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Changes in Operations Research in the United States, 1945-1955

Although OR resists precise definition, it will be helpful at the outset to think of it as only the quantitative analysis of technical activities, such as military operations or business activities.

This paper moves (too) rapidly between various vignettes in the postwar history of OR, highlighting the tension at the pedagogical, professional and methodological levels between the informal methodology of wartime OR and the adoption of a set of useful but abstract new tools. The object is to expand these sections and add others to turn this into a dissertation chapter.

When World War II came to its end, the civilian members of the Navy's Operations Research Group (ORG, a descendant of the early war Anti-Submarine Warfare Operations Research Group, ASWORG) began to relax and reflect upon their accomplishments. Beginning in 1942, following the example of British scientists, they had become students of warfare, speaking with the lower ranks as well as commanders, gathering data from missions and applying basic mathematical tools and experimental instincts to make sense out of the chaos of battle and to recommend improvements. The leader of the ORG MIT physicist Philip Morse and his wartime colleague Columbia chemist George Kimball wrote a report on the group's activities entitled "Methods of Operations Research," which they completed in 1946. Chapter 2 of the report began with lessons in elementary statistics, and subsequent chapters contain illustrations of how these methods were applied to the various problems of warfare. Morse and Kimball wrote that they hoped scientists could apply their talents equally well to problems of peace, especially in industry, and they styled the report as an OR textbook with that goal in mind.[1] The first and last chapters in the report, however, contained a detailed exposition about the attitude OR workers needed to work effectively within a military environment, and the very last

[1] Philip M. Morse and George E. Kimball, 1946, Office of the Chief of Naval Operations, Operations Evaluation Group Report No. 54, "Methods of Operations Research". There was no British text that purported to teach how to do OR from basic statistics upward, though C. H. Waddington's *O.R. in World War 2*, which was also intended as a guidebook to the problems of U-boat warfare rather than as a history, *per se*, suffered a similar fate and was not published until 1973.

paragraph of the later published version points out that while a general scientific background and training in the operation being studied will be important in performing OR, "above all" an operations researcher must have "a personality that will permit him to talk successfully to all ranks, from the bottom to the top, as the measure of his achievement may depend on this basic ability to adapt himself to all grades of personnel."[2] If this was supposed to be an OR textbook, it was clear that OR was a fundamentally different science from physics and chemistry.

By the time Morse and Kimball's report was issued the Navy ORG had already become the Operations Evaluations Group (OEG). Morse, after a brief return to MIT, soon thereafter became first director of Brookhaven National Laboratory before moving on to head up the Department of Defense's Weapons Systems Evaluations Group (WSEG), only returning to the Physics Department at MIT full-time in 1950. Kimball, meanwhile, returned directly to the Chemistry Department at Columbia. A large number of other scientists had passed through groups directly associated with wartime OR. The Air Force retained its Operational Analysis Division, and the Army established the Operations Research Office (ORO) in partnership with Johns Hopkins University.[3] In addition to many wartime laboratories associated with the Office of Scientific Research and Development that had contact with scientists in OR groups, the MIT Rad Lab foremost among them, there were also a number of organizations employing scientists who studied the processes of warfare outside of the rubric of OR such as the Applied Mathematics Panel, directed by Warren Weaver, and Air Force Statistical Control, where the future Secretary of Defense Robert McNamara worked. These groups were later disbanded or folded into the peacetime military hierarchy with permanently staffed positions.

[2] Philip M. Morse and George E. Kimball, 1951, *Methods of Operations Research*, New York: The Technology Press of the Massachusetts Institute of Technology and John Wiley & Sons, Inc., p. 145. The OEG report contains this same passage on p. 144, but it is not the last word.
[3] The history of these organizations will be detailed in a forthcoming book by Erik Rau.

Even as OR made the transition to peacetime in the military, it began to make its way into academics and industry, largely on the backs of those who had done it or come into contact with it during the war. Before the war even ended, the Rad Lab's Edward L. Bowles recommended that MIT set up a course on "Methods and Problems in Operational Analysis," an idea that Morse heartily endorsed.[4] MIT held a meeting in 1947 to discuss setting up such a course, and it was offered for the first time the following year in the Mathematics Department as "M371-2: Operations Research" and was taught by George Wadsworth who had worked under Morse in the ORG and became project director at the OEG after the war, but had since returned to the Institute. The course description, first listed in the 1949-50 course catalog, is revealing in that it continued to portray OR as a rather *ad hoc* application of "scientific" methods to specific problems, transmitted only with difficulty to peacetime activity:

> Two term course designed for fourth year and graduate students who wish to become familiar with the operational methods developed particularly in the armed services during World War II. Both terms commencing with the development of the philosophy and the mathematical methods necessary for the applications which will follow. While as many uses as possible of this scientific method to industrial and business problems will be considered, many of the applications will necessarily have to come from military examples for which they were developed.[5]

The following year the line "Both terms commencing with the development of the philosophy and mathematical methods necessary for the applications which will follow" was omitted. It is difficult to say for certain what the "philosophical" methods of OR may have been, but I conjecture it may have been associated with the interpersonal relationships that Morse and Kimball believed were so crucial to OR practice.

Morse, meanwhile, had been working on a broader scale to establish OR as a professional field by writing articles and visiting various scientific societies. He noted in his autobiography:

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[4] Memorandum to Dr. Compton and Dean Harrison, J. R. Killian, Jr., Executive Vice President, re: acoustics program, 9/5/1944. MIT, Office of the President, 1930-1958 (Compton-Killian) (AC 4), Box 150. Institute Archives and Special Collections, MIT Libraries, Cambridge, Massachusetts.

[5] Massachusetts Institute of Technology Bulletin, Catalogue Issue (Cambridge, Massachusetts: MIT, 1949).

"Other O/R veterans also were working for the same ends. We managed to penetrate the sanctum of the National Academy of Sciences or, rather, of its operating subsidiary, the National Research Council (NRC)."[6] Horace Levinson, treasurer of Bamberger's and Macy's stores, and Arthur Brown of the OEG had persuaded Marsten Morse, chairman of the NRC Division of Mathematics (and a critic of the wartime Applied Mathematics Panel[7]), to form a Committee on Operations Research that, according to Morse, would write a report "that might impress the academic world."[8] In 1950 Levinson and Alan Waterman (who would become first director of the National Science Foundation in several months) brought the NRC's work to MIT to explore the possibility of establishing a research-oriented program to train OR scientists. It was an easy sell. The provost Julius Stratton wrote to Levinson that MIT was "indeed interested" and was willing to work with the NRC on developing a proposal.[9]

Philip Morse also returned to MIT in 1950 and took up the reigns in establishing the graduate program. Instead of founding an OR department, or, as some other institutions chose, creating an OR program within an engineering department, in 1952 MIT set up a Committee on Operations Research, chaired by Morse, that advised OR-oriented dissertations within an existing department. Although there was some talk about subsuming OR within the Sloan School of Industrial Management (also established in 1952), Morse resisted the suggestion, insisting that OR retain its close attachment to the sciences. He prided the program's flexible nature that allowed students to divide their time between departments. In early 1953, responding on behalf of MIT to a survey inquiring about university OR teaching, he listed a variety of

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[6] Philip M. Morse, *In at the Beginnings: A Physicist's Life* (Cambridge, Mass.: The MIT Press, 1977) p. 290.
[7] See Larry Owens, "Mathematicians at War: Warren Weaver and the Applied Mathematics Panel, 1942-1945," in *The History of Modern Mathematics*, ed. David E. Rowe and John McCleary (Boston: Academic Press, 1989).
[8] Morse, *Beginnings*, p. 290.
[9] Letter from J. A. Stratton, Provost, to Horace Levinson, 12/1/1950. The Papers of Philip McCord Morse (MC 75), Box 10. Institute Archives and Special Collections, MIT Libraries, Cambridge, Massachusetts.

courses appropriate for studies in OR: Machine Computation, Communication Theory, Social Psychology of Industry, Human Communication Networks, Group Organization, Econometrics, Technology of Industrial Control, and, of course, Probability and Statistics.[10] In 1955 the Committee on Operations Research became the Operations Research Center, with its own offices and administrative staff. The same year MIT awarded its first PhD in OR. The Wharton School of Business at the University of Pennsylvania, Johns Hopkins University, the Case Institute of Technology and the Naval Postgraduate School, meanwhile, had all initiated OR programs of various forms and sizes of their own.[11]

In 1949, as MIT was taking its first steps in developing its OR curriculum, Raymond Stevens, a vice-president of Cambridge, Massachusetts-based consulting firm, Arthur D. Little, had been convinced by some of the company's staff members who had done military work during the war that they should offer OR services to their clients. Stevens charged one of his staff members, Harry Wissman, with the task of gathering together an OR group for the company. Wissman brought in Arthur Brown, John Lathrop and Sherman Kingsbury from the OEG, recent Harvard Business School graduate John Magee (who would go on to become president of A. D. Little), as well as a number of younger physicists and engineers. George Kimball became a consultant to A. D. Little and later signed on full time. Morse and Wadsworth were also persuaded to become active consultants to their neighbor. The firm served as a key role as a point of first exposure for OR. For instance, their test project for their new OR group was analyzing the already well-studied problem of catalog shipping based upon customer mail order purchasing history at Sears, Roebuck & Co. The A. D. Little analysts were able to make

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[10] Response to ORSA Education Committee survey, filled out by Philip Morse, 1/5/1953. AC 4, Box 165.

[11] "Annual Meeting of the Society, Cleveland, Ohio, May 15-16, 1953," Report of the Education Committee, *Journal of the Operations Research Society of America* 1 (4) 1953, pp. 248-251; and Joseph F. McCloskey, "New Operations-Research Curriculum at the University of Pennsylvania," *Journal of the Operations Research Society of America* 1 (5) 1953, p. 305.

important progress with the problem and their OR services were retained for as long as Sears remained in the mail order business.[12] A. D. Little also aided their MIT neighbors in the establishment of an OR summer course catering to participants in industry and government that began in 1953 and continued for 15 years. According to Morse, the course created a "domino effect" wherein the participation of one aircraft company one year was followed by several aircraft companies the following year, followed by companies from oil and electronics.[13]

In 1952, meanwhile, 71 people met in Harriman, New York to establish the Operations Research Society of America (ORSA), the second OR association ever established (following the founding of the Operational Research Club in Britain, which later became the Operational Research Society). Thirty-four of the participants were actively employed by the military, seventeen were from universities (five from MIT alone), three were from A. D. Little, two were from the RAND Corporation, and the rest represented various private companies and research institutes. Seventy-five others were invited, but unable to attend, and the newly formed society held a list of some 700 names gathered by the NRC Committee. The meeting elected Morse as their first president and they began publishing their journal that same year. By 1955 ORSA could boast [approx. 1000?] members.[14]

In 1954, meanwhile, The Institute of Management Science (TIMS) was created as an explicit alternative to ORSA. The founders of TIMS wanted to create an organization less beholden to mathematics and military interests, more in tune with managers' concerns, and less hierarchical than ORSA, which divided its members into full and associate members. The

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[12] See John Magee, "Operations Research at Arthur D. Little: The Early Years," *Operations Research* 50 (1) 2002, pp. 149-153.

[13] Morse, *Beginnings*, p. 292; and E. C. Williams and P. M. Morse, "The History and Development of Operations Research," p. 9. Talk delivered [by Morse] at AIAA/ORSA Forum on Systems Analysis and Social Change, Washington, D. C., 3/18/1968. MC 75, Box 27.

[14] Data taken from "Members Attending the Founding Meeting," *Journal of the Operations Research Society of America* 1 (1) 1952, pp. 26-27; see also Thornton Page, "The Founding Meeting of the Society," *Journal of the Operations Research Society of America* 1 (1) pp. 18-25.

Hungarian mathematician Andrew Vazsonyi, who was elected TIMS' first past president (a post mandated by the institute's constitution), later remarked:

> ORSA was dominated by the Phil Morse and George Kimball crowd, people who were always talking about the things they did for the military during World War II. Many of us thought that ORSA needed another approach, something oriented toward management, but we didn't think we could get the Morse crowd to change. It turns out we were right.[15]

At the same time, Morse himself was concerned about the increasing dominance of mathematical theory within the field of OR. In one 1955 speech, while praising theoretical accomplishments, he warned that "the development of experimental techniques seems to be almost totally neglected." He explained:

> Operations research is an experimental science, concerned with the real world. It is not an exercise in pure logic…. Those of us who carried on operations research during the war should know this. We soon found that theoretical predictions of weapons effectiveness, based on laboratory measurements, very seldom gave the right result. We had to find out what happened when the new weapon got in the hands of the troops, not what it did when run by Ph.D in a laboratory.[16]

Morse's pedagogical program was designed to allow students to draw on a diverse array of resources to apply to real problems with real managers. OR for Morse was never meant to be the accumulation of mathematical theories; they were only a means to the proper application of a more general scientific approach to studying human activity.

Nevertheless, the continuing evolution of George Wadsworth's OR course's catalog description bears witness to the increasing role of independent theory in OR practice. In 1956 it was changed to:

> Development of the concepts of probability and mathematical models in physical, industrial and laboratory situations as the scientific approach to small and large-scale operations. Basic problems involving probability; also inverse probability, geometrical probability, distribution theory, and the construction of mathematical models, game theory, linear programming, time series and prediction theory, and stochastic processes.[17]

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[15] See Peter R. Horner, "TIMS Turns 40," *OR/MS Today*, 20 (2) 1993, pp. 40-43; quoted in Peter R. Horner, "History in the Making," *OR/MS Today*, 29 (5), 2002, available online at: <http://lionhrtpub.com/orms/orms-10-02/frhistory.html>.

[16] Philip M. Morse, "Where is the New Blood?" *Journal of the Operations Research Society of America*, 1955, *3*: 383-398, quote on pp. 384-5.

[17] MIT Bulletin, Catalogue Issue (Cambridge, Massachusetts, MIT, 1956).

The war had been left behind. While the war had lasted, mathematical sophistication was extremely rare within OR groups, which usually did not find a need for it under the pressing conditions. Even though the application of probability theory, still prominent in the 1956 description, was central to the war aims, only a few novel techniques came to the forefront during that time. John von Neumann and Oskar Morgenstern's theory of games, published in 1944, did find its way into Morse and Kimball's report in the special context of whether or not it would be worthwhile to institute a countermeasure to an enemy measure, thereby tipping the enemy off that their measure had been identified.[18] However, game theory did not become prominent within OR (and Management Science—TIMS was an active publisher of articles on game theory) until it was brought in with the mathematically-related linear programming in the early 1950s.

The history of linear programming provides an excellent example of the avenues and tensions involved in the incorporation of a novel mathematical technique into the OR canon. Linear programming refers to the selection of a "program" of actions defined by a series of linear equations and inequalities, the coefficients of which are determined by a specified schedule. For a simple example, a schedule of shipping prices between a number of factories and a number of warehouses would define a problem wherein a variable number of units could be shipped from each factory to each warehouse to fulfill the warehouse's inventory requirements. The object is then to program a specific number of units from each factory to each warehouse while minimizing cost. In 1947 the Air Force set up Project SCOOP (Scientific Computation of Optimum Programs) to improve its programming methods. It was here that the mathematician George Dantzig, who had worked for Air Force Statistical Control during the war, formulated the

[18] Morse and Kimball, 1946, pp. 102-109.

problem axiomatically. In search of a solution Dantzig first went to the Cowles Commission at the University of Chicago where he met the economist Tjalling Koopmans[19] who had worked for the British Merchant Shipping Mission during the war and, as we shall see, became very interested in the problem and organized an influential conference on linear programming in 1949. In the meantime, though, since the economists at Cowles could not provide an answer, Dantzig went back to work on it himself and soon developed the simplex algorithm, which has proved to be an enduring approach to the problem. Soon thereafter Dantzig presented his formulation of linear programming to John von Neumann who immediately saw the fundamental connection with the theory of games.[20]

The importance of linear programming and the simplex method in certain managerial situations involving well-defined parameters is clear. There can be no question that Dantzig's contributions were of great and uncontroversial value to OR practitioners and soon became one of the new profession's most important methods. Problems involving nonlinear parameters and parameters that changed over time prompted the growth of nonlinear programming and dynamic programming as areas of research in their own right. Linear programming also offered a promising inroad to problems with inexact parameters, but in such cases application took a much more subjective character. Dantzig was well aware of the problem, noting in his first book on the subject that most situations in real-life were not clearly defined. He suggested:

> In some applications it may be necessary to give considerable thought to the differences between reality and its representation as a mathematical model to be sure that the differences are reasonably small and to assure ourselves that the computational results will be operationally useful.[21]

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[19] Koopmans had come to economics from physics, which he had studied under Hans Kramers at Utrecht and Leiden.
[20] The history of Dantzig and linear programming is assembled from George B. Dantzig, *Linear Programming and Extensions* (Princeton: Princeton University Press, 1963) pp. 12-29; George B. Dantzig, "Reminiscences about the Origins of Linear Programming," *Operations Research Letters* 1 (2) 1982, 43-48; and "George B. Dantzig," *More Mathematical People: Contemporary Conversations*, eds. Donald J. Albers, Gerald L. Alexanderson, Constance Reid; (San Diego: Academic Press, 1990) pp. 61-79.
[21] Dantzig, *Linear Programming*, p. 7.

Dantzig argued that, as in all sciences, there was no definably proper way to apply a model to any given situation. He left that issue up to practitioners, noting that the adequacy of a model was frequently a matter of disagreement, and offered his text as an approach to "deterministic" programming problems.

Meanwhile, linear programming had proved a boon to the Cowles Commission in their work on updating Walrasian neoclassical economic theory, a task that was extremely distant from deterministic programming problems. In the late 19th century the French economist Leon Walras argued that markets should be analyzed not as the product of direct communication between buyers and sellers, but as an "auction" of goods and services wherein each step of the auction would be represented by a list of prices. New lists were created by an evaluation of unsold goods and services under the previous list, a process known as tatonnement. When tatonnement ceased the auction came to an end and the market was considered to have reached equilibrium. Tjalling Koopmans, among other economists, saw linear programming as a sort of short cut to equilibrium past the relatively blind process of tatonnement [this is probably an oversimplistic characterization].[22] Koopmans and his Cowles colleagues' work following the war were later awarded several Nobel Prizes. That Dantzig did not share Koopmans' own prize (which he won in 1975 with Leonid Kantorovich) was a matter of some controversy and a disappointment to Koopmans himself.[23]

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[22] For a detailed (and opinionated) history of the adoption of linear programming into economics see Philip Mirowski, *Machine Dreams: Economics Becomes a Cyborg Science* (New York: Cambridge University Press, 2002) esp. Ch. 5. Mirowski has decried the developments of neoclassical economics at the Cowles Commission as an OR-mediated invasion of command and control "cyborgs" into economics. At the outset, economics had access to linear programming before OR, but aside from this problem of defining linear programming mathematics as OR, I believe further research will help elucidate reveal a more complicated relationship between OR and economics drawing on the tensions between OR application and the continued development of OR theory that we have been examining here.

[23] See M. L. Balinski, "Mathematical programming: Journal, society, recollections," in *History of Mathematical Programming*, eds. J. K. Lenstra, A. H. G. Rinnooy Kan, A. Schrijver; (New York: North-Holland, 1991) pp. 5-18.

The adoption of linear programming in OR was closely related to its adoption in economics. Koopmans himself joined ORSA in 1954 after the Cowles Commission had already moved to Yale University. Dantzig, who had gone to work for the RAND Corporation in John Williams' Mathematics Department in 1952, became a fellow in ORSA in 1955, though he had been an active participant in the foundation of TIMS a year earlier and he published much of his work in *Management Science*. As much as A. D. Little and MIT were forging new paths into industry with their summer program, mathematics was binding OR and economics together elsewhere. Theory and practice were both evolving rapidly as OR began to establish itself in the postwar world. [The more concrete establishment of OR will become the basis for a subsequent section why Jay Forrester's work on system dynamics, beginning in the late 1950s developed so independently. Much of the above history remains to be worked out more precisely, though.]