Foreword

After a long and distinguished career, Christoph Witzgall retired from the National Institute of Standards and Technology (NIST), Gaithersburg, Maryland, in October 2003. In honor of his many contributions to Operations Research, Optimization, and Numerical Analysis, the Mathematical and Computational Sciences Division at NIST sponsored a symposium on “Topics in Operations Research,” which was held on May 13, 2004. The featured speakers at the symposium were Christoph Witzgall (NIST), Jack Edmonds (University of Waterloo), Saul Gass (University of Maryland), Alan Goldman (Johns Hopkins University), Karla Hoffman (George Mason University), Jim Lawrence (George Mason University), Doug Shier (Clemson University), Josef Stoer (Universität Würzburg), William Stone (NIST), Francis Sullivan (Institute for Defense Analysis, Center for Computing Sciences), and Paul Boggs (Sandia National Laboratory). The articles in this Special Issue of the *Journal of Research of the National Institute of Standards and Technology* represent contributions of speakers and attendees at this symposium.

The title of the Symposium, “Topics in Operations Research,” reflects the fact that Christoph Witzgall’s career is tightly woven into the fabric of the field of Operations Research at NIST. In fact, from 1979 to 1982, he served as acting Chief of its Operations Research Division. We will try to summarize some of those developments here.

Operations Research (OR) at NIST traces its beginnings to an early electronic computer, the SEAC (Standards Eastern Automatic Computer), which was designed and built at National Bureau of Standards (NBS)[1]. The SEAC commenced operations on June 20, 1950. At the time the SEAC was the only stored-program computer in the Nation, and the fastest such machine in the world. It permitted for the first time large-scale OR applications such as determining the best deployment of aircraft to ensure a balance between combat reserve and training. This and similar applications were formulated by George B. Dantzig and collaborators as linear programming problems and solved using his simplex method as programmed on the SEAC, starting a long history of research into linear programming and related issues at NIST. In those early days, this work was conducted under the Numerical Analysis Group, which included researchers Ky Fan, Karl Goldberg, Alan J. Hoffman, and Morris Newman. A highlight of this period was a demonstration by Hoffman of “cycling” by the simplex method. Also at the time, a separate NIST branch, the Institute for Numerical Analysis (INA), was housed on the UCLA campus. There, Theodore S. Motzkin and his collaborators achieved major results on solving linear inequalities. Hestenes, also at INA, developed the fundamental conjugate gradient method, still a workhorse for solving linear systems and optimizing differentiable functions. It should be noted that Stiefel at ETH, Zürich, independently developed the conjugate gradient method and later collaborated with Hestenes in jointly publishing the method.

In the Fall of 1957, Alan J. Goldman joined the NIST Applied Mathematics Division. He had been one of a group of mathematicians at Princeton, under the leadership of Albert W. Tucker, who were foremost in establishing mathematical foundations of linear and nonlinear optimization. The impact of his energy, broad interests, and competence was immediate. More than anyone, he was destined to carry the torch of OR at NIST. In 1961, he took the helm of the newly formed Operations Research Section within the Applied Mathematics Division. The initial members were Bernice K. Bender, John R. (Jack) Edmonds, Lambert S. Joel, and Charles Zahn. Highlights of these years include an algorithm of polynomial complexity for the maximum matching problem by Edmonds as well as his example of a matroid not representable by a matrix. Christoph Witzgall joined the OR Section in 1962. He worked on the first comprehensive study of the central facility location problem, and, with Zahn, on implementing matching algorithms. In the following year, the Section grew with the addition of Joel Levy and Philip Meyers.

In 1964, the Department of Defense requested participation by the OR Section in a task force investigating the economics of commercial supersonic air travel. In this endeavor, Goldman and Witzgall were joined by William (Bill) Hall, who eventually moved from the Computation Laboratory to the OR Section. This activity presaged an emerging emphasis on large-scale mathematical models. It also set the tone for the mode of operation for the following decades: responding to critical needs in other agencies of Government and also drawing stimulation for theoretical investigations from real life applications. This mode of operation was reinforced by the formation, also in 1964, of the Technical Analysis Division (TAD) of NIST to carry out analysis and modeling in the governmental arena. The synergy between the two organizations was evident also in their cooperation on the North East Corridor Transportation Project. This led to a sustained effort by the OR Section in the area of shortest path algorithms and

[1] In 1988 NBS was renamed the National Institute of Standards and Technology (NIST). In this article we will refer to both institutions as NIST.

transportation networks by Judith Gilsinn, who joined the OR Section from TAD, Christoph Witzgall, and, later on, Douglas Shier, Ralph Schofer, who also joined from TAD, and finally by Bill Hall and Howard Hung. The majority of the latter work, and the work by Witzgall, was sponsored by the Urban Mass Transit Administration (UMTA) of the U.S. Department of Transportation.

The potentially toxic effects of lead in the environment rose to a national concern in the early 1970s. Working with HUD and, initially, TAD, Gilsinn analyzed data on the incidence of elevated blood lead levels for the cities of New Haven, CT, Aurora, IL, and Chicago, IL, and combined them with Census data. The result was the first substantiated national estimate of the nature and extent of lead poisoning. Hall and, later on, Shier continued the project, analyzing a large urban data base assembled from the city of Pittsburgh including lead paint prevalence, attempting to capture corresponding local distributions of elevated lead levels. In a sequel to this effort, Shier embarked on the study of a large data set of pediatric blood lead levels collected during 1976 in New York City. He demonstrated a strong cyclic variation of blood levels which correlated highly with ambient air lead levels, and also with the amount of lead present in gasoline sold during the same period. These results reinforced and critically defended the decision to phase out leaded gasoline in the United States. For his work, Shier received the Award for Scientific Advancement in Mathematics from the Washington Academy of Science in 1979.

The Section's move in 1966 to the new campus in Gaithersburg was one of the last such moves to be accomplished. Also, with the establishment of the NIST Center of Applied Mathematics (CAM) in 1978, the OR Section achieved division status. It had grown by recruiting Richard (Ric) Jackson and Patsy Saunders, and with post-docs Douglas Shier and Karla Hoffman accepting permanent employment. Shier later left for a faculty position at Clemson University. Hoffman went on to become President of INFORMS[2] and Professor of Operations Research at George Mason University. In a major technical development while at NIST, she worked with faculty appointees Garth P. McCormick and James Falk, both at George Washington University, on optimizing non-convex functions. Hoffman's subsequent years also saw an extensive and high-impact effort in cooperation with Manfred Padberg of New York University that led to the breakthrough development and successful implementation of a computationally feasible integer programming algorithm. Former post-doc James Lawrence serves also on the faculty of George Mason University and is currently a faculty appointee in his capacity as expert on combinatorial issues.

Facility location remained an area of major interest and activity, furthered, in particular, by the teaching and collaboration of Richard L. Francis. Following Witzgall's work on locating a central facility so as to minimize distance, or travel time, to such a facility, Goldman launched a series of analytical investigations of such problems as maximizing distances away from undesirable locations. Saunders and Francis collaborated on designing, implementing, and real life testing of a model for building evacuation. Using a parametric integer programming approach, Witzgall and Saunders assisted the U.S. Postal Service in selecting cities for a proposed but later abandoned electronic mail service. In the 1980s, finally, Paul Domich and Marjorie McClain designed and implemented a highly successful facility location model with a then innovative graphical interface for the Internal Revenue Service to best choose the location of their branch offices.

OR provided the context for examining a number of policy questions. For example: How could compliance with government rules and regulations be encouraged? What extent of examination would balance the costs of discovery against the proceeds of evasion? During the early 1970s Goldman and faculty appointee Martin Pearl of the University of Maryland conceived of the balancing of this conflict of interest as a two person game, working out and publishing the theoretical aspects of this approach. The audit procedures of the Internal Revenue Service (IRS) provided a prime testing ground for this idea. In 1978, Hoffman, Joel, and Pearl compared a first-cut implementation of the game-theoretical approach to the audit strategies employed by the IRS at the time. Their model was indeed able to achieve the same level of compliance given the same data in a simulated environment.

A first of its kind, the 1977 Workshop at NIST on "Utility and Use of Large-Scale Mathematical Models" is indicative of a strong emphasis on the theory and practice of large-scale mathematical modeling. It was organized with the help of faculty appointee Saul Gass of the University of Maryland, who also edited the proceedings. The subsequent years were marked by a major collaboration with the Energy Information Administration (EIA) of the Dept. of Energy. Gass and faculty appointee Carl Harris of Virginia Tech, together with Jackson, Hoffman, Joel, and Saunders, undertook an in-depth evaluation of oil and gas supply models that had been developed at EIA, culminating in the 1979 workshop "Validation and Assessment Issues of Energy Models." This work led to Witzgall

[2] The Institute for Operations Research and the Management Sciences (INFORMS) is the world's largest professional society for professionals in the field of operations research.

and Saunders joining an effort at the EIA to develop an oil and gas forecasting model, in particular, the portion modeling the production, transportation, distribution and pricing of natural gas. This model was used for almost a decade to issue the formal forecasts of the EIA.

Alan J. Goldman left NIST in 1979 to join the faculty of Johns Hopkins University in Baltimore. Until the permanent replacement, Josef Engel, came aboard in 1982, Witzgall served as Acting Division Chief. The division grew again with the addition of Javier Bernal and Marjorie McClain, and the permanent employment of Paul Domich. In 1984, the OR Division was merged with the Mathematical Analysis Division, under Fred Johnson, which was later combined with the Scientific Computing Division to form the Applied and Computational Mathematics Division under Paul Boggs. The Division changed its name to Mathematical and Computational Sciences Division (MCSD) in 1997. Its group, Optimization and Computational Geometry now including Isabel Beichl and David Gilsinn, might be considered an institutional successor to the OR Division. Economical aspects of operations research are pursued by the Applied Economics Group lead by Harold Marshall. This group, in fact, joined the OR division in 1979 until reverting back to the Building and Fire Research Laboratory (BFRL) in 1982. Collaboration, however, remained strong involving, Hall, Chapman, Gass, and Steven Weber, in particular, concerning a linear programming based planning tool providing guidelines for cost-effective fire-safe retrofits of health care facilities.

Until he left in 2000, Paul Boggs actively engaged in and furthered research on optimization methods in the division, focusing on interior point methods for linear programming. Specifically, his work with Domich, along with Janet Rogers of the Statistical Engineering Division, lead to the implementation of a rapidly converging algorithm, 03D, for solving linear programming problems. The hallmark of this algorithm is its reliance on 3D projections to derive crucial search directions. This algorithm is at the core of a major subsequent development, a sequential quadratic programming algorithm for general optimization, developed, analyzed, and implemented with Anthony Kearsley and faculty appointee Jon Tolle of the University of North Carolina. Theoretical work by Witzgall centered on the limit property of analytic centers, first for linear programming, and later with McCormick, for general sequential unconstrained minimization techniques (SUMT).

Much more could have been mentioned about OR activities at NIST addressing, for instance, inland consolidation centers of the U.S. Maritime Administration, fire service facility planning and districting, micro-navigation and pointing location systems of the U.S. Army, airport terminal throughputs, U.S./Canadian salmon fisheries, fire engine replacements, IRS telephone information systems, and selecting rail properties for improvement. The Special Issue Editor is indebted to Christoph Witzgall for his many recollections. To do thorough justice to all of the OR accomplishments would take a book (the Editor's pipe dream). Other prominent sources for some of the history contained in these notes include early project reports of the Applied Mathematics Division, the three volume history of NIST ("Measures of Progress" by R. C. Cochrane, "A Unique Institution" by E. Passaglia, and "Responding to National Needs" by J. F. Schooley), the book "History of Mathematical Programming: A Collection of Personal Reminiscences," edited by J. K. Lenstra, A. H. G. Rinnooy Kan, and A. Schrijver, Amsterdam and North-Holland (1991), and last but not least, the "Annotated Timeline of Operations Research: An Informal History" by Saul Gass and Arjang A. Assad, Kluwer (2005).

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