

Box
on
Quality and Discovery

Series page to come

Box on Quality and Discovery

with Design, Control, and Robustness

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To Claire,
my never failing source of encouragement and inspiration

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Foreword

Almost fifteen years have passed since the publication of *The Collected Works of George E. P. Box*, Volumes I and II, under the editorship of George Tiao (1985). These have been active years in the life of the gentleman for whom these early volumes were produced. His continuing originality, and verve, provide us today with a cornucopia of new writings. On 18 October 1999 George Box was 80 years old. It seems only fitting to acknowledge this special occasion with a new celebration of his published works.

On this occasion our editors asked Professor Box if he'd like to sort through his papers and perhaps add a few words. He agreed and has selected, extracted, and arranged these in logical order to form the chapters of this book. We now have vignettes of his thoughts, reminiscences of earlier days, and renewed insights. The book is divided into six parts. The first of these are directed to managers, another to those who would apply experimental design, another for those who study and work in experimental design, a group encouraging the flirtation between control engineering and statistics, a group devoted to variance reduction and the concept of robustness and, finally, some of his songs.

In addressing the concerns of managers, Box recognizes that they are more likely to be interested in prescriptions for problem solving and prevention rather than in descriptions of specific statistical tools. These chapters thus emphasize the application of the scientific method. They advise the manager to view their processes as ongoing iterative learning exercises. An early requirement is to open avenues of communication with those who run each process and then to listen. Success further requires the willingness to make changes based on the information gathered—read “experiment.” Analogous the Deming’s “Plan, Do, Check, Act” is Box’s refrain “Conjecture, Design, Experiment, and Analyze,” which I much prefer, particularly the advice that analysis has as its primary objective the creation of new conjectures. That’s Box’s message to managers, workers, students, scientists, and statistical academics alike.

The second part is titled “Design of Experiments for Quality”. When the journal *Quality Engineering* was started, Box was asked if he would contribute a “column”

to each issue. The result was a series of popular short articles describing the uses of statistics, principally experimental design, adapted to the pursuit of *quality* products and processes. His audience were those who were anxious to employ tools that might lead to improved quality of products and processes, and sequential experimentation received special emphasis. All the papers are terse and clear, and give new meaning to the acronym KISS (Keep It Simple, Statistician). Two additional articles are included in this group, one discusses factorial design dispersion effects and the second the need for hands-on practice in the teaching of statistics.

The third collection, “Sequential Investigation and Discovery,” has the consulting statistician in mind. Here *discovery* joins with *quality*, the theme in Box’s mind for this entire volume of works. The emphasis of the first few chapters is on the necessary alternation between inference and deduction, estimation and hypothesis testing. Box argues that, in applying the scientific method, planning for data that place inferences in jeopardy is every bit as important as increasing the power of a test. “Surprise!” is every bit as important as “Gotcha!” This point is driven home with Box’s description of a detective gathering evidence to find a thief contrasted with that of a prosecutor who must prove the guilt of the accused. The final chapters discuss fractional factorial and response surface designs and offer Box an opportunity to reminisce on the early events that stimulated his interest. Clearly, close rapport between experimenter and statistician was the essential element.

The fourth group is titled “Control.” In his introduction he recalls the events that brought him to this important arena. This work vastly changes the field of Statistical Process Control (SPC). Historically, SPC evokes the application of Shewhart or similar “control” charts. Their purpose is to monitor processes assumed to be reasonably stable. When unusual events are discovered, they stimulate searches for assignable causes that may lead to process improvement. The several chapters in this group describe both theory and practice leading to feedback control appropriate for the SPC environment. A simple graphical technique (recently named Box–Jenkins charts to honor their originators) is described for adjusting a process to acquire minimum variability about target. The idea of appropriately adjusting processes to target is new to most quality professionals and much education lies ahead. SPC now has two mutually supporting techniques, one for monitoring and a second for adjustment. Many of the papers on which these chapters were based were precursors to the recent book by George Box and Alberto Luceño, *Statistical Control by Monitoring and Feedback Adjustment* (Wiley, 1997).

The final group is titled “Variance Reduction and Robustness.” The subject of split plot designs allows Box to bring into focus Dr. Genichi Taguchi’s contributions to the application of statistics in industry. Split plot designs and Taguchi’s inner and outer array designs have identical structure. Taguchi employed these designs to determine conditions providing “robust” manufactured product and process environments. In the early 1950s, Box was the first person to employ the word robust in describing the influence of nonnormality and other departures from assumptions upon the usefulness of the t and F tests. The origins of the statistical uses of the word “robust” are reviewed in Box’s commentary. From the papers in this section we find that robustness is a function of specifications, variability caused by measurement, the

process, the environment, the transmission of error, the choice of metric, and the search for an optimum or best conditions.

As one reads this book, fundamental ideas emerge, blend, and reemerge. In contrasting the themes of inference versus testing, or mathematical exactitude versus statistical robustness, one is reminded of the horns and strings in an orchestra. Each component has its separate role and yet their fullest expression occurs when they are combined. Additional themes of *quality* and *discovery* provide resonance and balance. The pursuit of quality requires meeting standards and positive feedback leading to improvement. Discovery requires planning for information-laden data and welcoming the phenomenon of surprise. And to pursue musical analogy further, technical flourishes occur, as in the work on projected factorial designs, Cuscore charts, and the selection of sampling intervals for discrete feedback control. Alphabetic optimality of experimental designs adds just the touch of required dissonance.

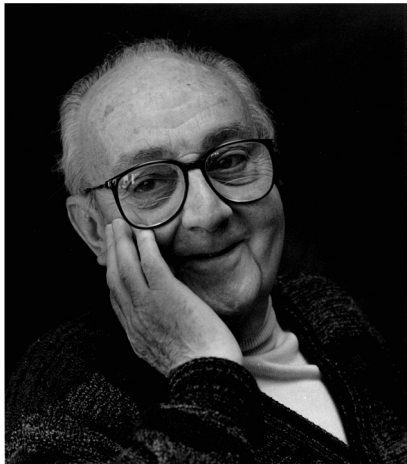
In their totality, the papers on which this book is based form a collection of master works. They are unique. Read an opening paragraph and you know the name of the composer. Their full expression cannot be captured in a few words. Several have refrains so simple you are sure you thought of them first. “All models are wrong, some models are useful.” “When Murphy speaks—listen.” And who can forget robust statistics, happenstance data, and lurking variables? On occasion, these works contain elements of considerable complexity and yet they are all suffused with a unifying message. We learn that statistics is not mathematics but possesses its own philosophy, that statistics and the scientific method are together entwined, that collaborative work provides a statistician’s greatest rewards, and that statistics well taught easily captures the imagination of the student, worker, manager, and scientist.

I met George Box in January 1953 when, at the invitation of Miss Gertrude Cox, he accepted a one-year appointment to the Institute of Statistics in Raleigh, North Carolina. He became my major professor and to this day I wonder at my good fortune.

J. STUART HUNTER
Professor Emeritus, Princeton University

My Professional Life

By George Box



My professional life has been profoundly influenced by many generous and talented people. It was forever changed when J. Stuart Hunter, by a happy conspiracy with Miss Gertrude Cox and Frank Grubbs of ARO, brought me in 1953 to the United States from England. I came on leave of absence from my industrial job at ICI and spent a wonderful year with the folks at the Institute of Statistics at North Carolina's State College. Stu and I worked together on RSM, and other aspects of experimental design, and became close friends.

I spent three more years with ICI after my return to England, developing Evolutionary Operation and working with the physical chemists on kinetic models. The study of mechanistic models such as these allowed a deeper understanding of

our processes and led to interesting work on nonlinear estimation and the numerical solution of simultaneous differential equations.

In 1956 John Tukey and Sam Wilks invited me to head up the Statistical Techniques Research Group at Princeton. Martin Wilk was deputy director and our long-term visitors included Henry Scheffé, Martine Beale, Norman Draper, Don Behnken, Colin Mallows, H. L. (Curly) Lucas, and G. S. Watson. Some of the permanent members—in particular, Stu Hunter, Merve Muller, and John Tukey—spent part of their time with the group and part working in industry. The result was a never-ending series of lively discussions from which we all greatly benefited. The arrival of Gwilym Jenkins marked another turning point in my life and began a long and happy collaboration on time series, forecasting, and control.

During my earlier visit to the United States, in 1953 I had met Cuthbert Daniel. He took me on my first consulting trip and I was, and remained, fascinated by this wise and witty man so full of valuable and original ideas. Sometime in 1958, Stu, Cuthbert, and I decided that a new journal was needed to meet the needs of applied statisticians. We believed that balance might be maintained if it was jointly managed by ASQ and ASA. I think the Chemical Division of ASQ came up with \$5000 to get it started. The three of us got the other \$5000 by organizing and teaching a short course for industry. We jointly wrote the statement of purpose that appears on the inside front cover of every issue. (I think this might be re-read more often.) The name *Technometrics* was suggested by R. A. Fisher. The journal would never have got off the ground without the talent and enthusiasm of its founding editor, J. Stuart Hunter, under whose guidance it quickly became widely read and respected.

In 1960, I was invited to start a new statistics department at the University of Wisconsin–Madison and Stu Hunter and Norman Draper both came to help. Among many other duties I found myself responsible for a course on the advanced theory of statistics. I had seven students. By great good fortune these included George Tiao, Bill Hunter, and Sam Wu. I had almost no previous experience in teaching, so I made up the course as I went along, and although as a student I had been thoroughly indoctrinated with Neyman–Pearson theory, my attempts to make sense of statistical inference became more and more Bayesian with every passing week. George Tiao was my bellwether and, whenever he looked worried, I knew I should look again at what I had just written on the blackboard. Our subsequent work together began a lifelong friendship and, eventually a book on Bayesian methods.

The beer and statistics seminar got started very soon after I arrived in Madison. Students, mostly from statistics and engineering, met, originally in my basement, every Monday night. For more than 30 years, the ever-changing group discussed a great variety of problems brought by engineers, chemists, biologists, and administrators. They came from university departments, from industry, and from local government. I believe we helped them and they certainly educated us. One of the enthusiastic Monday-nighters was Bill Hunter, whom I had known as an engineering student at Princeton. With the help of Olaf Hougen, Bill and I initiated joint projects with the Chemical Engineering Department on automatic optimization and on model

building techniques. It was not long after that, that Stu, Bill, and I started our book *Statistics for Experimenters*, soon to be called BH².

George Tiao and Bill Hunter became faculty members, who both profoundly influenced the development of the Statistics Department at Madison. Norman Draper has been another long-term pillar of the department. He and I worked together for many years; and our collaboration resulted in books on evolutionary operation and on response surface methods.

The department prospered and attracted many talented faculty. In particular, I remember debates with Steve Stigler whose office was next to mine and who liked to tease me about my Bayesian proclivities. I continue to learn from his fascinating historical discoveries and to enjoy his sense of humor. (He once told me, with only a trace of a grin, that my sawtooth diagram representing the interplay between induction and deduction had recently been discovered carved on the wall of a cave and dated about 3000 B.C.)

Beginning in the 1970s George Tiao and I made several visits to Spain to teach short courses on the design of experiments and on time series. The moving spirits who brought us there were Daniel Peña from Madrid and Albert Prat from Barcelona. This was the start of a long and continuing association with a beautiful country and with two enterprising and generous friends.

Bill Hunter and I became interested in “Quality” some sixteen or so years ago. We had, for a long time, worked together on statistical methods, in particular experimental design, for the improvement of industrial processes; but Bill quickly saw that quality ideas should also be employed to improve the social environment. He instigated and taught a new course in Quality Improvement held in the evening with enthusiastic participants from city and state governments, health care, local banks, and industry. With Bill’s help, Quality Improvement projects were begun in the city department of motor vehicles, in the police force, in garbage collection, and so forth. As a consequence, the University set up the Center for Quality and Productivity Improvement (CQPI) in the College of Engineering with Bill as its first director. Its mission was to teach and conduct research on the many aspects of quality. These initiatives continued to flourish under the wise direction of Søren Bisgaard and they remain a lasting tribute to Bill’s memory. In particular, to date members of the Center and our many visitors have produced over 180 publications (many of the papers that appear in this volume were initially CQPI reports) describing research on many different aspects of quality. Also, a large number of short courses have been taught for industry emphasizing experimental design.

One of the Center’s most enthusiastic supporters has been Bill Hill of Allied Signal, who a very long time ago was my graduate student. He has always provided an important link between academia and industry and recently, under the banner of the “Six Sigma” movement has helped top management appreciate the enormous potential of modern process improvement methods. These techniques, appropriately organized and applied at all levels in his company, have met with outstanding success.

One of the more recent visitors to CQPI was Alberto Luceño, a professor from the University of Cantabria. We have worked together particularly on feedback

adjustment methods appropriate in the context of SPC. This has resulted in my visiting Spain for many months and in Alberto's coming to Madison for similar visits. Our happy companionship eventually led to the publication of the book on control.

I cannot end without reference to some earlier happenings. I have told elsewhere (see De Groot, 1987) how in WWII I accidentally became an amateur statistician and how as the result of a series of lucky circumstances, the first real statistician I ever met was R. A. Fisher. He invited me, an unknown and ignorant army staff sergeant, to his house and with great patience and kindness spent the whole day with me, not only solving my problem but also working with me on the calculations.

After this I had no doubt that I wanted to be a statistician and, with the help of a post-war program similar to the G.I. Bill, went to study at University College London. I was welcomed there with great kindness by Egon Pearson and I remember with particular affection the generosity and humor of my thesis supervisor, H. O. Hartley.

My greatest debt is to George A. Barnard, who for over 50 years has been my mentor and cherished friend; without his early and continued encouragement my life would have been very different and much less interesting.

Not least for all the fun we have had together, I must express my gratitude to my co-authors—Søren Bisgaard, Conrad Fung, Stephen Jones, Tim Kramer, Alberto Luceño, Patric Liu, Dan Meyer, José Ramirez, David Steinberg, and John Tyssedal.

Special thanks are due to Murat Kulahci, Lan Zhang, and Ernesto Barrios for their invaluable help in preparing the manuscript and the diagrams for this book, and to Lisa Van Horn who produced the completed book with cheerful thoroughness and dispatch.