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History of Operations Research

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Abstract We discuss the history of operations research (OR) from the following perspectives: the origins and people of OR; the major sites of early United States OR research; the best stories from contributors to early OR; and lessons learned, or how history informs OR today.

Keywords operations research; history; perspectives

Tutorial Outline

Part I: Origins and People of Operations Research (OR)—A Quick Tour
Part II: The Major Sites of Early U.S. OR Research
Part III: The Best Stories from Contributors to Early OR
Part IV: Lessons Learned, or How History Informs OR Today

Prologue

Over the last 10 years, we have taken intersecting paths along the complex network that defines the background, development, and worldwide acceptation of OR as a scientific-based profession that is directed at resolving decision problems in business, government, industry, and society. Prior to these travels, we both spent our careers (and still are) in consulting, teaching, and related research. So, it is fitting to ask, what do we find in the pursuit of the historical aspects of OR that make it of interest to us and, we hope, of interest to you? But first, we discuss some brief background on the origins of OR and how we became interested in that area:

OR had its origins in the late 1930s when a group of British Royal Air Force officers and civilian scientists were asked to determine how recently developed radar technology could be used for controlled interception of enemy aircraft. The task required scientists from various disciplines to leave their academic and laboratory settings and participate in field operations, testing, and evaluation. This embryonic but seminal applied research activity was followed by the formation of OR groups to investigate military problems encountered by the services on land or sea, or in the air. The resulting methodological approach was called operational research in the United Kingdom and operations research in the United States. The salient feature of this research activity was to bring scientists from diverse disciplines directly into the field to solve operational military problems and make related tactical and strategic recommendations. Throughout World War II (WWII), on both sides of the Atlantic, OR groups analyzed critical military problems. The solutions they produced led to changes in military strategy and tactics that greatly improved results. OR helped the Allies win the war.

At the end of WWII, the U.S. military services, recognizing the wartime contributions of OR, continued their support of OR groups with the problems focusing on logistics, combat modeling, and force planning. Similarly, senior scientists who had participated in wartime

OR in the United Kingdom and United States were convinced that OR could be used to solve management and operational problems of nonmilitary enterprises and government. OR groups were soon formed and employed by governmental entities and private companies in the United Kingdom and United States, professional societies were organized, OR consultancies were established, and academic OR programs were initiated. Today, OR is recognized worldwide as a modern, decision-aiding science that has proved to be of great value to management, business, and industry.

Early in our education, we developed an interest in the history of science driven by our own curiosity in the sciences, especially mathematics. We augmented our schooling by biographical tales from Eric Temple Bell's *Men of Mathematics* and the story of how mathematics developed across the centuries from Carl Boyer's *A History of Mathematics*. Later, we moved on to such works as Norbert Wiener's two-volume autobiography, *Ex-Prodigy* and *I Am a Mathematician*, and Constance Reid's *Hilbert*. Thus, by the time each of us entered into a research-oriented course of training, we had developed an appreciation of the value of such historical accounts in shaping our views of how one matures as a scientist. Our interest in this area continued as we read John Stillwell's *Mathematics and Its History*, or the collection of interviews in *Mathematical People*, edited by Donald Albers and Gerald Alexanderson. In the past two decades, dozens of historical or biographical collections have been published in other sciences, notably the physical, biological, economic, and computer sciences, providing a wealth of material for those interested in the historical development of these fields. In contrast, we were struck by the paucity of studies devoted to the history of OR.

In the past, there have been a few articles that recounted the early history of OR; Joseph McCloskey's three papers that appeared in *Operations Research* in 1987 come to mind. More recently, we have Maurice Kirby's book, *Operational Research in War and Peace*, and our book, *An Annotated Timeline of Operations Research: An Informal History* (2003). **We are believers in the need for such historical accounts. By neglecting this need, the failure to chronicle our field will mean that important lessons will be lost to the coming generations of OR researchers, practitioners, and students.**

Our theme for this tutorial is guided by the last sentence above. The process of editing *Profiles in Operations Resaerch*, cited below, impressed a pivotal point upon us, namely, the urgency of capturing the information of early OR efforts now rather than later. We have found that as we lose contact with the early contributors to the field, obtaining or verifying the relevant information becomes significantly harder. Inevitably, the opportunity of interviewing the original contributors is lost, primary sources and materials are discarded or destroyed, and memories fade. All of this points to the need for a more reliable approach to preserving the archival materials in the history of OR.

Part I: Origins and People of OR–A Quick Tour

Definitions of OR:

What is Operations Research?

"Operations research is a scientific method of providing executive departments with a quantitative basis for decisions regarding the operations under their control." (C. Goodeve. Operational research. *Nature* 161(4089):377–384, 1948.)

Operations research is the "mathematical or scientific analysis of the systematic efficiency and performance of manpower, machinery, equipment, and policies used in a governmental, military, or commercial operation." (*American Heritage Dictionary of the English Language* 921, 1976.)

Operations research is the science of decision making.

References (Annotated):

A. A. Assad and S. I. Gass, eds. *Profiles in Operations Research: Pioneers and Innovators*. Springer, New York, 2011.

In this book, the editors, who also served as authors, worked with 38 other authors to produce the first book that describes the history of OR by relating, in biographical form, the achievements of OR pioneers and innovators. The 43 profilees, listed in alphabetical order, are as follows:

Profilees

Russell Lincoln Ackoff	Ellis A. Johnson
E. Leonard Arnoff	Leonid Vital'evich Kantorovich
Egon Balas	George E. Kimball
Evelyn Martin Lansdowne Beale	George Kozmetsky
Anthony Stafford Beer	Harold W. Kuhn
Richard E. Bellman	John D. C. Little
Patrick Blackett	John F. Magee
Alfred Blumstein	Harry Markowitz
Seth Bonder	Hugh Jordan Miser
Abraham Charnes	Philip McCord Morse
C. West Churchman	Howard Raiffa
William W. Cooper	Berwyn Hugh Patrick Rivett
George B. Dantzig	Bernard Roy
Jay Wright Forrester	Thomas L. Saaty
D. Ray Fulkerson	Herbert A. Simon
Saul I. Gass	Jacinto Steinhardt
Murray Aaron Geisler	Albert W. Tucker
Ralph E. Gomory	Steven Vajda
Charles Frederick Goodeve	Andrew Vazsonyi
David Bendel Hertz	John von Neumann
Ronald A. Howard	Harvey M. Wagner
	Philip Starr Wolfe

The editors' objective, as noted in the book's preface, is as follows:

> OR is a relatively young field. Many of its developers are still alive and records of their accomplishments are available from them and/or from colleagues and friends. Similarly, for those who have passed on, writings and reports of their OR activities are still reasonably accessible, and can be amplified with the memories of close collaborators or friends. These fortunate circumstances related to timely access led us to believe that the history of OR could be told in a comprehensive and interesting manner through individual profiles. We felt that we had a window of opportunity to capture the story of these pioneers as they charted their courses through the early years of OR and saw it mature as a field. To accomplish this objective, we drew upon historical and technical articles, autobiographies, biographies, interviews, the resources available via the World-Wide Web, and existing accounts of the history of OR. And, most important, we were able to find authors who, as close colleagues or friends, were in the best position to relate the professional and personal histories of the persons they profiled.
>
> We have organized the 43 profiles of this book chronologically, in ascending order of the date of birth (by day, month, and year) of the profilees. The reader progressing from Patrick Blackett's profile (Chapter 1, born in 1897) through Ronald Howard's profile (Chapter 43, born in 1934), will be exposed to a history of the origins and early development of OR—how it evolved—all interwoven with personal backgrounds, tales, vignettes, and pictures.

P. M. S. Blackett. Operational research. *Operational Research Quarterly* 1(1):3–6, 1950.
P. M. S. Blackett. Operation research. *Physics Today* 4(November):8–20, 1951. (This is a review of the book *Methods of Operations Research*, Morse and Kimball, 1951, listed below.)

Patrick Blackett is known as the father of OR. Early on (1936), he worked on British pre-WWII air-defense problems and introduced the concept of bringing scientists out of their laboratories into the field where the problems were encountered. In the 1950 journal article (the first paper printed in the first journal dedicated to OR), Blackett answers three basic questions about his

experiences with OR: "Is it new? If so, in what way? Is it scientific?" (p. 3). He notes that because all definitions of OR "include some such phrase as 'the application of scientific method'" (p. 4). the answer to the third question is yes. He then goes on to discuss the scientific method and how OR's "novelty," as developed in WWII, is the level at which the work is done, in the comparative freedom of investigators to seek out their own problems, and in the direct relation of the work to the possibilities of executive action. Further discussion, including his description of the qualifications required of an OR worker, provides yes' answers to the first two questions. In Blackett's 1951 piece, he makes clear his distaste for the mathematization of the subject that was later in full swing, especially in the United States. The OR studies in WWII had been firmly rooted in data generated by actual military operations, Blackett's emphasis on the primacy of data in OR is indeed entirely in keeping with the basis of his career in physics (p. 19): "In a sense, of course, probability theory in the form of the simple laws of chance is the key to the analysis of warfare . . . . My own experience of actual operational research work, has however, shown that it is generally possible to avoid using anything more sophisticated . . . . In fact the wise operational research worker attempts to concentrate his efforts in finding results which are so obvious as not to need elaborate statistical methods to demonstrate their truth. In this sense advanced probability theory is something one has to know about in order to avoid having to use it" [Blackett 1951, p. 19]. (Blackett received the 1948 Nobel Prize in physics for his prewar work on cosmic radiation.)

S. I. Gass and A. A. Assad. *An Annotated Timeline of Operations Research: An Informal History.* Springer Science/Kluwer Academic Publishers, New York, 2005.

In this book, the authors trace the early beginnings of OR from the work of Cardano's *The Book on Games of Chance* (1564), in which chance was first defined as the ratio between the number of favorable outcomes to the total number of outcomes. In a sequence of short stories, pictures, and tales, the *Timeline* describes the prehistory of OR and its development through Taylor's principles of scientific management to the founding of OR in the United Kingdom and the spreading of OR developments and applications throughout the world, especially in the United States. A great read!

S. I. Gass and A. A. Assad. Tales from the time line—The definition of OR and the origins of Monte Carlo simulation. *Interfaces* 35(5): 429–435, 2005.

The authors relate the stories about how the first definition of OR, as promulgated in the book *Methods of Operations Research* by Morse and Kimball (1952), came to be and about the card game that led the mathematician Stanislaw Ulam to propose Monte Carlo simulation and give it its name. (See Kittel 1947 below.)

S. I. Gass and C. M. Harris. *Encyclopedia of Operations Research and Management Science*, 2nd ed. Kluwer Academic Publishers, Norwell, MA, 2001.

The second edition of the first comprehensive encyclopedia in OR and management science. The third edition is in press.

Miser–Harris Presidential Portrait Gallery. INFORMS. http://www.informs.org/About-INFORMS/History-and-Traditions/Miser-Harris-Presidential-Portrait-Gallery.

The Miser–Harris Presidential Portrait Gallery contains pictures and biographical sketches of presidents of the Operations Research Society of America (ORSA), the Institute for Management Science (TIMS), and INFORMS. It provides a quick introduction to some of the leaders in our field through short capsule biographies. The gallery is named in honor of two leaders in our profession: Hugh Miser (1917–1999) and Carl Harris (1940–2000). Hugh Miser was a prominent and strong voice in advocating the need for preserving the history and traditions of our field. Carl Harris provided the initial idea and impetus for the conception of the gallery and was intimately involved with its formation and development until his untimely demise. The first phase of the gallery concentrated on the first 10 presidents of ORSA and TIMS. The gallery was unveiled at the INFORMS headquarters in Linthicum, Maryland. Later, Arjang Assad prepared a "traveling version" of the gallery for display at the 2002 INFORMS Meeting in San Jose, California. Recently, Paul Gray has enhanced the gallery significantly to include all past presidents of ORSA, TIMS, and INFORMS.

M. W. Kirby. *Operational Research in War and Peace: The British Experience from the 1930s to 1970.* Imperial College Press, London, 2003.

The historian Maurice Kirby was funded by the UK Operational Research Society to write the history of operational research in the United Kingdom. Kirby relates the prehistory of OR in the

United Kingdom and then takes the reader to the founding of OR by British scientists in their development of radar and its evaluation and deployment prior to the start of WWII. He then details how OR was diffused during the war—its accomplishments on land, sea, and air—and how OR in the United Kingdom was first employed in industry, business, and the public sector.

C. Kittel. The nature and development of operations research. *Science* 105(2719): 150–153, 1947.

This is the first paper on OR published in the United States. Kittel, a noted solid-state physicist, was an analyst for the Antisubmarine Warfare Operations Group (ASWORG). In his article, he gave a concise statement of the origins of OR, described WWII OR, and presented his definition of OR: "Operations Research is a scientific method for providing executive departments with a *quantitative basis for decisions*" [Kittel 1947, p. 150 (italics in original)]. The British WWII analyst Charles Goodeve modified it and promulgated it in the United Kingdom. (See first definition box on p. 2.) Although Morse and Kimball (1951) began their unclassified version of *Methods of Operations Research* (see below) with Goodeve's modified version, it was basically ignored in the United States.

J. K. Lenstra, A. H. G. Rinnooy Kan, and A. Schrijver, eds. *History of Mathematical Programming: A Collection of Personal Reminiscences.* Elsevier Science, Amsterdam, 1991.

This important compilation is one of the first sources devoted to firsthand accounts of the development of mathematical programming by key contributors. The contributors include Michael Balinski, George Dantzig, Jack Edmonds, Ralph Gomory, as well as many others.

J. F. McCloskey. The beginnings of operations research: 1934–1941. *Operations Research* 35(1):143–152, 1987.
J. F. McCloskey. British operational research in World War II. *Operations Research* 35(3):453–470, 1987.
J. F. McCloskey. U.S. operations research in World War II. *Operations Research* 35(6):910–925, 1987.

The three articles by the OR historian Joseph McCloskey were commissioned by ORSA and TIMS. Part 1, published in the first issue of 1987, traces the scattered beginnings of OR research from WWI up to the activities of the British before and during the early months of WWII. It is interesting to find that Thomas Edison, as head of the U.S. Naval Consulting Board in WWI, "developed statistics to aid in evasion and destruction of submarines . . . and analyzed zigzagging as a method of protecting merchant shipping against submarines" [McCloskey 1987, pp. 143–144]. Part 2 gives an overview of British OR activities during WWII from the defense of Britain by its aircraft fighter command (Royal Air Force), its coastal command, and especially the development and deployment of antisubmarine tactics. The article also focuses on the bomber command activities over Germany and sums up the WWII OR activities in the UK Army and Royal Navy through the invasion of Europe. Part 3 describes the WWII U.S. military OR activities—the first OR group formed in the United States; the ASWORG under the direction of physicist Philip Morse; the very successful mining of the Japanese sea based on an OR analysis; and the first Army Air Force OR group assigned to the U.S. Eighth Bomber Command in England under the direction of the lawyer John Harlan, who would later be appointed to the Supreme Court by President Eisenhower.

J. F. McCloskey and F. N. Trefethen, eds. *Operations Research for Management.* Johns Hopkins University Press, Baltimore, 1954.

The first publication that covered the history of OR and the relationship between management and the operations researcher (authors include Charles Goodeve, Lawrence Henderson, and Ellis Johnson); the methods of OR including statistics, information theory, linear programming, queueing theory, suboptimization, symbolic logic, computers, game theory (authors include Russell Ackoff, David Blackwell, Walter Cushen, Joseph Harrison, Charles Hitch, and Philip Morse); and case histories including the famous studies of utilization of Negro manpower in the army (Alfred Hausrath) and operations research in agriculture (Charles Thornthwaite)—how Seabrook Farms changed its method of determining when to harvest peas by bouncing them off the fender of an automobile to a more systematic and accurate statistical analysis.

C. W. McArthur. *Operations Analysis in the U.S. Army Eighth Air Force in World War II.* American Mathematical Society, Providence, RI, 1990.

Charles McArthur was a bombardier in the Army's Eighth Air Force in WWII but had no knowledge or contact with the early OR group that was formed in the Eighth Air Force. After the

war, he became a mathematician, and his acquaintance with OR began when he found out that some of his teachers were wartime OR analysts. His aim in the book was to relate the wartime OR accomplishments of the many mathematicians and other scientists who served in the Eighth Air Force. One interesting story is how the statistician William (Jack) Youden convinced the Eighth Air Force to adopt a new bombing tactic. It was Jack who had proposed that instead of each bombardier releasing his aircraft's bombs independently of the others, that all aircraft release their bombs in a salvo based on the command of lead bombardier. The salvo strategy was against regulations and forbidden—no one knew why! This change resulted in at least a 1,000% increase of bombs on target.

H. J. Miser. The history, nature, and use of operations research. J. Moder and S. Elmaghraby, eds. *Handbook of Operations Research*, Vol. I. Van Nostrand Reinhold, New York, 1978.

This chapter provides a historical and institutional account of the field as seen by Hugh Miser. Although the chapter is tersely written and intended to be an overview, it remains interesting for two reasons. First, it was written by a prominent and forceful proponent of the need for capturing the history and traditions of OR. Second, through its organization, it nicely indicates the various components of a comprehensive history of OR and its development.

P. M. Morse. *In at the Beginnings: A Physicist's Life*. MIT Press, Cambridge, MA, 1977.

Although this book is an autobiography of Philip Morse, it is an important read for those who want to learn more about U.S. WWII OR activities (Morse was director of the first OR group in the United States, the ASWORG) and how, in 1952, Morse brought OR into the academic field by organizing MIT's Committee on Operations Research and then became the first director of MIT's interdepartmental Operations Research Center in 1955. Morse relates an interesting story on how he, based on work conducted by the ASWORG analyst Jacinto Steinhardt, found out that the Allies had broken the cryptographic code used by German submarines to send messages to their headquarters. Morse is recognized as the father of OR in the United States; he was the first president of ORSA.

P. M. Morse and G. E. Kimball. Methods of operations research (classified secret). Report, Operations Evaluation Group, Office of the Chief of Naval Operations, Washington, DC, 1946. (This report has been declassified.)

P. M. Morse and G. E. Kimball. *Methods of Operations Research*. John Wiley & Sons, New York, 1951. (Dover reprint, 2003.)

Philip Morse and George Kimball wrote the first methods of operations research book based on their WWII experiences solving problems for ASWORG; Kimball, a chemist from Columbia University, was Morse's deputy. The document, written soon after the war, was classified secret. Although we understand that a few copies were available unofficially, the material was officially unclassified in 1951 and published by MIT and Wiley. Although most of the chapters describe methodological aspects and their applications (and are a bit dated), the reader will find the first chapter, "Introduction" and last chapter, "Organizational and Procedural Problems," still of great value. Also, there is a chapter on "The Use of Measures of Effectiveness" that is probably the first of such material related to OR analysis. Note that the book does not mention queueing except for how to organize the number of wash tubs at a field mess station to decrease the waiting lines; also, of course, there is no mention of linear programming because it was developed after the war.

The Center of Naval Analysis (CNA) has made PDF copies of the original secret manuscript available for free at the website noted above.

E. P. Rau. The adoption of operations research in the United States during World War II. A. C. Hughes, and T. P. Hughes, eds. *Systems, Experts and Computers: The Systems Approach in Management and Engineering, World War II and After*. MIT Press, Cambridge, MA, 57–92, 2000.

This article by a historian of science and technology focuses on wartime OR in the United States. The article draws upon primary sources to give a detailed account of the Office of Scientific Research and Development (OSRD) and related groups.

C. R. Schrader. *History of Operations Research in the United States Army*, Vol. 1, 1942–1962. Office of the Deputy Under Secretary for the Army for Operations Research, U.S. Army, Washington, DC, 2006.

The Army historian, Charles Schrader, is responsible for three published volumes with the same title except for the years covered: Volume I covers 1942–1962 (WWII through the early years of the

Cold War), Volume II covers 1961–1972 (OR during the Vietnam War), and Volume III covers from the end of the Vietnam and Cold Wars to the First Persian Gulf War and the defense drawdown that followed. Volume I begins with a prologue on the classical and early modern antecedents of OR from Archimedes (the patron saint of OR), who invented a number of "military devices and techniques" (especially a new type of catapult, the Archimedes Claw, that could overturn ships), continues with the "scientific" analysis of the Napoleonic wars, and concludes with the early war-oriented OR of WWI.

K. R. Tidman. *The Operations Evaluation Group: A History of Naval Operations Research*. Naval Institute Press, Annapolis, MD, 1984.

In this volume, Keith Tidman covers the full history of U.S. Naval Operations Analysis. He traces the embryonic group of civilian scientists who, in 1942, tackled some of the early enemy submarine attacks soon after Pearl Harbor. Under the initial structure of the ASWORG, their work led to the formation of the Navy's Operations Evaluation Group (OEG) in April 1942. Today, the OEG is part of the CNA and is "the oldest military OR organization in the United States, and one of the oldest in the world" (p. 2). A key feature of OEG employment is that the OR analyst must spend time assigned to an active part of the Navy. Through its field program, OEG deploys analysts to operational commands around the world, and in times of crisis or conflict, dispatches additional analysts to support the military's operating forces (real-world on-the-job training!).

Part II: The Major Sites of Early U.S. OR Research

There are many ways to chronicle the development of OR. The book chapter by Miser (1978) cited above, through the organization of its sections, reminds us about the various aspects of what would amount to a comprehensive history of OR: in addition to covering the science and practice of OR, Miser devotes sections to trends, professional societies, journals, books, and education (which includes academic OR programs). In each of these areas, one could envisage a historical account of the field and its development.

Although a chronological approach is most widely used, a different perspective on the history of OR emerges if we think of the major research sites and the clusters of individuals located at such centers. The direct interactions of a center's researchers provided a significant impetus for the development of techniques and applications that fit the local OR research program and beyond. Here, we present an initial attempt at outlining this geographical approach to the development of OR in the United States.

Los Alamos National Laboratory, New Mexico

It may appear strange to mention this nuclear research laboratory as an OR site. But the idea and development of the field of simulation originated at Los Alamos (circa 1946). Soon afterward, a major unsolved problem in theoretical physics, which was the impetus that led to the need for simulation, was resolved by Monte Carlo simulation on the University of Pennsylvania's Moore School of Electrical Engineering computer, the ENIAC. The original Los Alamos mathematicians who led the way were Stanislaw Ulam and John von Neumann. The approach soon attracted the attention of others including Enrico Fermi, Nicholas Metropolis, and Robert Richtmyer. Metropolis named the method and was responsible for the ENIAC calculations. This story is told in the Gass and Assad "Tales from the time line: The definition of OR and the origins of Monte Carlo simulation" (see above), based on the following sources:

R. Eckhardt. S. Ulam, J. von Neumann, and the Monte Carlo method. N. G. Cooper, ed. *From Cardinals to Chaos: Reflections on the Life and Legacy of Stanislaw Ulam*. Cambridge University Press, New York, 131–137, 1989.

R. P. Feynman. Los Alamos from below. L. Badash, J. O. Hirschfelder, and H. P. Broida, eds. *Reminiscences of Los Alamos, 1943–1945*. Reidel, Dordrecht, The Netherlands, 124–128, 1980.

H. H. Goldstine. *The Computer: From Pascal to von Neumann*. Princeton University Press, Princeton, NJ, 1993.

N. Metropolis. The beginning of the Monte Carlo method. N. G. Cooper, ed. *From Cardinals to Chaos: Reflections on the Life and Legacy of Stanislaw Ulam*. Cambridge University Press, New York, 125–130, 1989.

N. Metropolis and E. C. Nelson. Early computing at Los Alamos. *Annals of the History of Computing* 4:348–357, 1982.

N. Metropolis and S. Ulam. The Monte Carlo method. *Journal of the American Statistical Association* 44(B):335–341, 1949.
S. M. Ulam and J. von Neumann. On the combination of stochastic and deterministic processes: preliminary report (abstract). *Bulletin of the American Mathematical Society* 53:1120, 1947.
J. von Neumann and R. D. Richtmyer. Statistical methods in neutron diffusion. Report LAMS-551, Los Alamos Scientific Laboratory Los Alamos, NM, 1947. [Reprinted in S. Ulam, A. R. Bednarek, and F. Ulam, eds. *Analogies Between Analogies: The Mathematical Reports of S. M. Ulam and His Los Alamos Collaborators.* University of California Press, Berkeley, 16–36, 1990.]

The Pentagon, Washington DC

Project SCOOP (Scientific Computation of Optimal Programs) grew out of the U.S. Air Force Pentagon-based research program formed in June 1947 and was officially designated as Project SCOOP in October 1948. Headed by the economist Marshall Wood, with George Dantzig as chief mathematician, the main objective of Project SCOOP was to plan the requirements for Air Force programs. At the core of Project SCOOP was the interpretation of an economy or organization based on Dantzig's mathematical statement of the LP model, which extended the Leontief input–output model of an economy. With keen foresight, Wood and Dantzig identified the promise of Project SCOOP:

> To compute programs rapidly with such a mathematical model, it is proposed that all necessary information and instructions be systematically classified and stored on magnetized tapes in the "memory" of a large scale digital electronic computer. It will then be possible, we believe, through the use of mathematical techniques now being developed to determine the program which will maximize the accomplishment of our objectives within those stated resource limitations. (Wood and Dantzig 1949, p. 17)

Historically, Project SCOOP marks two momentous developments. First, it is considered the birthplace of linear programming—Gass (2002) called it "the first linear-programming shoppe" (p. 63). Second, it was the locus of the first LP computer-based applications and the source of funds for other research organizations and their entry in LP research. Gass (1997) wrote, "All of us in OR are indebted to Project SCOOP. The linear-programming model, the simplex method, the first computer-based solution of LP problems, much of the theory of linear and mathematical programming, the basic computational theory of linear programming, and the extension of LP to industry and business all stemmed, wholly or in part, from the research and developments of Project SCOOP" (p. 246).

Project SCOOP involved a long list of researchers who went on to play major roles in OR and computer science. Apart from Dantzig and Wood, those who were directly involved in and/or supported by Project SCOOP in the Washington, DC area included Leon Gainen, Saul Gass, Murray Geisler, Leon Goldstein, Isidor Heller, Alan Hoffman, Julian Holley, Walter Jacobs, George O'Brien, Alex Orden, Thomas Saaty, Emil Schell, Philip Wolfe, and Max Woodbury.

In addition, various individuals based at other research institutions were affiliated with Project SCOOP through research connections or sponsored projects: Abraham Charnes and William Cooper at Carnegie Mellon University, and Albert Tucker, Harold Kuhn, and David Gale through Princeton University.

George Dantzig left the Pentagon in June 1952 for the RAND Corporation. By 1955, Project SCOOP was starting to wind down, but it had already made its mark on OR by assembling and supporting a remarkable network of researchers that extended beyond the Pentagon to the National Bureau of Standards, Princeton University, Carnegie Mellon University, and the RAND Corporation, among others.

S. I. Gass. Comments on the history of linear programming. *IEEE Annals of the History of Computing* 11(2):147–151, 1989.
S. I. Gass. In the beginning there was linear programming. *Interfaces* 20(4):128–132, 1990.
S. I. Gass. The Washington operations research connection: The rest of the story. *Socio-Economic Planning Sciences* 31(4):245–255, 1997.
S. I. Gass. The first linear-programming shoppe. *Operations Research* 50(1):61–68, 2002.
S. I. Gass. In memoriam: The life and times of the father of linear programming. *OR/MS Today* 32(4):40–48, 2005.
A. Orden. Solution of systems of linear inequalities on a digital computer. *Proceedings of the Association of Computing Machinery*, Pittsburgh, May 2, 1952.

M. Wood and G. Dantzig. Programming of interdependent activities, I, general discussion. *Econometrica* 17(3–4):193–199, 1949. [Also published in T. C. Koopmans, ed. *Activity Analysis of Production and Allocation.* John Wiley & Sons, New York, 15–18, 1950.]

Princeton University

Princeton University is the birthplace of modern game theory. It started with the pioneering and foundational work of von Neumann and Morgenstern, and the publication of their book, *Theory of Games and Economic Behavior* (1945, 2nd edition 1947). Soon afterward, under the sponsorship of the Office of Naval Research, Professor Albert W. Tucker and his graduate students, Harold Kuhn and David Gale, further developed game theory, clarified its relation to linear programming, underscored the common role of duality in both areas, and laid out the basic framework for nonlinear programming. Other key players at Princeton included Richard Bellman, Ralph Gomory, John Nash, Lloyd Shapley, and Martin Shubik.

The seminal incident that started all this is the now-famous 1947 Princeton meeting between George Dantzig and John von Neumann described in

G. B. Dantzig. Linear programming. *Operations Research* 50(1):42–47, 2002. [Originally appeared in *History of Mathemtical Programming*, 1991, cited above.]

Other recollections of the work at Princeton are given in the following sources:

H. W. Kuhn. Being in the right place at the right time. *Operations Research* 50(1):132–134, 2002.
M. Shubik. Game theory and operations research: Some musings 50 years after. *Operations Research* 50(1):192–196, 2002.

The RAND Corporation, Santa Monica, California

The RAND Corporation was established in March 1948 as an independent not-for-profit corporation "to further and promote scientific, educational, and charitable purposes, all for the public welfare and security of the U.S.A" (http://www.rand.org/about/history.html). It grew out of Project RAND, a research entity established in March 1946 as a freestanding division of the Douglas Aircraft Company of Santa Monica, California. Its initial funding came from General H. H. Arnold of the Army Air Force who allocated funds left over from his wartime research budget.

Under the leadership of such individuals as John Williams, who headed the mathematics division, RAND was able to attract some of the best minds in applied mathematics and OR in the 1950s. RAND also provided a perfect environment for introducing OR to new members. For example, Richard Bellman, who started his association with RAND in the summer of 1948, specifically mentions George Dantzig's algorithm for linear programming as his "first exposure to effective numerical solution, which subsequently became a central theme of my research" (Bellman 1984, p. 135). During the late 1940s and early 1950s, RAND's staff included George Brown, George Dantzig, Ray Fulkerson, Abe Girschick, Ted Harris, Harry Markowitz, Alec Mood, William Orchard-Hays, Lloyd Shapley, and Philip Wolfe. Its summer program and visiting engagements regularly attracted prominent researchers from across the country. These included Kenneth Arrow, David Blackwell, Samuel Karlin, Oskar Morgenstern, John Tukey, Herbert Simon, and Martin Shubik.

Another area of key importance at RAND was logistics. This effort was led by Murray Geisler who was recruited to RAND in 1953 from Project SCOOP. The staff of the RAND Logistics Department investigated cost-effective approaches to spare parts management and inventory control. An overview of this work and the growth of the logistics activities at RAND is given by Geisler (1986).

The following sources give interesting accounts of the history and development of RAND from 1948 to the late 1950s.

R. Bellman. *Eye of the Hurricane: An Autobiography.* World Scientific Publishing Company, Singapore, 1984.
V. Campbell. How RAND invented the postwar world. *Invention & Technology* (Summer): 50–59, 2004.
G. B. Dantzig. Murray Geisler obituary. *OR/MS Today* 12(5):5–6, 1985.
J. Digby. Operations research and systems analysis at RAND, 1948–1967. *OR/MS Today* 15(October):10–13, 1988.
S. Dreyfus. Richard Bellman on the birth of dynamic programming. *Operations Research* 50(1): 48–51, 2002.
M. A. Geisler. The simulation of a large-scale military activity. *Management Science* 5(4): 359–368, 1959.

M. A. Geisler. Logistics research and management science. *Management Science* 6(4):444–454, 1960.
M. A. Geisler. Appraisal of laboratory simulation experiences. *Management Science* 8(3): 239–245, 1962.
M. A. Geisler. *A Personal History of Logistics.* Logistics Management Institute, McLean, VA, 1986.
R. E. Levien. RAND, IIASA, and the conduct of systems analysis. A. C. Hughes and T. P. Hughes, eds. *Systems, Experts and Computers: The Systems Approach in Management and Engineering, World War II and After.* MIT Press, Cambridge, MA, 433–461, 2000.

MIT, Cambridge, Massachusetts

After WWII, a number of scientists returned to their academic homes and research programs. Some of the individuals who played an active role in military OR started to consider the application of OR to areas outside the military domain. MIT played a special role in this transition through the person of Philip M. Morse (see Morse 1977 above).

Upon his return to MIT, Morse focused on the establishment and growth of OR as an interdisciplinary team effort grounded in the use of science. In 1952, MIT agreed to the formation of the Committee on Operations Research to coordinate education and research in the subject, with Morse as its chairman. As interest in OR grew, a more formal cross-departmental Operations Research Committee (ORC) was formed, with Morse as its chair from 1956 to 1969. Through his contacts with the Office of Naval Research and the Army Research Office, Morse obtained two small research grants with which he initiated a number of research programs. He was able to give financial support to a diverse set of graduate students whose undergraduate degrees were in physics, mathematics, electrical, civil, and mechanical engineering. Other faculty involved in the ORC included Dean Arden and William Linvill (electrical engineering), George Wadsworth and Herbert Galliher (mathematics), David Durand and Robert Solow (economics), and Harvey Wagner, Ned Bowman, and Michael Gordon (Sloan School of Business). Later, under the direction of Morse, John D. C. Little wrote the first doctoral dissertation in OR.

Alongside the work at MIT, some of the first nonmilitary applications of OR were being carried out at the newly formed Operations Research Group at Arthur D. Little (ADL) led by Harry Wissman. MIT's Philip Morse and George Wadsworth were ADL consultants, and, later, they were joined by George Kimball from Columbia University. The group included John Magee, John Lathrop, Sherman Kingsbury, Martin Ernst, and David Boodman, among others.

H. Feshbach. Philip McCord Morse. *National Academy of Sciences* 65:243–255, 1994.
J. D. C. Little. Philip Morse and the beginnings. *Operations Research* 50(1):146–148, 2002.
J. D. C. Little. IFORS' operational research Hall of Fame: Philip McCord Morse. *International Transactions in Operational Research* 10(3):307–309, 2003.
J. F. Magee. Operations research at Arthur D. Little, Inc.: The early years. *Operations Research* 50(1):149–153, 2002.
P. M. Morse. The beginnings of operations research in the United States. *Operations Research* 34(1):10–17, 1986.
P. M. Morse. Letter to the Editor—George E. Kimball. *Operations Research* 16(4):872, 1968.
P. M. Morse. *In at the Beginnings: A Physicist's Life.* MIT Press, Cambridge, MA, 1977.

Carnegie Mellon University, Pittsburgh, Pennsylvania

In 1949, William Larimer Mellon, President of the Gulf Oil Company, gave the Carnegie Institute of Technology (Carnegie Tech) six million dollars to establish what became the Graduate School of Industrial Administration (GSIA). The first members of GSIA were Carnegie professors George Leland Bach, as dean of the GSIA, and Elliott Dunlap Smith. Earlier, in 1946, Bach had hired William (Bill) Cooper as an assistant professor in Carnegie Tech's economics department; he asked Cooper to join him at the GSIA. The fourth GSIA addition was Herbert Simon, Bach's undergraduate friend from the University of Chicago (Bach, Cooper, and Simon had all graduated from the University of Chicago). Carnegie Tech was joined with the Mellon Institute in 1967 to form the Carnegie Mellon University.

Cooper began his long collaboration with Abraham Charnes in 1949; Charnes had joined Carnegie Tech in 1948. This collaboration produced over 200 coauthored papers, book chapters, proceedings articles, and 12 books and monographs. Much of their early work was sponsored by the U.S. Air Force's Project SCOOP (see Cooper 2002)—which investigated the blending of aviation gasoline, goal programming, and chance-constrained programming. Cooper then became the leader of the OR faculty at the GSIA. He was able to attract both funding and problems from external sources, thus

creating one of the first sites where OR was applied to industrial problems (Gleeson and Schlossman 1992). Of importance was the famous paint factory project on which Holt, Modigliani, Muth, and Simon (1960) collaborated.

W. W. Cooper. Abraham Charnes and W. W. Cooper (et al.): A brief history of a long collaboration in developing industrial uses of linear programming. *Operations Research* 50(1):35–41, 2002.

W. W. Cooper. Memorial to Herbert A. Simon. M. Augier, and J. March, eds. *Models of a Man*. MIT Press, Cambridge, MA, 67–74, 2004.

H. Crowther-Heyck. *Herbert A. Simon: The Bounds of Reason in Modern America*. Johns Hopkins University Press, Baltimore, MD, 2005.

In addition to providing an account of Simon's career, this source is very useful in describing the institutional context at Carnegie-Mellon and its role in changing the nature of business education. The latter is also addressed in the next article.

R. Gleeson and S. Schlossman. The many faces of the new look: The University of Virginia, Carnegie Tech, and the reform of management education in the postwar era, part I. *Selections* (Winter) 9–27, (Spring) 1–24, 1992.

F. Glover and R. Sueyoshi. Contributions of Professor William C. Cooper in operations research and management science. *European Journal of Operational Research* 197:1–16, 2009.

C. C. Holt, F. Modigliani, J. F. Muth, and H. A. Simon. *Planning Production, Inventories, and Work Force*. Prentice-Hall, Englewood Cliffs, NJ, 1960.

J. Muth. Herbert Simon and production scheduling. M. Augier and J. March, eds. *Models of a Man*. MIT Press, Cambridge, MA, 377–380, 2004.

F. Phillips and L. Seiford. IFORS' Operational Research Hall of Fame: Abraham Charnes. *International Transactions in Operational Research* 13(3):273–277, 2006.

H. A. Simon. *Models of My Life*. Basic Books, New York, 1991.

Case Institute of Technology, Cleveland, Ohio

While still in its infancy as a professional field, OR found its first academic home at Case Institute of Technology. In 1951, West Churchman and Russ Ackoff moved to the Department of Engineering Administration at Case. In making this move, they wished to realize their vision of OR which was heavily imbued with their philosophical views of systems thinking. Together with Len Arnoff, whom they recruited from CalTech in 1953, Churchman and Ackoff established the path-breaking Operations Research Group (ORG) at Case. The three of them formed the basic cadre of the Case ORG.

The ORG was one of the first OR academic units in the United States, and Case was the first university to offer both masters and doctoral degrees in OR. Other faculty involved with the group included William Abendroth, Fred Hanssmann, and Michael Leyzorek, later to be joined by John D. C. Little, Patrick Rivett (as a visitor from the United Kingdom), and Glen Camp. Eli Naddor was their first Ph.D. graduate; Sid Hess (2002) graduated in the second wave.

In June 1952, the OR staff gave the first short (week-long) course in OR designed for "those in industry, business, and government who were interested in determining the potential value of OR to their own organizations" (Arnoff 1957, p. 290). The course was repeated each June. Out of the lecture material from this course grew the first textbook in OR: *Introduction to Operations Research* by Churchman et al. (1957). During the period 1951–1957, the Case OR program faculty grew from 6 to 30 (Arnoff 1957, Dean 1994). One of the important early features of OR, as taught at Case, was the emphasis on interactions with industry through short courses and team projects: the graduate programs placed special emphasis on "the experiential aspect of OR education" by providing the graduate students the opportunity to work as research assistants on sponsored research projects (Arnoff 1957, p. 290).

E. L. Arnoff. Operations research at Case Institute of Technology. *Operations Research* 5(2): 289–292, 1957.

B. Dean. West Churchman and operations research: Case Institute of Technology, 1951–1957. *Interfaces* 24(4):5–15, 1994.

S. Hess. I had never heard of OR. *OR/MS Today* 29(5):38, 2002.

W. Ulrich. In memory of C. West Churchman (1913–2004): Reminiscences, retrospectives, and reflections. *Journal of Operational Transformation and Social Change* 1(2–3):199–219, 2004.

Part III: The Best Stories from Contributors to Early OR

This part of the tutorial reviews the remarkable career paths of some OR pioneers and innovators with respect to their selecting OR as their main field of interest. In discussing these paths, we note the academic roots of the individuals (where they went to college and how they chose their initial field of study) and describe their early research work, the process of their finding a dissertation topic, and what attracted them to OR. In the case of most of the early contributors to the field, we found that some chance event put them on the path that led them to a most rewarding professional career in OR.

Part IV: Lessons Learned, or How History Informs OR Today

This final section of the tutorial focuses on the insights and takeaways from the work of several OR pioneers and innovators that continue to be relevant to the challenges OR faces in the 21st century. The collective wisdom of this group of contributors defines what OR is all about. At the same time, we have found views and opinions of the fundamental character of OR and its approach to problem solving. We review how the contributors' perspective on OR was influenced by their education and experiences as researchers and practitioners, what set them apart as leaders of an emerging discipline, and their own preferences as to how OR should develop as a field. We argue that the resulting cumulative historical lens continues to provide a useful background for some of the debates on the future of OR taking place today.

The OR Person's Collection of Early Important Books (by Year)

J. von Neumann and O. Morgenstern. *Theory of Games and Economic Behavior*, Princeton University Press, Princeton, NJ, 1947.

The seminal book that sets forth the modern axiomatic notion of utility, the basic concepts of games of strategy, and their application to economic and social theory. It is here that we first learn about utility and gambles, zero- and nonzero-sum games, mixed strategies, and two-person and n-person games. The book was originally published in 1944, but the revised 1947 edition (von Neumann and Morgenstern 1947) is considered the standard reference; it is here that the first statement of utility theory appeared.

W. Feller. *An Introduction to Probability Theory and Its Applications*, Vol. I. John Wiley & Sons, New York, 1950.

This basic reference helped introduce early OR researchers (and many students) to probabilistic concepts with applications to Markov chains, renewal theory, random walks, and stochastic processes.

T. C. Koopmans, ed. *Activity Analysis of Production and Allocation*. John Wiley & Sons, New York, 1951.

This is the proceedings of the June 20–24, 1949, Cowles Commission for Research in Economics conference held at the University of Chicago (also known as the 0th Mathematical Programming Symposium). It is noted for being the first general publication on linear programming and contains Dantzig's papers on the linear-programming model, the general and transportation simplex methods, linear programming and game theory, plus related papers by Arrow, Dorfman, Gale, Koopmans, Kuhn, Morgenstern, Samuelson, Simon, and Tucker, as well as Brown's fictitious play method for solving zero-sum two-person games.

J. McKinsey. *Introduction to the Theory of Games*. McGraw-Hill Book Company, New York, 1952.

This is the first textbook that covered the concepts of game theory as developed by von Neumann and Morgenstern, including a discussion of linear programming and its relationship to two-person zero-sum games.

A. Charnes, W. Cooper, and A. Henderson. *An Introduction to Linear Programming*. John Wiley & Sons, New York, 1953.

This was the first publication to give an extended discussion of the economic interpretation of linear programming (using the famous nut-mix problem), coupled with the basic mathematical

theory and explanation of the simplex method and duality. It also includes discussion of how to perturb a linear-programming problem that resolves the issue of degeneracy.

T. Whitin. *The Theory of Inventory Management.* Princeton University Press, Princeton, NJ, 1953.

Whitin presents an early compendium of basic inventory control methods, theory of the firm, and military applications. The second edition (1957) was expanded to include material published by Whitin and coauthors after 1953 that appeared in *Management Science*, *Journal of the Operations Research Society*, and *Naval Research Logistics Quarterly*, plus an article by Wagner and Whitin, "Dynamic Problems in the Theory of the Firm."

J. Williams. *The Compleat Strategyst.* McGraw-Hill Book Company, New York, 1954.

The Compleat Stretegyst is the first popular, nontechnical treatment of game theory. The book discusses a variety of two-person, zero-sum games including the birthday problem, whose solution states that if you are not sure if today is your spouse's birthday, bring home a present in any case.

S. Vajda. *The Theory of Games and Linear Programming.* Methuen & Co., London, 1956.

As an early book (the first of British origin), Vajda presents a systematic account of both game theory and linear programming, including duality and related solution procedures. Vajda, who is considered to be the prime force behind introducing linear programming to British practitioners and academics, followed up with (among others) the 1958 book *Readings in Linear Programming* (John Wiley & Sons), which discusses a wide variety of applications.

R. Bellman. *Dynamic Programming.* Princeton University Press, Princeton, NJ, 1957.

In this book the originator of dynamic programming presents his important approach to resolving multistage decision problems and the famous principle of optimality: "An optimal policy (set of decisions) has the property that, whatever the initial state and initial decision are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision" (p. 83).

R. D. Luce and H. Raiffa. *Games and Decisions: Introduction and Critical Survey.* John Wiley & Sons, New York, 1957.

This was the first book to integrate in a rather nonmathematical manner (no proofs) the concepts of von-Neumann–Morgenstern utility theory and game theory. It made these theories accessible, especially to OR practitioners, and helped set the future course of decision making under uncertainty.

C. Churchman, E. Arnoff, and R. Ackoff. *Introduction to Operations Research.* John Wiley & Sons, New York, 1957.

This was the first integrated text in OR written by three OR pioneers who were then associated with the Case Institute of Technology. Although written for the "prospective" consumer and "potential" practitioner, and without exercises, it served as a basic text for many years.

S. Gass. *Linear Programming: Methods and Applications.* McGraw-Hill Book Company, New York, 1958.

This was the first book on linear programming that was designed as a text. It grew out of an introductory course in linear programming given at the Graduate School of the U.S. Department of Agriculture in Washington, DC. The first and subsequent editions (5th in 1985) were translated into Russian, Spanish, Polish, Czechoslovakian, Japanese, and Greek, and were the first such books in their respective countries.

R. Dorfman, P. A. Samuelson, and R. Solow. *Linear Programming and Economic Analysis.* McGraw-Hill Book Company, New York, 1958.

This book was the first to emphasize and explain the economic aspects of linear programming. Included are discussions that relate linear programming to the analysis of the firm, duality, Leontief input–output systems, the theory of equilibrium, welfare economics, and game theory.

This book brought the power of linear programming and its application to business and industry and to the economic profession. Samuelson and Solow received the Nobel Prize in economics in 1970 and 1987, respectively.

P. M. Morse. *Queues, Inventory and Maintenance.* John Wiley & Sons, New York, 1958.

Written by a prime mover of OR in the United States, this expository book brought together for the first time key theoretical and applied aspects of queues. It was the first book published in the ORSA Publications in Operations Research series.

T. L. Saaty. *Mathematical Methods of Operations Research.* McGraw-Hill Book Company, New York, 1959.

This was the first graduate-level text that presented the basic mathematical aspects of OR as applied in optimization, linear programming, game theory, probability, statistics, and queueing, with applications and problems. It is noted for the chapter "Résumé of Queueing Theory."

J. G. Kemeny and J. L. Snell. *Finite Markov Chains.* Van Nostrand Company, Princeton, NJ, 1960.

The first English language presentation of finite Markov chains, this book, designed as an undergraduate text, describes applications to random walks, Leontief input–output models, and occupational mobility.

J. Forrester. *Industrial Dynamics.* MIT Press, Cambridge, MA, 1961.

The originator of the field that applies a differential equation model with feedback loops to the dynamic analysis of complex systems. The technique has been extended to *Urban Dynamics* (1969), for analyzing urban growth and decay, and *World Dynamics* (1971), for analyzing environmental and population issues.

F. Ford Jr. and D. Fulkerson. *Flows in Networks.* Princeton University Press, Princeton, NJ, 1962.

The first unified treatment of the subject, this seminal book by Ford and Fulkerson (1962) helped to establish network analysis and related results in graph and combinatorics as OR areas of research and application.

G. Dantzig. *Linear Programming and Extensions.* Princeton University Press, Princeton, NJ, 1963.

A major contribution, it is the full treatment of linear programming by the "father" of linear programming and the inventor of the simplex method. Written as a text, it has also served generations of OR analysts and students as a source book for both theory and applications. It includes most of Dantzig's theoretical and applied contributions to linear programming and their extensions up to that time.

A. Charnes and W. W. Cooper. *Management Models and Industrial Applications of Linear Programming*, Vols. I and II. John Wiley & Sons, New York, 1965.

This major work is both a text and collection of the many theoretical and applied advances developed by two of the pioneers in OR and linear programming. It is a source book for an untold number of OR researchers and graduate students.

F. Hillier and G. Lieberman. *Introduction to Operations Research.* Holden-Day, San Francisco, 1967.

This is a widely used introductory OR text. Aimed at junior and senior undergraduates and first-year graduates students, it was used by both business and engineering schools. Now in its ninth edition (2009, McGraw-Hill Book Co.), it is as popular as ever.

H. Wagner. *Principles of Operations Research.* Prentice-Hall, Inc., Englewood Cliffs, NJ, 1969.

Written as an undergraduate and graduate text for students in business, economics, engineering, liberal arts, and public administration, this book set a new standard for such texts in terms of its inclusiveness and clarity of writing. It received ORSA's Lanchester Prize for the best publication in the English language, as well as the AIIE Book Award. Its reduced-size companion book, *Principles of Management Science*, also served as a basic collegiate introductory text.