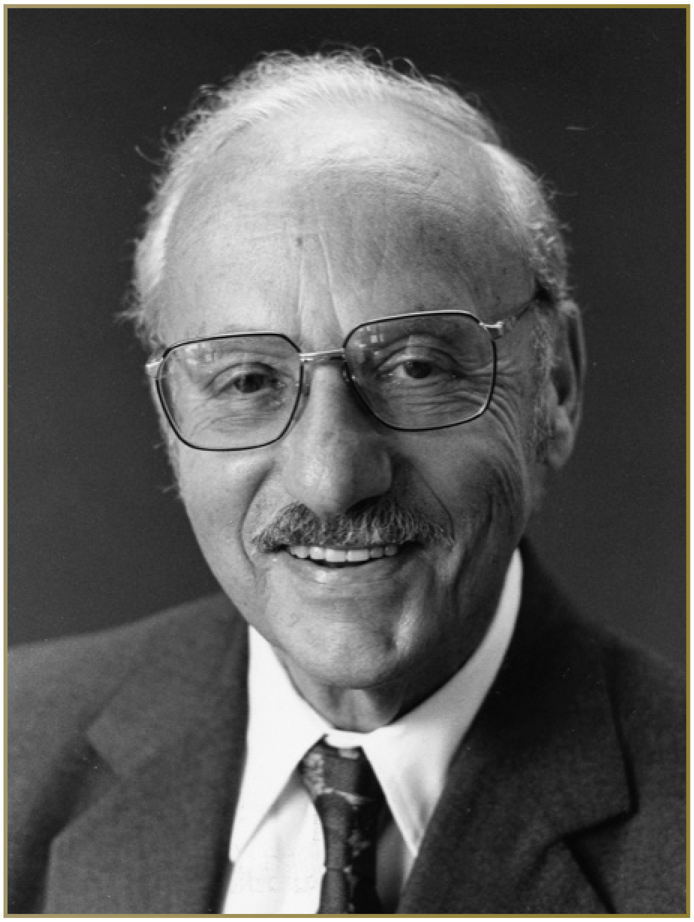
# George B. Dantzig

November 8, 1914–May 13, 2005
Elected to the NAS, 1971

*A Biographical Memoir by Richard W. Cottle*



George B. Dantzig. *Photo by Edward Souza, Stanford News Service.*

**George B. Dantzig** was the C. A. Criley Professor of Transportation Sciences and Operations Research at Stanford University. Known as the "father of linear programming and inventor of the simplex method," he was instrumental in the growth of many related areas of finite-dimensional optimization, also called "mathematical programming."

George B. Dantzig was born on November 8, 1914, in Portland, Oregon. It was the hope of George's parents,[i] Tobias and Anja (née Ourisson), that George would become a writer, hence the names "George Bernard"—resembling George Bernard Shaw. Tobias and Anja studied mathematics at the Sorbonne and greatly admired celebrated French mathematician Henri Poincaré, after whom George's brother, Henry, was named.

Being a recent immigrant with a strong Russian accent, Tobias Dantzig doubted his suitability for teaching mathematics. Instead, he took nonacademic jobs, one of which was as a lumberjack. Fortuitously, he had a chance encounter at a public library with the chairman of the Reed College mathematics department. Their discussion led to his being encouraged to pursue a career in academia. Tobias took this advice and obtained a Ph.D. in mathematics at Indiana University. He went on to hold several university-level academic positions, most notably at Johns Hopkins University and the University of Maryland. In 1936, George would receive his bachelor's degree in mathematics and physics from the latter. He then enrolled as a scholarship student in the Horace Rackham School of Graduate Studies at the University of Michigan, from which he received a master's degree in 1938 in mathematics.[ii]

Upon completion of this degree, George took a job at the U.S. Bureau of Labor Statistics. There, he was asked to review an article by mathematical statistician Jerzy Neyman. The article impressed him and engendered his desire to study mathematical statistics at the University of California, Berkeley under Neyman's supervision. It is here that the inspiring George Dantzig legend really begins.

As a doctoral student in mathematics at Berkeley, Dantzig took two statistics courses from Neyman. One day, arriving late for one of these classes, George noticed two problems written on the chalkboard. He understood them to be a homework assignment. He worked on the problems and found them more challenging than usual, but he finished them, nonetheless. He asked Neyman if they should be turned in, to which the great professor responded, "Yes, just throw them on my desk." George did so despite the messy condition of that desk. Weeks passed. Then early one Sunday morning, George's doorbell rang. It was Neyman, manuscript in hand, saying that he had written an introduction to the solution to one of the problems. He wanted George to submit it for publication. It seems that *both* problems on the chalkboard that fateful day were open questions in the field of mathematical statistics. Dantzig's solutions to these problems ultimately formed the content of his doctoral dissertation.[1,2]

Dantzig's doctoral studies at Berkeley were interrupted by the outbreak of World War II. George took a leave of absence to join the Combat Analysis Branch of Statistical Control at the U.S. Army Air Force headquarters in Washington, D.C. There he received commendations for his work and in 1944 received the War Department's Exceptional Civilian Service Award. Once the war was over, he returned to Berkeley and completed the requirements for the Ph.D. in 1946.

George then returned to the Pentagon as a mathematical advisor to the comptroller of the newly created U.S. Air Force. His assignment concerned the mechanization of planning procedures to support time-staged deployment of training and supply activities. It was in this capacity, in 1947, that the linear programming problem and the simplex method for its solution took shape in his mind.

The word "programming" in the sense of "linear programming" includes the mathematical formulation of a plan to achieve a goal by determining activity levels satisfying a system of finitely many conditions (constraints) modeled by linear inequalities or a mathematically equivalent system of linear equations in nonnegative variables. Such a formulation becomes a linear programming problem when seeking values of the variables that satisfy the system of constraints while also yielding a desired extremal value (e.g., minimum) of a particular linear form called the "objective function." In a nutshell, this says that linear programming concerns the finite-dimensional optimization of a linear function subject to a system of finitely many linear constraints. A canonical and concise symbolic expression of this is: to find

$$\min z,\ x \geq 0 \text{ such that } Ax = b,\ cx = z$$

where $x = (x_1, \ldots, x_n)$, $A$ is an $m$ by $n$ matrix, and $b$ and $c$ are column and row vectors, respectively. The data and variable values are assumed to be real numbers. Solving this kind of optimization problem normally requires an algorithm designed for the purpose. Dantzig's simplex method (of linear programming) is such an algorithm.[iii]

Dantzig originally called his work "programming in a linear structure" and presented it in 1948 at a meeting of the Econometric Society at the University of Wisconsin-Madison. The session in which Dantzig spoke included many prominent mathematicians and economists. One of these was the mathematical statistician and economic theorist Harold Hotelling, who (in the discussion period following the talk) voiced the objection that "the world is nonlinear." John von Neumann came to the flustered young Dantzig's defense, saying that if one has an application that satisfies the axioms of the model, then it can be used. Otherwise not. Unfortunately, only the abstract of this talk was published.[3] Nonetheless, the abstract is notable for its vision of the subject's potential to solve real-world problems, its connections with existing ideas, and its manifold opportunities for further development. That potential has been realized with diverse applications aimed at finding the best levels of activities that yield the desired extreme (minimum or maximum) of an objective function. Applications of this sort can be found in production planning, financial planning, and marketing. Other areas of application are scheduling, combinatorial optimization, and least-cost network flow problems. Still further applications are found in nonlinear programming algorithms in which linear programming subproblems can arise.

Much has been written about George Dantzig as "the father of linear programming" and "inventor of the simplex method." An element that deserves more emphasis is Dantzig's fervent determination to "solve problems of the real world." The preface of his famous book, *Linear Programming and Extensions,* opens with the statement, "The final test of a theory is its capacity to solve the problems which originated it." In his 1997 textbook coauthored with Mukund Thapa, George Dantzig singled out three of his own early contributions.[4] The first two of these have to do with modeling.[iv] First, he said, was his recognition that "most practical planning problems could be reformulated as a system of linear inequalities." His next achievement was to replace "ground rules for selecting good plans by general objective functions." He attached great importance to this aspect of modeling, but it would be a mistake to attribute the concept of an objective function to Dantzig. It was the introduction of the objective function concept in the military planning arena that marked progress. In 1947, this kind of thinking was a novelty. These modeling insights, coupled with his third contribution, the invention of the simplex method, made a powerful combination. Indeed, it was recognized in 2000 as one of the "top 10 algorithms of the twentieth century" by *Computing in Science and Engineering.*[v] The successes of these contributions significantly stimulated the development of the automatic computing industry.

While employed at the Pentagon, George Dantzig played a major role in what must have been an extremely exciting professional meeting: the Conference on Activity Analysis of Production and Allocation. The proceedings of that 1949 conference are rich in historical information and reveal much about Dantzig's many-sided involvement in the development of linear programming.[5] Of the twenty-five chapters in the proceedings, five are authored (or co-authored) by Dantzig. Not one of these five uses the term "linear programming" in its title.[vi] George often credited Tjalling Koopmans for having (in the summer of 1948) proposed "linear programming" in place of "programming in a linear structure." Although Dantzig and others adopted this recommendation, his early use of titles such as "The Programming of Interdependent Activities: Mathematical Model" and "Maximization of a Linear Function of Variables Subject to Linear Inequalities" more clearly revealed his purpose to an audience not yet familiar with such notions.

We can only imagine what was going on in George Dantzig's professional life in the next few years after the Madison and Chicago conferences of 1948 and 1949. Indeed, he was employed at the U.S.A.F. headquarters from 1946 to 1952. These years must have been occupied with the development and the application of his new discoveries to Air Force problems, because his publication list indicates just one paper in 1949 followed in 1951 by the five publications that he presented at the Chicago conference.

Hired as a research mathematician at the RAND Corporation in 1952, Dantzig had a greater opportunity to develop the theory of linear programming. Yet this work was generally done with an eye to the furtherance of its utility in practical applications. Sometimes this motivation was military or industrial in nature; other times it was computational—one theorem or algorithm in support of another. In this capacity, George produced the core literature of linear programming and simultaneously added to the reputation of the illustrious RAND Mathematics Department. In 1960, having established the building blocks of linear programming and, incidentally, doing much to advance the fledgling fields of operations research and management science, George Dantzig left RAND to become a professor of industrial engineering at Berkeley. When asked in a 1986 interview, "what caused you to leave RAND and return to the academic world," he gave a brief description of the Mathematics Division and ended by saying "there were no new people being hired to work with us as disciples."[6] Within a year at Berkeley, he established the Operations Research Center (ORC), located at the university's Richmond Field Station, and began building one of the most active groups of its kind.

One of George's fruitful characteristics was a talent for achieving several purposes with a single activity. This penchant can be illustrated by one of his practices as director of the ORC. The wood-frame house where the ORC was located had a large room that served as a library. In the center of the room stood a conference table that was usually covered by piles of books, reprints, and technical reports. It was the responsibility of the most recently hired research assistants to spend some time in the library sorting and filing these items. (This was the first purpose.) George believed that by having these items in their hands, the graduate students might just find something of interest and later use it in their own research. (This was the second purpose.)

It was in these surroundings that George established his outstanding career as a teacher and mentor to scores of doctoral students. Indeed, at Berkeley, Dantzig was the thesis advisor (either de facto or de jure) of eleven students, myself included.[vii]

In 1966, George left Berkeley and took a position at Stanford University. He joined the Computer Science Department and the program in Operations Research (OR). The latter became a department (now the Management Science and Engineering Department) the next year; although Dantzig's appointment was joint between these two, his allegiance was primarily with OR.

At Stanford, Dantzig poured his energy into building up the mathematical programming side of the OR department. At the same time, he was elected president of the Institute of Management Sciences (TIMS), which many years later merged with the Operations Research Society of America (ORSA) to become INFORMS. In his career at Stanford—which lasted into the late 1990s—Dantzig mentored forty-three doctoral students (again either de facto or de jure). The subjects of their theses ranged over large-scale linear programming, stochastic optimization, integer programming, economic applications, nonlinear programming, and complementarity theory.

Along the way, there were other enterprises as well. In the late 1960s and early 1970s, George promoted the creation of a high-level mathematical programming language (MPL) for writing computer programs for optimization. With a group of colleagues, he created the System Optimization Laboratory (SOL), which still exists. He developed a strong association with the International Institute for Applied Systems Analysis in Laxenburg, Austria, at one time heading up its Methodology Group. Dantzig also had close links to the Technical University of Linkoping in Sweden and the Technion in Haifa, Israel. His book *Compact City,* co-authored with Thomas Saaty, was published in 1973.[7] Although not a bestseller, it did manage to attract interest in the urban planning world and was translated into Japanese.

A touch of controversy arose when the Nobel Prize in Economics was awarded in 1975. The prize was given to Leonid

V. Kantorovich and Tjalling C. Koopmans but *not* George B. Dantzig.[viii] Believing that Dantzig's contributions had been slighted, distinguished scholars around the world attempted to put the matter right. In the end, these efforts were unsuccessful. Nevertheless, they set in motion a train of events whose importance cannot be overlooked. In that same year, Dantzig received the National Medal of Science (presented by Pres. Gerald Ford) and the John von Neumann Theory Prize (presented by ORSA and TIMS). Years later, he received the Silver Medal awarded by the Operational Research Society of the United Kingdom. Altogether, George Dantzig received nine honorary doctorates, four from abroad. He became a member of the National Academy of Sciences in 1971. In 1975, he was elected to the National Academy of Engineering and became a fellow of the American Academy of Arts and Sciences.

The Dantzig legacy certainly includes his building of linear programming and the simplex method. Had this been his only contribution, its subsequent evolution would have justified his inclusion in the mathematical pantheon. But there were so many more discoveries in which he played a significant part. For instance, one can point to his seminal work on large-scale linear programming models; these typically involve a special matrix structure that prompts the development of algorithmic inventions for achieving greater computational efficiency and ultimately greater real-world applicability.[ix] Among such publications are the generalized upper-bounding and the classic work on the decomposition principle.[8,9] An important theoretical contribution is found in the generalized simplex method paper, which shows how to avoid the phenomenon of cycling in the standard simplex algorithm.[10] Two other notable publications are on the solution of a (then) large-scale traveling salesman problem[11] and the subject of linear programming under uncertainty,[12] which involves models with uncertainty in at least some of the activities. Dantzig regarded these as "the real problem."[x]

George Dantzig became an emeritus professor in 1985, but he remained active in teaching and research until 1998. George's vitality and longevity gave us opportunities to celebrate a few of his decennial birthdays. Speaking at a banquet in honor of George's seventieth birthday, Alan Hoffman remarked that George Dantzig was "old enough to be a legend, but too lively to be a statue." This perceptive statement was true in 1984 and remained so for more than a decade. A long lifetime of energy, intelligence, and dedication is surely the stuff of which the Dantzig legend is made.

As for Dantzig's impact, we must recall the 1963 textbook *Linear Programming and Extensions* (known by mathematical programmers as the "Bible of linear programming")[13] and then the two 1997 volumes, *Linear Programming. 1: Introduction* and *Linear Programming, 2: Theory and Extensions,* both written jointly with Mukund N. Thapa.[14,15] At Berkeley and Stanford alone, these works—and Dantzig's broad-based research that lay behind them—provided precious educational opportunities for more than fifty doctoral students to write their dissertations. One can only marvel at the magnitude of George Dantzig's influence on the academic and industrial research communities of the world.

George suffered from the complications of arteriosclerosis and passed away at his home on May 13, 2005. At the time, his survivors included his wife, Anne, and three children, David Franklin Dantzig (b. 1945), Jessica Rose Dantzig Klass (b. 1948), and Paul Michael Dantzig (b. 1950).

George B. Dantzig was a man of great exceptional dedication, intelligence, and warmth. He had remarkable insight concerning the abilities of others and knew how to provide opportunities for the fulfillment of their aims. In many cases, this drew them into his circle of colleagues and research partners. The greatness of his spirit will live forever in the memory of his family, friends, and colleagues.

## Acknowledgments

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## Notes

i Tobias Dantzig (1884–1956) was born in Shavli, Lithuania. His wife, Anja (1888–1963) was born in Łodz, Poland. Her name at birth was Anja Gitla Uryson, but her surname was changed to the Ourisson prior to marrying Tobias.

ii According to the signature page of Dantzig's doctoral dissertation, his master's degree dates from 1938, not 1937. The difference probably relates to the time between his completing the degree requirements and having it conferred.

iii In thinking about how to solve a linear programming problem, Dantzig devised two approaches, each of them with a corresponding "geometry." The first one emphasized column vectors formed from the given data. The second one involved systematically traversing edges of the polyhedron of vectors $Ax = b$, $x \geq 0$ to find an optimal extreme point. In the foreword of his 1997 textbook with Mukund Thapa, Dantzig states that "the term Simplex Method arose out of a discussion with T. Motzkin, who felt that the approach I was using, when viewed in the geometry of the columns, was best described as a movement from one simplex to a neighboring one."[16] Cottle and his coauthors recount why Dantzig used the word "simplex" in the name "simplex method" in their 2007 obituary.[16]

iv Dantzig often stated his great admiration for the modeling work of Wassily Leontief, such as *The Structure of the American Economy*.[17] To quote Dantzig from a 1990 interview, "in my book he is a hero."[18] Martin C. Kohli describes "the ongoing collaboration between Wassily Leontief and the Bureau of Labor Statistics" in the June 2001 issue of *Monthly Labor Review*.[19]

v It can be argued that the simplex method was invented and published before Dantzig independently discovered it.[20] A method published in Latin by Jesuit priests Roger Joseph Boscovich and Christopher Maire in 1757 (and later known as "Boscovich's method") for solving a least absolute value regression problem with nonnegative variables and a single linear constraint is equivalent to a variant of the simplex method.[21] An article by Frank L. Hitchcock would also suggest this,[22] and it seems virtually certain that the algorithm would have been invented later. Nonetheless, the simplex method is still generally regarded as one of Dantzig's foremost contributions.

vi One title refers to the "programming problem," but "linear" is omitted.

vii George considered me to be his first doctoral student. We became colleagues, research collaborators, and friends for nearly forty years.

viii Officially, "The Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel."

ix In this regard, one must take account of the computational environment with which researchers of the day contended.

x In addition to the publications listed in the Selected Bibliography, a longer such list can be found in *The Basic George B. Dantzig,* an anthology requested—and approved—by George B. Dantzig.[23]

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