analyzing One Product for Several Customers
Willy Fiallo	GE Industrial Systems	Digital Products Repair and Return Cycle Improvement
Luis Gomez	GE Industrial Systems	Variation Reduction in Fabrication Area Electronic Overload Line Balancing
Audrey Lee & Ai Chu Wu	Maria Carillo High School	Using Statistics to Improve Quality and Productivity
George Mishkoy	Academy of Sciences of Moldova	Stationarity Conditions for a System with Priorities and Orientations
Bulent Sener	GE CRD	Highly Accelerated Reliability Testing and MTBF Prediction Simulation tools
Christopher Stanard	GE CRD	Six Sigma Special Topics: Z-Shifts, Statistics & Non-Standard Data Analysis

Exhibitors

Minitab

SAS

STATGRAPHICS