HOW REASON ALMOST LOST ITS MIND: THE STRANGE CAREER OF COLD WAR RATIONALITY

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FORTHCOMING FROM UNIVERSITY OF CHICAGO PRESS

The authors are highly indebted to the Max Planck Institute for the History of Science, Berlin (MPIWG) for the institute's hospitality and support and to Josephine Fenger, who heroically rounded up the images, sought permissions, and compiled the bibliography. Thomas Sturm's and Judy Klein's participation was supported in part by, respectively, the Spanish Ministry for Science and Innovation (MICINN) (Reference number FFI 2008-01559/FISO) and the Institute for New Economic Thinking (INET) (Grant Number IN011-00054)

Chapter Two

The Bounded Rationality of Cold War Operations Research

Frankfurt/Rhein-Main US Air Force base 1948: On his seventieth day on the LeMay Coal and Feed Run, Lieutenant Fred V. McAfee, a self-described flour and dehydrated potatoes man who "was not above hauling macaroni," iterated his very regular life:

> They briefed me on the basic pattern to follow and I've done it so many times since, I could repeat their lecture. I was assigned a 6,500-foot altitude. I had ten tons of flour, used 2700 rpm and forty-five inches of manifold until I broke ground and then I throttled back to 2500 rpm and forty inches. At 500 feet I dropped her back again, this time to 2300 rpm and thirty-four inches. I climbed on a course of 180 degrees for seven minutes, at an indicated speed of 160 miles an hour, leveled off at my assigned altitude, where my power settings were reduced still again to 2050 rpm and twenty-nine inches. My indicated air speed was 170 miles an hour. I'd picked up Darmstadt beacon. Presently it was Aschaffenburg, then Fulda's range and presently I was in the corridor [see **Figure 2.1** for the radio beacons that guided planes to the air corridors]. I let down over Tempelhof at 170 miles an hour, pushed her in and watched them unload.

> Then back here. Then Berlin. And so it’s been for seventy days. A very regular life.[1]

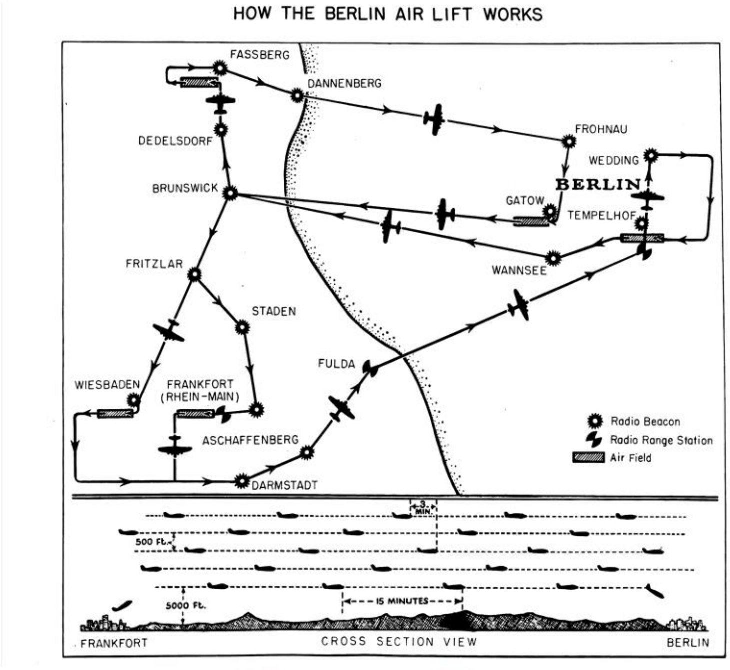

Figure 2.1 Plan for the Berlin airlift highlighting the British and American bases that the planes took off from, the radio beacons in the western zones, the boundary line with the Russian zone of eastern Germany, the three air corridors through that zone, and the Gatow and Tempelhof airports in the British and American sectors of Berlin, respectively. Flying at a designated altitude enabled planes to land every three minutes at Tempelhof
Source: New York Times Paris Bureau, US National Archives, RG 342-G, Box 25

The regularity of McAfee’s life was a product of an assembly-line style of scientific management that the US Air Force used in Operation Vittles to get essential supplies to the blockaded zones of western Berlin in 1948 and 1949. The management methods used at the USAF air bases for the logistics of the airbridge harked back to the early twentieth-century time studies of Frederick Winslow Taylor and motion studies of Frank and Lillian Gilbreth. At the Air Force headquarters at the Pentagon, however, a group of applied mathematicians in the Project for the Scientific Computation of

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[1] Lt. Fred McAfee quoted in Paul Fisher, “The Berlin Airlift,” *The Beehive, United Aircraft Corporation* 23 (1948): 14-15.

Optimum Programs (Project SCOOP) was using the Berlin airlift to create a new science of managing. The mandate of Project SCOOP was to mechanize the planning process by constructing computable algorithms that could determine the *best* time-staged deployment of personnel and materials for a military operation such as the Berlin airlift. With the aid of mathematics and electronic digital computers, the Project SCOOP team hoped to achieve through centralized planning the optimal combination of resource items and production activities that a decentralized, competitive market structure would have achieved. The ingenious design of an algorithm for deriving economically rational decisions from an equation system that included an objective function maximizing, for example, the tonnage delivered to Berlin and a matrix quantifying the interdependency of inputs and outputs was, however, years ahead of the electronic digital computing capacity necessary to implement the algorithm. As we will see, with their punched card calculators in 1948 the only *optimal* program that Project SCOOP could determine was for the least cost diet that could provide the essential nutritional needs of an active, urban economist weighing 70 kilograms; Operation Vittles had to be planned with sub-optimal protocols.

Scarce computing capacity limiting the scope of the optimizing mathematics became a dominant trope in subsequent Cold War US military-funded research, including the production planning for Project SCOOP and Office of Naval Research done by Herbert Simon and his economist colleagues at the Carnegie Institute in the 1950s. The Carnegie research team had to adapt their maximizing models so that the solutions could be obtained with existing, limited computational resources. Intrigued by how that practical limitation shaped theoretical developments, Simon conceived of a framework of “bounded rationality” and called for the development of descriptive models of rational behavior based on “satisficing” (making do with reasonable aspiration levels) rather than “maximizing.” For Simon, the economists’ narrow focus on rationality as a quality of the choice outcome had to be broadened to include the “procedural rationality” that was a quality of the decision process and sensitive to the costs of searching and computing. Thus while holding out the promise of an optimal allocation of resources in the absence of any market, the mathematical programming protocols that Project SCOOP initiated also nurtured Nobel Prize-winning musings on bounded rationality. But first back to Berlin.

2.1 Operation Vittles

The shattered, occupied, and zoned city of Berlin was a major, if not the key, battleground for the Cold War. There were no hot war battles between the two superpowers in Berlin, but it was a significant setting for their brinkmanship, crises, and settlements. In 1944, a year before the end of World War II, allied powers in the European Advisory Commission determined the post-war zones in Germany and Berlin that would be occupied by the Soviet Union, the United States of America, and Britain. The Yalta conference in 1945 accorded France sectors carved out from the planned US and British jurisdictions. Berlin was surrounded by the land intended for Soviet occupation, but the Commission established the traffic routes by which American, British, and French garrisons in the respective Berlin sectors could be supplied: a twenty-mile wide air space for each of three air corridors, a railway line from Helmstedt, and a highway from Marienborn. After Germany’s surrender on May 8, 1945, the zoned occupation proceeded according to plan.

In the spring of 1948, the American, British, and French occupying forces took steps toward a more unified and autonomous western Germany, including issuing new currency for their combined zones in western Germany. The Soviet Union, worried about the potential for a separate, powerful German state, responded with increased restrictions on travel to Berlin and insisted that the currency of the Soviet zone be the sole currency for Berlin. On the 23rd of June the western allies announced their plan for a new *Deutsche Mark* in the French, British, and American-occupied zones of Berlin. That same day, the Soviet authorities issued the East German Mark (also called the *Deutsche Mark*, colloquially referred to as the *Ostmark*) with the intention of it being the currency for all of Berlin. The Soviet occupying forces began a complete blockade of road, rail, and river traffic to and from the American, British, and French sectors of Berlin and cut off key sources of electrical power to those sectors.

Britain, France and the US were faced with the choice of withdrawing from Berlin or remaining at a high cost. The US government decided "to remain in Berlin, to utilize to the utmost the present propaganda advantage of our position to supply the city by air and, if the restrictions continued, to protest to the Soviets and keep the Berlin situation before World attention."[2] On Sunday June 26, 1948 the Berlin airbridge (*Luftbrücke*) began with the USAF Operation Vittles and the British Operation Plane Fare. The American and British airlifts were ultimately successful in getting sufficient supplies to the western zones of Berlin for the 2.5 million people who lived there.[3] On May 12, 1949 the Soviet

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[2] The Berlin Crisis, 1948. US Department of State, Foreign Policy Studies Branch, Division of Historical Policy Research, Research Project No. 171.Washington, DC, 5.

[3] The French also had a few planes helping out, but US and British planes carried most of the material for the French zone. At one point there was a dispute between the American air crews and the French when the former balked at hauling wine in. The outraged French "sent a delegation armed with their dietary history

Union lifted the road blockade in exchange for an agreement to a meeting of the respective four foreign ministers. In order to build up a cushion for possible future stoppages, Operation Vittles continued until the last official flight on September, 30 1949. For most of that time, Major General William H. Tunner, initially serving under General Curtis LeMay, the commander of the USAF in Europe, was the commanding officer for Operations Vittles Operation Vittles. [4]

Tunner and his staff measured, evaluated, and dictated the procedures for loading, flying, and unloading aircraft. They used physical models of the layouts of the airspace altitudes and airfield facilities to study bottlenecks and simulate improved operations (see **Figure 2.2)**. Tunner's philosophy was that achieving a "precise rhythmical cadence…constant as the jungle drums" determined the success of an airlift; after analyzing the data he insisted on only a three-minute interval between take-offs because it provided "the ideal cadence of operations with the control equipment available."[5] The boring regularity of Lieutenant McAfee's piloting days on the LeMay Coal and Feed Run was exactly as planned. (see **Figure 2.3**)

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through all times. Their chief contention was that wine was to them equally as important as potatoes to a German, black bread to a Russian, or ketchup to a Texan." (Fisher, "Berlin Airlift," 9).

[4] William H., Tunner, *Over the Hump*, (1964; repr., Washington: Office of Air Force History United States Air Force, 1985), 167. Tunner, a 1928 graduate of the US Military Academy at West Point, had during World War II successfully commanded *The Hump* operation that airlifted supplies from India over the Himalayas for the fighting in China. Tunner described his Asian, Berlin, and subsequent Korean airlift experiences in his *Over the Hump* memoirs.

[5] Tunner, *Over the Hump,* 174.

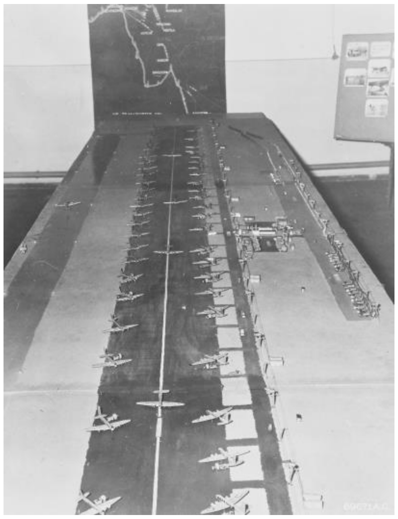

Figure 2.2 The plotting board of the airlift terminal at the British base at Fassberg Germany, “helps loading officers to study new methods of operations before putting them to work on a large scale. The models, which may be moved to test loading plans, include U.S. Air force C-54s, British trucks, and German trains and track sidings. Although an RAF base, all Berlin-bound cargo is flown from Fassberg in U.S. Air Force planes.”
Source: US Air Force, US National Archives, RG 342- G, Box 25

Figure 2.3 Unloading planes at Tempelhof, 28 October 1948
Source: New York Times Paris Bureau, National Archives, RG 306-PS, Box 85

Before Tunner had taken over in late July 1948, the Air Force had assigned minimum amounts of cargo to be delivered. On October 14, 1948, the day before he left to assume his iconic Cold War role as Chief of the Strategic Air Command, General Le

May signed an agreement with the British Air Forces of Occupation for a merger of their operations under Tunner's command with the primary mission being the delivery to Berlin, "in a safe and efficient manner, the maximum tonnage possible, consistent with combined resources of equipment and personnel available."[6]

The switch from the goal of minimum quotas by aircraft to maximum tonnage by operation, the precisely managed cadence, Tunner's leveraging of data analysis, and his encouragement of tonnage competitions between squadrons (see Figure 2.4) ensured that Operation Vittles brought 2.3 million tons of food to West Berlin via 277,500 flights.

Figure 2.4 To increase competition for maximizing tonnage delivered to Berlin, Tunner ordered the publicity at every airfield of daily output by squadron. The undated USAF photograph is the HOWGOZIT board at Fassberg RAF Station. ,
Source: US National Archives, RG 342- G, Box 25

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[6] Tunner, *Over the Hump,* 187.

At the peak of the airlift, planes were landing in the western zones of Berlin at a rate of one every sixty-two seconds. Tunner's scientific management, however, was limited to the careful analysis and improvement of single-purpose operations with given personnel and equipment. The maximums that Tunner strove for were what mathematicians would describe as "local" ones, and his staff's capacity for weighing alternatives was extremely limited.

The high cost of Operation Vittles, (comprising 14% of the entire USAF budget) came at a time when the US government was under considerable pressure to cut military budgets and steer resources to a still recovering peacetime economy. Operation Vittles validated the Air Force Comptroller's plan initiated in 1947 to increase the cost-effectiveness of Air Force operations through the mechanization of the planning process. The US military had long standing procedures for what they referred to as "programming" military operations.[7] Planners in the Pentagon headquarters would use rules of thumb, judgment based on experience, and arbitrary decisions to construct a time-phased schedule of activities and of quantities of material and personnel necessary to meet the strategic goals for a planned operation. The new approach envisioned by the Comptroller's office was to use mathematical protocols and eventually electronic digital computers to determine the *best* combination of activities and logistical schedule for an operation and construct a flexible procedure capable of easy recalculation of a new optimal schedule of action in response to changes in goals or resources. With this

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[7] The term "programming" in the "linear programming" and "dynamic programming" frameworks developed in the late 1940s draws from the traditional military use of the term as a time-phased scheduling of operations. Although the USAF Project SCOOP team designed algorithms to solve mathematical programming models with digital computers, they used the term "coding", not programming, to describe the writing of machine instructions for the computer.

research, management science in the Air Force and subsequently in US industry went from the time and motion studies for improving singular output with given inputs to the computer-enhanced optimal allocation of alternative inputs to alternative outputs.[8]

2.2 Project SCOOP

In World War II, Captain Charles "Tex" Thornton created the US Army Air Force Statistical Control unit to improve budget control and planning by using statistical information for management decisions and operations control. The Statistical Control group employed, among others, George Dantzig,[9] Robert McNamara, and Harvard

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[8] This history uses the terms "management science" and "operations research" interchangeably, but also acknowledges that in the early 1950's, some of the protagonists in our story elected to distinguish the two through separate professional organizations. Operations research emerged from the quantitative decision making in World War II brought to bear on the planning of specific military operations or the evaluation of alternative weapons systems. Phillip Morse and other World War II military operation researchers founded the Operations Research Society of America (ORSA) in 1952. Merrill Flood (whom we encountered in the previous chapter and will return to in chapter 5), as well as William Cooper, and Abraham Charnes from the Carnegie Institute, were key organizers of The Institute of Management Sciences (TIMS), founded in 1953; Project SCOOP's chief mathematician, George Dantzig, was a founding member of TIMS and his SCOOP colleague Murray Geisler served as 8th President. In the early 1950s ORSA had a stronger association with the military and concrete problem-orientated applications, and TIMS with the identification of basic research relevant to the practice of management. A common analogy of the distinction between operations research and management science was that of chemical engineering and chemistry respectively. Even in the early years, however, there was some overlap in membership, executive officers, and professional journal topics. Also the US military underwrote a considerable amount of the research that was published in both professional journals. ORSA and TIMS began sponsoring joint meetings in 1974 and formally merged in the Institute of Operations Research and Management Science (INFORMS) in 1995. The early history of two organizations is documented in Saul Gass and Arjang Assad, *Annotated Timeline of Operations Research* (New York 2005) and Gerald William Thomas, *A Veteran Science: Operations Research and Anglo-American Scientific Cultures, 1940-1960* (Harvard University PhD thesis 2007). Merrill M. Flood, "The Objectives of TIMS," *Management Science* 2 (1956): 178-184, p. 179 and Melvin Salvesen, "The Institute of Management Sciences: A Prehistory and Commentary on the Occasion of TIMS' 40th Anniversary, *Interfaces*, Vol. 27, No. 3 (May - Jun., 1997), pp. 74-85 also shed light on the ORSA/TIMS distinctions.

[9] George Dantzig (1914-2005) received his PhD in Mathematics in 1946 from the University of Berkeley after working as a statistician first at the Bureau of Labor Statistics (1938-1939) and then at the Pentagon (1941-1946). Dantzig's solution to two unproven theorems in statistics, which he mistakenly assumed were homework assignments from his professor Jerzy Neyman, formed part of the story-line in the film *Good Will Hunting*. Dantzig was a founding member of the Institute of Management Science (TIMS), its president in 1966, the first recipient in 1974 of the von Neumann

business professor Edmund Learned. According to Dantzig's historical account, Learned developed what the group called "a program for programming"- a generic time-phased schema that would connect the scheduling of many command agencies in any detailed operation (such as that pictured in **Figure 2.5**). [10] In Learned's World War II schema, improvements in reducing the time it took to develop a new program for a major military operation emerged from the ordering of some 46 major sequential steps for a unidirectional information flow that was compatible with the temporal flows within the hierarchical bureaucratic structure of the USAF.

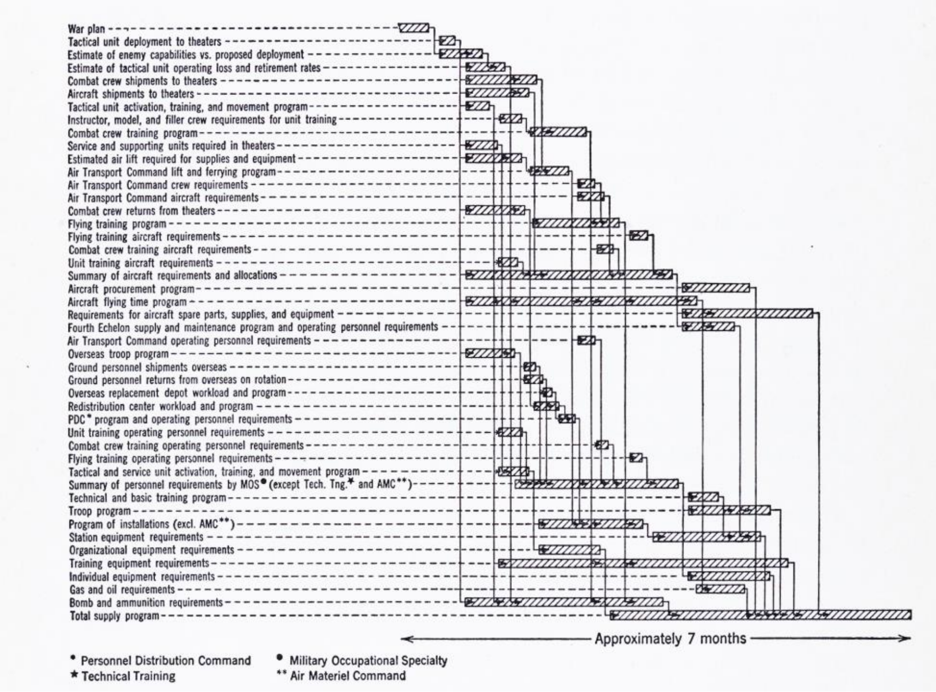

Figure2.5 Schematic diagram of major steps in Air Force wartime program scheduling before Project SCOOP.
Source: Marshall K. Wood and Murray A. Geisler, "Development of Dynamic Models for Program Planning," *Activity Analysis of Production and Allocation: Proceedings of a Conference,* edited by Tjalling C. Koopmans (New York: John Wiley & Sons, 1951), 191.

Theory Prize awarded jointly by the Operations Research Society of America and TIMS, and a recipient of the US National Medal of Science.

[10] George B. Dantzig, "Concepts and Origins of Linear Programming,"RAND P-980 (1957).

Despite the care the Statistical Control group took in constructing the scheme, they estimated that after World War II it would take seven months to complete the process of detailed programming for a major new operation—too long in the nuclear era. Also Learned's schema could not solve the *economic* problem of planning because it did not take into consideration *alternative* uses of resources to determine the most cost-effective way to achieve an operational goal.

Under the 1947 plan to separate the Army Air Forces from the Army and constitute it as an autonomous branch of military service, the office of the Deputy Chief of Staff/ Comptroller General E. W. Rawlings took charge of program planning, statistical control, and budgetary functions. In June 1947, Rawlings formed a group in the Planning Research Division of the Directorate of Management Analysis at the Pentagon to mechanize program planning for the Air Force by developing decision-making protocols that could realize the future potential of electronic digital computers. That initial group included George Dantzig (Chief Mathematician), Marshall Wood (Chief Economist and Head of the Planning Research Division), and Murray Geisler (Head of the Division's Standard Evaluation Branch); others joined the effort soon after. On October 13, 1948, General Hoyt Vandenberg, the USAF Chief of Staff, conveyed to the entire Air Force the order of the Secretary of the Air Force that defined the "scope and character" of the newly-named Project for the Scientific Computation of Optimum Programs:

> a. The primary objective of Project SCOOP is the development of an advanced design for an integrated and comprehensive system for the planning and control of all Air Force activities.

> b. The recent development of high speed digital electronic computers presages an extensive application of mathematics to large-scale management of problems of the quantitative type. Project SCOOP is designed to prepare the Air Force to take maximum advantage of these developments.
>
> c. The basic principle of SCOOP is the simulation of Air Force operations by large sets of simultaneous equations. These systems of equations are designated as “mathematical models” of operations. To develop these models it will be necessary to determine in advance the structure of the relationships between each activity and every other activity. It will also be necessary to specify quantitatively the coefficients which enter into all of these relationships. For this purpose the structure will need to be analyzed and the factors evaluated with much greater precision and thoroughness than has ever before been attempted in Air Force program planning.
>
> d. Important advantages for the Air Force may be anticipated from SCOOP: First, the procedures to be developed will free the staff from its present preoccupation with arithmetic. Second, since the implications of alternative courses of action may be worked out in detail, it will permit the staff to concentrate attention on the appraisal of alternative objectives and policies. Third, attention will also be focused on factors: a premium will be put on the development of more efficient operating ratios. Fourth, the intensive analysis of structure, which is a prerequisite for the new procedures, will permit the integrated and parallel development of programs and progress (or statistical control) reports; this will permit a more rigorous control of actual operations.
>
> e. The objectives of SCOOP cannot be achieved immediately, but are to be attained gradually over a period of years….[11]

The Air Force directive ordering all echelons of the Air Force to support the new project for achieving optimum programs was announced a day before LeMay signed the agreement with the Royal Air Force to put both airlift operations under Tunner’s

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[11] General Hoyt S Vandenberg, "Air Force Letter No. 170-3, Comptroller Project SCOOP" Washington, DC, 13 October, 1948, Air Force Historical Research Agency IRIS Number 01108313: 1.

command with a goal of maximizing tonnage delivered. [12] Project SCOOP's scientific computation offered the prospect of a more cost-effective, dynamic approach to maximization than had been achieved before. The Pentagon-based project initiated a new applied mathematics of *optimization* – the decision-making process that determined with mathematical models and computable algorithms the way in which alternative inputs and activities could be combined to achieve a goal of maximum output (or minimum cost), subject to constraints. There are two important features to highlight here: from the beginning, the design of optimum programs for the Air Force was under the auspices of the Comptroller's office, and was thus a part of the budgetary planning and management analysis branch of USAF headquarters at the Pentagon; and the modeling and solution strategies were designed for electronic digital computers that would not be available for Air Force programming until the early 1950s. The context for the first feature was President Truman's insistence that the military budget had to be cut; there was considerable pent-up demand for a thriving consumer-based economy, the electorate would not tolerate increases in military spending for a possible future war, and the US monopoly on nuclear weapons ostensibly guaranteed national security.[13] The Air Force along with other military branches had to do more with less. Project SCOOP aimed to combine the science of economizing with effective computation.

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[12] In his reflections on his experience with Project SCOOP, Lyle R. Johnson, "Coming to Grips with Univac," *IEEE Annals of the History of Computing Archive* 28 (2006): 42, described the high level of concern in 1948 over a possible World War III, which prompted the Air Force to systematically study resources for rapid mobilization.

[13] The US monopoly lasted until the USSR successfully tested their first atomic bomb on 29 August 1949. Michael Gordin, *Red Cloud at Dawn: Truman, Stalin, and the End of the Atomic Monopoly* (New York: Farrar, Straus and Giroux, 2009) explores US military and diplomatic strategy during their short monopoly.

2.3 Dantzig's LP Model and Simplex Algorithm

The kernel of Project SCOOP's plan to mechanize decisions for determining the best schedule of action for military operations was George Dantzig's formulation in June 1947 of a linear programming (LP) model, his construction in August 1947 of the simplex algorithm for solving linear programming problems, and the subsequent coding of the simplex algorithm for digital computers.[14] The National Applied Mathematics Laboratories of the National Bureau of Standards (NBS) assisted the Pentagon team with the latter task.

Dantzig's model, which he described as a "linear technology," consisted of a linear "objective function" that stated mathematically that the sum of the outputs of the activities over a specified time period was to be at its maximum (or total costs were to be at their minimum); linear constraints in the form of equations that specified the technological relations between resource items that served as inputs to and outputs from production activities; and linear constraints in the form of inequalities that specified, for example, maximum available resource limits for inputs.

The objective of the linear programming model, to maximize gain or minimize loss through the best allocation of given resources, was consistent with an economist's representation of rationality. The modeling of the interdependencies of the components of the system was also heavily influenced by economics and in particular by the Nobel-prize winning research of the Russian-born economist Wassily Leontief. While a professor of

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[14] In 1947, Dantzig would describe what he was doing as "programming in a linear structure." In an informal encounter at the July 1948 RAND Corporation colloquium on "Theory of Planning," Tjalling Koopmans suggested that Dantzig shorten the name to "linear programming." George Dantzig, "Linear Programming," *History of Mathematical Programming: A Collection of Personal Reminiscences*, edited by Jan Lenstra , Alexander Kan, and Alexander Schrijver (Amsterdam, 1991): 29.

economics at Harvard University in the 1930s, Leontief had constructed quantitative input-output tables for the US economy that, for example, accounted for the fact that a given quantity of steel production required a given quantity of coal production. Concerned about repercussions from massive demobilization that would likely occur at the end of the war, the US Bureau of Labor Statistics (BLS) had hired Leontief in 1941 to begin construction of a large inter-industry input-output model of the US economy to measure the likely effects of demobilization on employment in different industries. [15] Dantzig and his colleagues at Project SCOOP appropriated Leontief’s matrix framework by conceiving of the Air Force as, “comprising a number of distinct activities. An Air Force program then consists of a schedule giving the magnitudes or levels of each of these activities for each of a number of time periods, such as weeks, or months, or quarters within the larger general time interval covered by the program.”[16] Each activity required and produced *items* such as trained personnel or equipment. Each distinct production activity was a column in the matrix and each item was a row. Data collected by the Comptroller’s office would provide the coefficients in the matrix cells indicating, for example how many aircraft were needed to fly 10,000 flights in three months from Fassberg to Berlin.

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[15] In *Linear Programming and Extensions*, (Princeton: Princeton University Press, 1963): 16-18, George Dantzig discusses the inspiration to his own work of Leontief’s quantitative model and the BLS’ use of input/output matrices of inter-industry data during World War II. See also Martin C. Kohli, “Leontief and the U.S. Bureau of Labor Statistics, 1941-1954: Developing a framework for measurement,” *The Age of Economic Measurement*, edited by Judy L. Klein and Mary S. Morgan. (Durham, NC: Duke University Press 2001): 190–212; and Judy Klein, “Reflections from the age of measurement,” ibid., 128-133).

[16] Marshall K Wood and Murray A. Geisler, *Machine Computation of Peacetime Program Objectives and Mobilization Programs,* Project SCOOP No. 8, report prepared for Planning Research Division Director of Program Standards and Cost Control,Comptroller, Headquarters U.S. Air Force. (Washington, DC, July 18, 1949), 36

Given the economists' assumption that *homo economicus* maximizes gain or minimizes loss and the relevance of Leontief's inter-industry model of an economic system, Dantzig also hoped that economists could supply him with an algorithm for solving military programming problems, which were essentially problems in the efficient and optimal allocation of scarce resources for a system. There was a decades-long tradition of using mathematics in descriptive economics to abstractly demonstrate that maximizing self-interest could lead to an efficient allocation of resources and an optimal point of tangency connecting consumers' and producers' interests. In June 1947 Dantzig met with the Dutch economist Tjalling Koopmans at the Cowles Commission at the University of Chicago.[17] As a statistician for the British Merchant Shipping Mission in Washington during World War II, Koopmans had worked on a programming problem of minimizing the number of ships needed to deliver a fixed amount supplies for the war effort. Dantzig learned on his visit to the Cowles Commission, however, that Koopmans and others working on "normative," prescriptive, system-wide allocation problems had not come up with an efficient way of computing numerical optimal solutions to complex cost-minimization or output-maximization problems. Noncomputability had forced Koopmans and other economists to abandon or resort to approximating trial-and-error solutions in their pursuit of a mathematical means for *planning* an optimal allocation of resources in a system.

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[17] Alfred Cowles, president of an investment firm in Colorado Springs, had a keen Depression-honed interest in the accuracy of stock market forecasts. In 1932, he established the Cowles Commission for Research in Economics. From the outset the commission had close ties with the Econometric Society and supported the statistical and mathematical research of prominent economists. In 1939 the Cowles Commission moved to the University of Chicago. In 1948, Koopmans took over as Director of Research and increased the Commission's emphasis on mathematical methods for the study of rational behavior. Dantzig discusses his June 1947 meeting with Koopmans at the Cowles Commission in Chicago in "Linear Programming."

In August 1947, Dantzig slew the dragon of noncomputability with his iterative “simplex” algorithm.[18] Dantzig’s algorithm had all the qualities of the ideal algorithm that, as we saw in **Chapter One**, A. A. Markov had eloquently praised: prescriptive precision, generality, and orientation to a desired result. For the first time, operations and economic researchers working on systematic optimal allocation problems were able to echo Gottfried Leibniz in saying “Let us calculate, Sir.” This new calculation-for-allocation capacity would go far in putting the “science” into management science and economic science in the 1950s and 1960s. In his August 5, 1948 briefing to the Air Staff, Dantzig asserted that

> one ranking mathematical economist at a recent conference at Rand confessed to me that it had remained for Air Force technicians working on the Air Force programing problems to solve one of the most fundamental problems of economics. What he meant is that the techniques which we are developing are equally applicable to planning in any large organizational structure, i.e. the Air Force, other Military Establishments, the National Economy (for Industrial Mobilization) and Potential Enemy Economies (for finding best means of the their neutralization). [19]

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[18] The simplex algorithm relied on the geometric property that the objective function will have a maximum value at a corner (vertex) of the convex feasible region bounded by the linear inequality constraints of the problem (e.g. arising from resource limitations or technological constraints). Dantzig’s algorithm was an iterative method for moving about the geometric form (created by the constraints) to find the point where the objective function was at its maximum. Acknowledging the efficiency and widespread successful application of the simplex algorithm, the journal *Computing in Science & Engineering* named it one of the ten algorithms with the greatest influence in the twentieth century. John C. Nash, The (Dantzig) simplex method for linear programming, *Computing in Science and Engineering* 2, no. 1 (2000): 29-31.

[19] U.S. Air Force Planning Research Division Director of Program Standards and Cost Control Comptroller. *Scientific Planning Techniques: A Special Briefing for the Air Staff 5 August 1948,* Project SCOOP Discussion Papers, 1-DU, (Washington, DC): 10. The conference that Dantzig referred to is most likely the month-long colloquium on “Theory of Planning” that the RAND Corporation held simultaneously with a colloquium on game theory during July 1948. Paul Erickson, "Optimism and Optimization," Chapter 3 in Erickson, *The World the Game Theorists Made* (forthcoming), has documented the stellar list of the 38 mathematicians, economists, and operations researchers, including Dantzig, Wood, and Koopmans, who participated in the planning colloquium and the enduring effect of the simultaneous colloquia on “cementing a relationship between game theory, programming, and the needs of the Air Force.”

As Koopmans acknowledged in his Nobel prize autobiography and his 1975 prize lecture, the initial conversation with Dantzig in the summer of 1947 and the contacts that were soon to follow proved very fruitful for Koopmans, the Cowles Commission, and the economics discipline.[20] Dantzig's successful articulation of what appeared to be an efficient algorithm for solving optimization problems as well as his demonstration of the pressing Air Force interest in the science of economizing led Koopmans to broaden his shipping problem into a generalized "activity analysis" and led the Cowles Commission, now under Koopmans's direction, to seek a major grant from the US Air Force via the RAND Corporation for research into the "Theory of Resource Allocation". The new focus on "optimal behavior" first appeared in the Cowles annual report for 1948 and 1949 and stands in stark contrast with the foci in 1947 report. The 1948-49 report describes the study of optimal economic behavior also known as "welfare economics" as, "a normative science: it starts with the accurate formulation of some objective to be regarded as economically good for society and derives rules of behavior from that objective."[21]

During the exploratory months of 1947, Dantzig also learned of the close connection between his linear programming approach and the game-theoretic approach that the mathematician John von Neumann and the economist Oskar Morgenstern had

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20 Tjalling Koopmans, "Autobiography", accessed August 6, 2011, http://nobelprize.org/nobel_prizes/economics/laureates/1975/koopmans.html;
Tjalling Koopmans, "Concepts of Optimality and Their Uses," accessed August 6, 2011, http://nobelprize.org/nobel_prizes/economics/laureates/1975/koopmans-lecture.pdf

[21] Cowles Commission, *Report for Period January 1, 1948 – June 30, 1949*, accessed August 6, 2011, http://cowles.econ.yale.edu/P/reports/1948-49.htm. The new focus on welfare economics and optimal behavior also corresponded with a change in 1948 in the research directorship at Cowles from Jacob Marschak to Tjalling Koopmans. That transition and the influence of military patronage at the Cowles Commission (with, for example, in 1951 the RAND Corporation underwriting 32% of the budget and the Office of Naval Research 24%) is documented in Philip Mirowski, *Machine Dreams: Economics becomes a Cyborg Science*. (Cambridge: Cambridge University Press, 2002), 215-222.

introduced in their 1944 book, *Theory of Games and Economic Behavior*. Both analytical frameworks were directed toward explicit, optimal decision making via the quantitative evaluation of alternative outcomes. In his first meeting with Dantzig on October 3, 1947, John von Neumann speculated that game theory and Dantzig's linear programming were analogues of each other.[22] Within two years of meeting von Neumann, Dantzig and other mathematicians had proved that every two-person zero sum game could be turned into and solved as a linear programming problem. [23] As we will see in the **Chapter Five**, outside of that limited class of games, optimal solutions could be as elusive as they were for computationally-strapped mathematical programming problems.

2.4 Project SCOOP's Limited Computational Capacity

As with its Cold War fraternal twin, game theory, which we will encounter in chapter five, linear programming was based on the mathematics of convex sets, and the simplex algorithm for Air Force programming depended on the manipulation of often large matrices with numerous multiplications. Multiplication speed was a key limiting factor on practical computation, and stored-program electronic digital computers were a

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[22] Donald Albers and Constance Reid, "An Interview with George B. Dantzig: The Father of Linear Programming," *The College Mathematics Journal* 17 no.4 (1986): 309.

[23] David Gale, Harold W. Kuhn, and Albert W. Tucker, "Linear Programming and the Theory of Games," in *Activity Analysis of Production and Allocation: Proceedings of a Conference*, , Cowles Commission for Research in Economics Monograph No. 13,, ed. Tjalling C. Koopmans (New York: John Wiley & Sons, 1951), 317-329; and George B. Dantzig, "A Proof of the Equivalence of the Programming Problem and the Game Problem," ibid., 330-338. In his chapter on "Optimism and Optimization," Erickson demonstrates how the recognition in 1947 of the essential connection between linear programming and the two-person zero-sum game spurred the development of game theory at the RAND Corporation, where it became strongly linked to the study of warfare through optimization, and Princeton University (professional home of Kuhn and Tucker), where the two mathematical approaches were used for Office of Naval Research projects on logistics. As game theory strayed outside the sheltering matrix of the zero-sum game (see chapter 5), its clear connection with optimization was severed and mathematical programming began to trump game theory as the research foci of RAND mathematicians.

necessity for dramatically improving multiplication speed.[24] The SCOOP team was heavily involved in examining the engineering alternatives for machines to reduce multiplication time. Dantzig tested experimental circuits and in October 1948 began planning with the National Bureau of Standards for an expected 1951 delivery of the first UNIVAC computer designed by J. Presper Eckert and John W. Mauchly.[25] In 1948, the Air Force Comptroller, General Rawlings, awarded the National Bureau of Standards $400,000 ($3.8 million in 2012 dollars) to design a quickly-constructed interim computer before the UNIVAC was ready. The NBS's SEAC was the first electronic computer to solve a small linear programming problem, but that did not occur until January 1952 and the limitations of the SEAC were such that it could not be used for programming military operations.

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[24] In 1948, Dantzig (U.S. Air Force, *Scientific Planning Techniques*, 14) explained to the Air Staff that their existing punch-card calculators could only do one multiplication every two seconds compared with the 1,000 multiplications per second in the electronic digital computers Project SCOOP was designing. The UNIVAC that the Air Force eventually acquired in 1952 could do about 465 multiplications per second.

[25] Under a World War II contract with the US Army, Eckert and Mauchly had designed the ENIAC for ballistics research and delivered it to the Aberdeen Proving Ground in 1946. By 1948, the ENIAC was still the only electronic large scale digital computer that was in operation in the United States (there were five digital electro-mechanical relay computers in operation and eight ones of various types under development). The US Census bureau had agreed to use the first UNIVAC built in the factory setting, but the USAF was the first institution to take delivery of a UNIVAC, having to reassemble 5,000 vacuum tubes. The details and significance of the pioneering efforts by the USAF to support development of electronic digital computers are documented in U.S. Air Force, *Scientific Planning Techniques*, 13-15 and by Lyle R. Johnson, "Coming to Grips with Univac". Other discussions of the early computational history of linear programming, include by Edward Dunaway, U.S. Air Force Oral History Interview by Daniel R. Mortensen, April 17, 1980, Transcript, Office of Air Force History IRIS No. 01129703; Edward Dunaway, U.S. Air Force Oral History Interview by James R. Luntzel, June 22, 1973, Transcript, Office of Air Force History IRIS No. 01129703; Saul I. Gass, "Model World: In the Beginning There Was Linear Programming," *Interfaces* 20 (1990): 128-132; William Orchard-Hays, "Evolution of Linear Programming Computing Techniques," *Management Science* 4 (1958): 183-190; idem "History of the Development of LP Solvers," *Interfaces* 20 (1990): 61-73, Alex Orden, "LP from the '40s to the '90s," *Interfaces* 23 (1993): 2-12; and Emil D. Schell, "Application of the Univac to Air Force Programming," *Proceedings of the Fourth Annual Logistics Conference* (Navy Logistics Research Project, Washington D.C., 1953): 1-7.

Until 1952, the Project SCOOP team was only able to compute a truly optimal solution to one non-trivial linear programming problem: In early 1948, the NBS staff used IBM electromechanical punched card calculators to compute what would have been the most economical diet for an active man in 1939. In 1941 in an unpublished Bureau of Labor Statistics memorandum, Jerome Cornfield had tried to formulate a linear program to find the lowest cost diet to meet the nutritional needs of a typical soldier, but he did not have a computationally efficient algorithm for solving for the optimum. Dantzig, a friend of Cornfield, took up this challenge using data from George Stigler's 1945 attempt to find the least cost of a daily diet combination of 77 different foods that met the recommended daily nutritional requirements of nine nutrients for a 154-pound economist living in a large city for the years 1939 and 1944. Stigler stated his cost minimization problem in the form of nine equations in 77 unknowns. Stigler also did not have computational capacity for an optimal solution so he had to make do with a "clever heuristic," as Dantzig described it, to approximate a solution. When the NBS staff solved Stigler's diet problem with Dantzig's simplex algorithm, calculators, and many staff-hours, they determined that the optimal diet in 1939 was $39.69 a year versus Stigler's estimate of $39.93.[26]

Although this computation was not directly relevant to Air Force operations, it was essential to the viability of Project SCOOP because it was the first major test of the computational efficiency of Dantzig's simplex algorithm. Searching for and testing for the most efficient way of computing a solution engendered its own analysis of optimal *procedures* and its own rationalization of algorithmic design and the production process

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[26] George B. Dantzig, "The Diet Problem," *Interfaces* 20 (1990): 43-47; George B. Dantzig, *Linear Programming and Extensions*, 551; George Stigler, "The Costs of Subsistence," *Journal of Farm Economics* 27, no.2 (May 1945):303-314.

for calculation. With echoes of Gaspard de Prony's atelier for calculating logarithms, which we encountered in **Chapter One**, the feat of finding the minimum cost of a diet supplying essential nutrients required nine statistical clerks working the equivalent of 120 staff days to perform the required 17,000 multiplications and divisions using desk calculators.[27] It would take months of testing small models on desk calculators before the Air Force team was convinced that the simplex method was both computationally efficient and practical, at least within the promise of digital computing capacity, and that it was not worthwhile to pursue better algorithms.[28] The IBM punched-card electrical accounting calculators available in 1948 and 1949, however, were not up to the task of manipulating the large rectangular matrices required for computing the optimal programming of Operation Vittles much less for the larger wartime and peacetime programs for overall Air Force Operations that would require the solution of simultaneous equations systems consisting of over 1000 equations in 1000 or more unknowns. In their 1949 report to the Air Staff on *Machine Computation,* Wood and Geisler explained their recourse to what Herbert Simon would later label as "procedural rationality":

> Because the computational requirements are limiting in the development of alternative and optimum programs, we are engaged in research on mathematical procedures for simplifying and speeding up the computations of programs to facilitate effective utilization of new electronic computing equipment as it becomes available."[29]

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[27] Dantzig, "The Diet Problem"; Mina Rees, "The Mathematical Sciences and World War II." *The American Mathematical Monthly* 87, no.8 (Oct., 1980): 618.

[28] Dantzig described the long process of exploring the computational efficiency of the simplex algorithm in an article in "Impact of Linear Programming on Computer Development." OR/MS Today 15 (August 1988): 12-17, and in his interview with Donald Albers and Constance Reid in 1986.

[29] Wood and Geisler, *Machine Computation*: 49.

The primary mathematical procedure for simplification to ensure computation that Project SCOOP resorted to was to use a “triangular procedure” to structure the relationships between end items and production activities. As with a fractal pattern, at almost every scale of modeling, Project SCOOP was forced to forgo an optimizing linear programming protocol in favor of the triangular procedure that was in essence the “rationalization, systemization, and mechanization” of the staff procedures highlighted in Figure 2.5.[30] :

> In order to obtain consistent programming the steps in the schedule were so arranged that the flow of information from echelon to echelon was only in one direction: thus the time phasing of information availability was such that the portion of the program prepared at each step did not depend on any following step. In our machine procedure we have similarly ordered the work in a series of stages.[31]

On the grandest scale of preparing for World War III, the SCOOP triangular patterning started with a war plan based on strategic guidance from the top echelon of the Department of Defense. The next step was to frame the Air Force as comprising distinct production activities and construct an input-output table of USAF activities during a war that would accomplish the strategic goals of the war plan. This wartime program would yield a quantitative statement of items (trained crews, equipment, bases) required to be on hand for M-day (mobilization day); “having defined this required M-Day position, we may then determine the action necessary to proceed from our present status to the

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[30] Wood, “Research Program at Project SCOOP” *Symposium on Linear Inequalities and Programming Washington DC, June 14-16, 1951*, Project SCOOP Manual No. 10, (April 1, 1952), 7.
[31] Wood and Geisler, *Machine Computation,* 7.

required M-day position under peacetime budgetary, personnel, and other limitations. This is the peacetime operating program."[32]

The construction of the input-output table of the civilian economy for the peacetime program required help from several federal government offices, including, the Bureau of Labor Statistics and the Bureau of the Budget, as well as universities, including Harvard and the Carnegie Institute of Technology. The limitations on computing capacity were such that within each of the large-scale wartime and peacetime programs the unidirectional echelon to-echelon approach would have to be repeated until one got to a level where mechanical computation with existing calculating resources was possible. The hope was that as computers improved, less and less triangular framing would be necessary and opportunities for maximization would become less localized. Before the UNIVAC arrived even for relatively small-scale operations such as the Berlin Airlift, however, Project SCOOP had to rely heavily on the triangular model.

2.5 Programming for Operation Vittles

In December 1948, Marshall Wood and George Dantzig presented a simplified version of their linear program for Operation Vittles at the winter meeting of the Econometric Society in Cleveland.[33] A hint of the mathematical structure of the Operation Vittles model is evident even in the greatly simplified version of the input-output coefficient matrix and equation system reproduced in **Figure 2.6**. The rows are the

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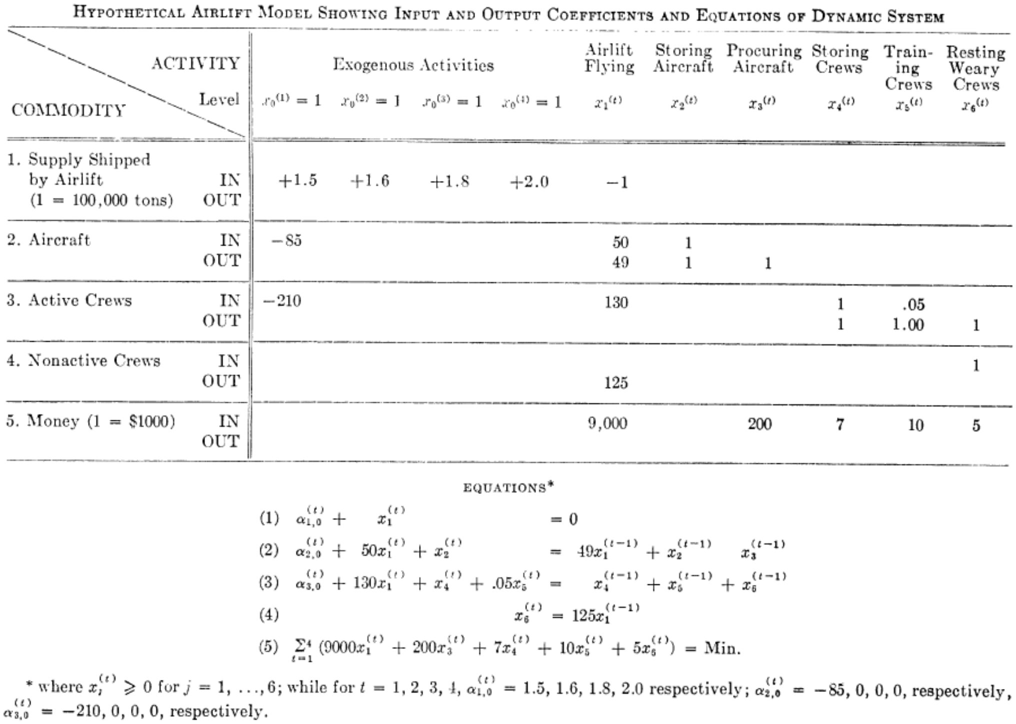
[32] Wood and Geisler, *Machine Computation*, 2.

[33] Marshall K. Wood and George B. Dantzig "Programming of Interdependent Activities: I General Discussion," *Econometrica*, Vol. 17, No. 3/4 (Jul. - Oct., 1949): 198; and George Dantzig, "Programming of Interdependent Activities: II Mathematical Model," *Econometrica*, Vol. 17, No. 3/4 (Jul. - Oct., 1949): 200-211.

items (commodities) that go into or come out of the activities (production processes), which are the columns of the matrix. The inner cells are the coefficients that measure either the input quantity of the items required at the beginning of a three-month time period to support a unit value of the activity or the output of the quantity of the item available at the end of the quarter due to a unit of this activity. The image shows a simplified table for just one quarter so for the longer planning periods that the model was designed for all of the activity columns would be repeated to the right of the table making it quite “rectangular.” Equation 5 at the bottom of the image is the objective function stating that the total costs summed over four three-month time periods and summed over all activities must be at its minimum value (the SCOOP team also demonstrated the dual nature of linear programming by presenting a version of the model with the total tonnage delivered to Berlin at its maximum). Successful computation would yield a “program” of action for the military in the form of quantities of the different types of activities needed to be performed at scheduled times in order to achieve maximum tonnage over 12 months (in the simplified version) or 36 months of the airlift, subject to resource constraints on the availability of the commodities and technological constraints in production.

Wood and Geisler presented a more formal elaboration at the seminal June 1949 conference on activity analysis organized by the Cowles Commission under the Commission’s contract with the RAND Corporation and the USAF for research into the theory of resource allocation. Koopmans organized the conference to bring together operation researchers from the military as well as academic economists and mathematicians. The proceedings published in 1951 served for many years as a canonical text on both linear programming (what Koopmans called “activity analysis”) and game theory.[34] Members of the Air Force Project SCOOP team presented seven of the papers, with Dantzig listed as an author or co-author for five of them.



HYPOTHETICAL AIRLIFT MODEL SHOWING INPUT AND OUTPUT COEFFICIENTS AND EQUATIONS OF DYNAMIC SYSTEM

COMMODITY \ ACTIVITY		Exogenous Activities				Airlift Flying	Storing Aircraft	Procuring Aircraft	Storing Crews	Training Crews	Resting Weary Crews
	Level	$x_0^{(1)} = 1$	$x_0^{(2)} = 1$	$x_0^{(3)} = 1$	$x_0^{(4)} = 1$	$x_1^{(t)}$	$x_2^{(t)}$	$x_3^{(t)}$	$x_4^{(t)}$	$x_5^{(t)}$	$x_6^{(t)}$
1. Supply Shipped by Airlift (1 = 100,000 tons)	IN	+1.5	+1.6	+1.8	+2.0	−1					
	OUT										
2. Aircraft	IN	−85				50	1				
	OUT					49	1	1			
3. Active Crews	IN	−210				130			1	.05	
	OUT								1	1.00	1
4. Nonactive Crews	IN										1
	OUT					125					
5. Money (1 = $1000)	IN					9,000		200	7	10	5
	OUT										

EQUATIONS*

$$(1)\quad \alpha_{1,0}^{(t)} + x_1^{(t)} = 0$$

$$(2)\quad \alpha_{2,0}^{(t)} + 50x_1^{(t)} + x_2^{(t)} = 49x_1^{(t-1)} + x_2^{(t-1)} \quad x_3^{(t-1)}$$

$$(3)\quad \alpha_{3,0}^{(t)} + 130x_1^{(t)} + x_4^{(t)} + .05x_5^{(t)} = x_4^{(t-1)} + x_5^{(t-1)} + x_6^{(t-1)}$$

$$(4)\quad x_6^{(t)} = 125x_1^{(t-1)}$$

$$(5)\quad \sum_{t=1}^{4} (9000x_1^{(t)} + 200x_3^{(t)} + 7x_4^{(t)} + 10x_5^{(t)} + 5x_6^{(t)}) = \text{Min.}$$

* where $x_j^{(t)} \geqslant 0$ for $j = 1, \ldots, 6$; while for $t = 1, 2, 3, 4$, $\alpha_{1,0}^{(t)} = 1.5, 1.6, 1.8, 2.0$ respectively; $\alpha_{2,0}^{(t)} = -85, 0, 0, 0$, respectively, $\alpha_{3,0}^{(t)} = -210, 0, 0, 0$, respectively.

Figure 2.6 Project SCOOP's simplified hypothetical model for the Berlin Airlift
Source: Marshall K. Wood and George B. Dantzig "Programming of Interdependent Activities: I General Discussion," *Econometrica*, Vol. 17, No. 3/4 (Jul. - Oct., 1949): 198

In their 1949 presentation, the SCOOP team claimed that one of the key advantages of the new mathematical model and algorithm they were presenting was its capacity to take into account dynamic opportunity costs: a cost of delivering more food today to Berlin is the opportunity foregone for ensuring greater food deliveries three months from now with a delivery today of material for constructing a runway. The pre-

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[34] Tjalling C. Koopmans, ed., *Activity Analysis of Production and Allocation: Proceedings of a Conference*, Cowles Commission for Research in Economics Monograph no. 13 (New York: John Wiley & Sons, 1951).

optimization way of programming military operations had been plagued with an inability to consider alternative courses of action for determining the *best* program:

> *So much time and effort is now devoted to working out the operational program that no attention can be given to the question whether there may not be some better program that is equally compatible with the given conditions*. It is perhaps too much to suppose that this difference between programs is as much as the difference between victory and defeat, but it is certainly a significant difference with respect to the tax dollar and the division of the total national product between military and civilian uses.
> Consideration of the practical advantages to be gained by comparative programming, and particularly by the selection of "best" programs, leads to a requirement for a technique for handling all program elements simultaneously and for introducing the maximization process directly into the computation of program. Such a technique is now in prospect.[35]

There are three key points that Wood and Geisler addressed in this passage: the promise of optimization to account for alternative uses and achieve the best outcome;[36] the declaration that this would enable the military to effectively pursue new operations without demands for higher taxes or lower civilian production; and the admission that the heralded innovation was "in prospect." With regard to the latter, Wood and Geisler had to present two sets of input/output coefficients and respective derived equations to illustrate

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[35] Marshall K. Wood and Murray A. Geisler, "Development of Dynamic Models for Program Planning," in *Activity Analysis of Production and Allocation: Proceedings of a Conference,* Cowles Commission for Research in Economics Monograph No. 13, ed. Tjalling C. Koopmans (New York: John Wiley & Sons, 1951): 194.

[36] In his 1947 discussion on the benefits of the linear programming approach over his own World War II "program for programing", Dr. Edmund Learned U.S. Air Force, S*cientific Planning Techniques,* 26, explained to the Air Staff:

> The most vital contribution which this new processing technique- new analytical technique - makes to the Air Staff is in the area of alternatives. As all of you know, we had plenty of problems during the war guessing at the general pattern of a program then running out the programing details, finding our lacks of balance and bottle necks after we had made the run…with this speedier method of computation it is possible for a Staff officer or the Chief of Staff to define a number of alternatives that he would like to see worked out in detail. They can be run rapidly on the machine.

models for programming the Berlin airlift: The optimizing “rectangular” model in prospect and the non-optimizing “triangular” model that could be solved on their current punched card electrical accounting equipment.

The Air Force lacked the computing capacity to deal with the large rectangular matrices in Project SCOOP’s original optimizing Berlin airlift model. For several years to come, they had to rely on non-optimizing models that were essentially small rectangular sets of few equations arranged in such a way that their coefficient matrices formed a sequentially descending diagonal that bisected the matrix into triangles. The triangular model, or TriMod as the SCOOP team often called it, rearranged and decomposed the general problems into hierarchical steps such that the algorithm had to solve for the levels for each activity in the earlier time period in order to solve for the activities at a particular moment.

Wood estimated that with the triangular model and punch-card calculators a full-scale wartime program would still take about six months to fully program, but the triangular protocols did yield computable solutions with significant cost reductions compared with previous planning practices. The triangular model with mechanical computation ensured consistent planning, smoother production, reduced waste and storage costs, and increased analytical capacity for assessing feasibility. Indeed, the new accounting discipline and the rationalization of planning and data collection procedures that the triangular model engendered fulfilled many of the Comptroller’s aspirations, and Air Force reliance on variations of the triangular model persisted long after Project SCOOP ended.

The temporally-constrained hierarchy of the triangular model could not incorporate dynamic considerations of opportunity costs of alternative production activities and it could not guarantee an optimum solution to qualitatively stated objectives such as "maximize tonnage delivered subject to constraints." The triangular model, however, could compute the required supporting activities to achieve a specified tonnage.[37] In other words, the triangular model, with far fewer computational resources than the optimizing linear programming model would have consumed, could satisfy an assigned aspiration level with precise calculations of necessary quantities of items and activities:

> With this formulation we have been we have been able to solve programming problems involving 100 activities and 36 time periods in one day by using present punched card equipment, obtaining answers which are realistic and useful. In the more general formulation this would be represented by 3,600 equations in 3,000 unknowns.[38]

Ultimately, the Berlin airlift did more for Project SCOOP than the SCOOP team did for the Operation Vittles. Even with the triangular model the SCOOP team was not able to contribute to day-to-day planning of the airlift. The airlift, however, provided empirical and conceptual feedback that enabled the research team to hone their model, and begin to construct templates for data reporting and a working database for

[37] Minor-scale optimization was still possible and could be expanded with the expansion of computing capacity. As Wood and Geisler (*Machine Computation,* 48) explained to the Air Staff,

> the triangular procedure has been organized so that small local maximization problems can readily be introduced into local areas of the model where alternatives are to be considered. As equipment of greater computing capacity becomes available, these areas can be gradually enlarged, permitting more and more consideration of alternatives. Thus the transition from a determinate model permitting only a single solution to an indeterminate model in which we select the best from among alternative solutions will be gradual, rather than an abrupt one.

[38] Wood and Geisler, "Development of Dynamic Models," 206.

input/output coefficients for Air Force operations. The experience tested and proved the principles and concepts of planning by machine computation and provided a good instructional example to demonstrate the linear programming model to the Air Staff as well as academic economists.[39] It also opened a door, which would prove difficult to close, for making-do with the non-optimizing or sub-optimizing triangular model.

It was the promised economic rationality of optimization, however, that was celebrated at the 1949 conference where Project SCOOP presented its linear technology and the Operation Vittles model to the academic world. Tjalling Koopmans, the conference chair, even went as far as to claim that Dantzig's linear program model and simplex algorithm settled an earlier debate as to whether centrally-planned allocation could lead to rational outcomes. European economists had engaged off and on since the late nineteenth century in the "socialist calculation" or "economic calculation" debate. The debate heated up with the perceived success of some forms of state production planning during World War I. In the 1920's and 1930's free-market champions such as Ludwig von Mises and Friedrich Hayek, however, had argued that the challenge of economic calculation prohibited planned economies from achieving an efficient allocation of resources and in so doing precluded rationality:

> Without economic calculation there can be no economy. Hence, in a socialist state wherein the pursuit of economic calculation is impossible, there can be – in our sense of the term – no economy whatsoever. In trivial and secondary matters rational conduct might still be possible, but in general it would be impossible to speak of rational production any more. There would be no means of determining what was rational, and hence it is obvious that production could never be directed by economic

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[39] Murray A Geisler, *A Personal History of Logistics*, (Bethesda, MD: Logistics Management Institute, 1986), 6.

> considerations. What this means is clear enough apart from its effects on the supply of commodities. Rational conduct would be divorced from the very ground which is it proper domain. Would there, in fact, be any such thing as rationality and logic in thought itself? Historically, human rationality is a development of economic life. Could it then obtain when divorced therefrom?[40]

Koopmans consciously took up this challenge and argued that economic calculation and rationality in centralized allocation was now possible: “To von Mises’ arguments regarding the unmanageability of the computation problems of centralized allocation, the authors oppose the new possibilities opened by modern electronic computing equipment. …Dantzig’s model is an abstract allocation model that does not depend on the concept of a market.”[41] What had been made clear to participants at the conference was the mathematical duality of maximizing output and minimizing costs and that the process of solving for the maximum output subject to constraints yielded what operation researchers called “efficiency prices,” (“imputed prices,” “accounting prices,” or “shadow prices”) that signaled worth in the absence of markets. This held out the prospect of computing meaningful valuations for planning the optimal allocation of resources in a system.[42]

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[40] Ludwig von Mises, “Economic Calculation in the Socialist Commonwealth,” 1920 reprinted in *Collectivist Economic Planning; Critical Studies on the Possibilities of Socialism*, ed.by Friedrich. A. Hayek (London: Routledge & Kegan Paul, 1935), 105.

[41] Tjalling C. Koopmans, “Development of Dynamic Models for Program Planning,” *Activity Analysis, of Production and Allocation: Proceedings of a Conference*, Cowles Commission for Research in Economics Monograph No. 13, ed Tjalling C. Koopmans (New York: John Wiley & Sons, 1951): 7.

[42] For example, Stephen Enke, an economist at the RAND Corporation, demonstrated that with linear programming economists could contribute “the principles of value determination and the logic of economizing” to determine the production, consumption, and allocation of the fissionable materials U^{235} and PU^{239} for which there were no markets or real prices [Enke, “Some economic aspects of fissionable material,” *Quarterly Journal of Economics* 68, no. 2 (1954): 217.

The Cowles Commission report on *Rational Decision-Making and Economic Behavior* announcing the publication of the proceedings of the 1949 conference and detailing subsequent Cowles research studies, illustrated the Commission's new emphasis on economic calculation and rationality:

> It was J.R. Hicks, the Oxford economist, who said that the foundations of economic theory were, essentially, nothing but "the logic of choice." Charles Hitch, of The RAND Corporation, expressed this in another way: "Economics is about how to economize." To be economical is to choose the best use of limited opportunities and resources…. All these cases of "economical" decision-making have the same logical content. In mathematical language, their common problem is to "maximize, subject to given conditions." "Rational behavior" and "optimal behavior" are still other words for economical decision-making.[43]

The report, issued two years after the conference on *Activity Analysis*, also entertained the notion that normative studies prescribing rational behavior had to take into consideration that actual behavior could be imperfectly rational or even irrational.[44] With their statement, "In order to make rational recommendations on human institutions and policies it is necessary to predict as well as we can people's actual, possibly irrational behavior," the Cowles Commission acknowledged a formal interest in research studies on less than rational behavior. Herbert Simon, who at the time of his participation in the *Activity Analysis* conference was working simultaneously under an Air Force research contract with Project SCOOP and the Cowles/RAND contract on resource allocation,

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[43] Cowles Commission for Research in Economics, *Rational Decision-Making and Economic Behavior, 19th Annual Report, July 1, 1950 – June 30, 1951,* accessed August 6, 2011, http://cowles.econ.yale.edu/P/reports/1950-51.htm

[44] Economists use the term "normative" to mean prescriptive – declaring what ought to be. This is in contrast to "positive" economics that describes what is.

would soon answer this call.[45] Although Simon would end up theorizing on imperfectly rational actual behavior, his starting point would be a normative perspective generated by the frustrated computation of optimal solutions for US military planning. The mathematical programming of Operation Vittles would not be the only endeavor where limited computational capacity forced operations researchers to make-do rather than maximize, and it was from his own confrontation with a noncomputability dragon that Simon would construct his theories of bounded rationality.

2.6 Project SCOOP and the Carnegie Institute of Technology

As part of their development of a large, peacetime inter-industry mathematical model for determining the feasibility of M-day plans, Project SCOOP and the Bureau of the Budget's Division of Statistical Standards in 1949 awarded the Graduate School for Industrial Administration (GSIA) at the Carnegie Institute of Technology in Pittsburgh Pennsylvania a three-year grant for research on "Intra-Firm Planning and Control."[46] The

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[45] Herbert Simon (1916-2001) described himself a mathematical social scientist. As an undergraduate at the University of Chicago and a graduate student at the University of California at Berkley, Simon sought out courses in physics, mathematical economics, and symbolic logic. Simon's doctoral thesis on administrative decision-making built on his operations research work for a city government. From 1949 until his death, Simon was a professor at the Carnegie Institute of Technology/Carnegie Mellon University. Simon received the Nobel Prize in Economics in 1978. Hunter Crowther-Heyck *Herbert A. Simon: The Bounds of Reason in Modern America,* (Baltimore: Johns Hopkins University Press, 2005) and Ester Mirjam Sent: "Herbert A. Simon as a Cyborg Scientist," *Perspectives on Science* 8, no.4 (2000): 380-406 and "Simplifying Herbert Simon," *History of Political Economy* 37, no. 2 (2005): 227-232) address the broad disciplinary span of Simon's work, including administrative decision making and computer simulated problem solving, and his departmental travels at Carnegie Mellon through industrial administration, psychology, and political science. In *Models of a Man,* edited by Mie Augier and James March (Cambridge, MA: MIT Press, 2004), forty of Simon's former colleagues and research partners, reflect on Simon's contributions to social science. In *Machine dreams,* 452-472, Philip Mirowski examines Simon's research for the Cowles Commission.

[46] Simon's 1952 notes on the GSIA "Research budget 1950-1952" (box 18, folder 1214, Herbert A. Simon Collection, Carnegie Mellon University Archives) indicate the contract with the Air Force and the Bureau

commitment involved researching the upstream data generating process that fed into the Project SCOOP's input-output models, improving production planning through an applied mathematics that combined logical, accounting, engineering, and computational frameworks, and training staff in new analytical methods of planning and optimization. This foundational contract between the military, the executive branch, and the university was a key path by which linear programming spread to operations research in private industry and by which management science became a profession backed by an analytical graduate business school curriculum and a professional organization.

To complement Project SCOOP's development of a peacetime inter-industry model, the Carnegie group agreed to direct their intra-firm analysis of production planning to companies that were either very important to the economy or representative of a key industry. The Carnegie team had an additional mandate to ultimately make the analysis "operational" or "handbook ready." Their goal was to get down to a protocol so accessible that production managers with little mathematical training could routinely manipulate the decision rules by plugging in values for the unknowns in a simple equation. As was common in military-funded Cold War operations research projects, the mathematical analysis was meant to culminate in computable decision rules for the optimal allocation of resources. As was also common in such projects from the late 1940's to the 1970's, limited computational resources necessitated a rationalization of procedures and stimulated the development of new modeling strategies.

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of the Budget financed on an annual basis the equivalent of 3 man-years of faculty research and 6 man-years of graduate assistant research per year in addition to overhead costs.

The faculty working on the GSIA Air Force research project split into two teams with "polar philosophies of optimizing behavior": The planning behavior approach of linear programming and the adaptive behavior approach of "servo control."[47] Each team ended up developing new procedures and strategies to match the optimization goal with the demands for accessible mathematics and effective computation.

GSIA economist William Cooper, CIT mathematician Abraham Charnes, and an engineer at the Philadelphia Gulf Oil Refinery, Bob Mellon, used linear programming to derive the optimum blend of aviation fuel at the refinery and presented their results at the 1951 Project SCOOP symposium on linear programming.[48] In order to make the linear programming approach "handbook ready" for production managers, Charnes developed a general means of handling complex mathematical problems that, in combination with Dantzig's simplex algorithms, made it possible to completely routinize the computing process.[49] His innovation for handling degeneracy opened the door for wide-spread industrial applications of linear programming, as did Charnes and Cooper's publication of their GSIA lectures notes that served as the go-to text on linear programming for operations researchers for many years.[50] Armed with operational optimization tools the GSIA team was at the forefront of professionalizing management science. Cooper was

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[47] Charles C. Holt, "Servo Control and Programming--Polar Philosophies of Optimizing Behavior," report November 20, 1951, folder GSIA--Air Force Research Project #6, Herbert A. Simon Collection, Carnegie Mellon University Archives.

[48] Abraham Charnes, William. W. Cooper, and B. Mellon, "Blending Aviation Gasolines—A Study in Programming Interdependent Activities". Paper read at Project SCOOP Symposium on Linear Inequalities and Programming, June 14-16, 1951.

[49] Abraham Charnes, "Optimality and Degeneracy in Linear Programming.," *Econometrica* 20, no.2 (1952): 169-170.

[50] William W. Cooper, Abraham Charnes, and A. Henderson, *An Introduction to Linear Programming* (New York: Wiley, 1953).

the founding president of The Institute of Management Science (TIMS), the first TIMS national meeting was held in Pittsburgh in October 1954, and in the first few years of the organization Charnes and Simon served as national officers on the editorial board of the professional organization's journal, *Management Science.*

At the other philosophical pole of optimization, Simon and engineer-turned economist Charles Holt appropriated mathematical approaches to modeling the feedback loops in servomechanisms.[51] They hoped to leverage this emphasis on modeling adaptive behavior to determine a firm's optimal response to changing external information from the market. A specific aim was to derive decision rules for scheduling production for the White Motor Company truck assembly plant that would minimize manufacturing and inventory costs. The servo-control approach they used relied on mathematically accessible linear differential equations with constant coefficients. Simon asked, "Under what conditions can the optimal production paths be represented by such equations?"[52] Simon's answer was that the cost function to be minimized must have a quadratic form—it must consist of only linear or squared terms, but no higher order (e.g. cubed) terms. With the transfer of their planning research projects initiated under Project SCOOP to Office of Naval Research (ONR) projects, Simon and Holt, continued to explore the

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[51] In his study of *Herbert A. Simon* (184-214), Hunter Crowther-Heyck examines the abiding theme of adaptation in Simon's models and its foundation on servo theory. Servomechanisms were error-actuated devices whose output controlled a system in response to the information, provided through a feedback loop, on the difference between the actual state and the desired (or predicted) state.

[52] Herbert A. Simon, "Notes on Two Approaches to the Production Rate Problem," (Cowles Commission Discussion Paper: Economics No. 2057, November 19, 1952) 2.

significance of the procedural economy gained by making the minimization of a quadratic production and inventory costs function the optimization objective.[53]

Project SCOOP's contract with the GSIA ended in June 1953, but the research for Air Force had laid the foundation for the larger and longer contract with the ONR for "Planning and Control of Industrial Operations" that began in the fall of 1952.[54] Under the ONR contract Simon, Holt, the economist Franco Modigliani, and the engineer-turned-business graduate student John Muth constructed, tested, and applied *dynamic programming* to derive linear decision rules to achieve optimal production rates at the Springdale paint manufacturing plant of the Pittsburgh Plate Glass Company. [55] Similar to the situation Project SCOOP had confronted, the company and the GSIA team had to make do with punched card calculators to compute the optimal solutions from models

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[53] The status of the Air Force research projects and the transfer of these to the ONR is discussed in the GSIA's final report to Project SCOOP (William Cooper, Final Report on Intra-Firm Planning and Behavior: A Research Project Sponsored by the U. S. Department of the Air Force at the Carnegie Institute of Technology Graduate School of Industrial Administration, July 1, 1953, Herbert A. Simon Collection, Carnegie Mellon University Archives, box 15, folder 1072). It was a relatively seamless transfer partly because as early as May 1948 Dantzig had briefed the Navy Staff on the aims and methods of Project SCOOP and had maintained contact in the course of developing the wartime and peacetime programs. Judy L Klein, *Protocols of* War *and the Mathematical Invasion of Policy Space, 1940-1970* (forthcoming), examines the application-driven theory that came out of both GSIA military planning contracts, including new forecasting tools, the articulated significance of quadratic cost functions for deriving linear decision rules, rational expectations, and the technical revolution in economic theory initiated by a strong emphasis on modeling strategies.

[54] During this time, Simon's research was also funded by a RAND Corporation contract with the Cowles Commission on the "Theory of Resource Allocation" and an ONR contract with Cowles for research on "Decision Making under Uncertainty."

[55] Impressed with Dantzig's demonstration of how to achieve effective numerical solutions at the 1948 colloquium on "Theory of Planning," Richard Bellman a mathematician at the RAND Corporation developed a new form of optimization for multistage decision processes. Bellman's dynamic programming included an economic criterion function maximizing damage to the enemy or minimizing losses and was essentially an algorithm for determining the optimal allocation of resources over time in contrast with linear programming's optimal allocation of resources across activities. Bellman first developed the protocol to give a rule at each stage of a nuclear war for deciding which enemy target to bomb with the relatively scare atomic weapons. (Judy L. Klein, *Protocols of War*). As with linear programming the optimization tool was quickly appropriated to other contexts via the academic-military-industrial complex exemplified by military-funded research at the Carnegie Institute.

and algorithms designed for digital computers. The Graduate School for Industrial Administration would be the first group at the Carnegie Institute to get a digital computer, but that would not happen until 1956. A key information-processing hurdle for the ONR Paint Project team arose from the need to take into account uncertainty into their multi-stage decision-making model. In order to plan production they needed to estimate future demand for different types of paint, but data collection and computation hurdles made it difficult to incorporate a probability distribution of future sales into the protocol without making some heroic assumptions about the independence of demand in one time period compared with another.

Herbert Simon solved this problem of noncomputability with his "certainty equivalence" theorem. Simon demonstrated that if the cost function to be minimized in a dynamic programming problem could be approximated by quadratic function then a single expected value of future sales (e.g. an average of past sales), rather than the entire probability distribution for forecasts, would be sufficient to quantify linear decision rules.[56] As Holt explained in a 1953 ONR report, approximating the total costs with a quadratic function, "yields linear decision rules which are mathematically simple to derive and computationally easy to apply."[57]

Simon took the lessons of making do with existing computational resources when crafting normative modeling strategies and applied it to the realm of positive, descriptive

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[56] Herbert A. Simon, "Dynamic programming under uncertainty with a quadratic criterion function," *Econometrica* 24 (1956): 74-81.

[57] Charles C. Holt, "Superposition Decision Rules for Production and Inventory Control," ONR Research Memorandum No. 3. October 27, 1953, Herbert A. Simon Collection, Carnegie Mellon University Archives, box 18, folder 1221.

economics. He argued in many forums that economists should be incorporating these approximating heuristics into their models of how economic man makes decisions.[58] In a working paper first circulated at the RAND Corporation in 1953 and published in the *Quarterly Journal of Economics* in 1955, Simon asserted that "the task is to replace the global rationality of economic man with a kind of rational behavior which is compatible with the access to information and the computational capacities…."[59] In that essay, Simon explored ways of modeling the *process* of rational choice that took into consideration computational limitations.

In his 1957 book on *Models of Man,* Simon introduced the term "bounded rationality." He argued that consumers and entrepreneurs were "intendedly rational," but they had to construct simplified models of real situations that were amenable to effective computation. For Simon a key to simplifying the choice process and reducing computational demands was "the replacement of the goal of maximizing with the goal of satisficing, of finding a course of action that was 'good enough'".[60] Simon explored theories of limits on the perfect rationality assumed by economists. These limits included

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[58] This was not the first time Simon challenged economists and their discipline. In his study of *Herbert A. Simon*, Hunter Crowther-Heyck documents the tensions spanning decades between Simon and his Carnegie colleagues in economics. Nor was this the first time that social scientists, or Simon himself, seriously contemplated notions of limited rationality. In their essay on "The Conceptual History of the Emergence of Bounded Rationality" (*History of Political Economy* 37, no. 1 (2005): 27-59), Matthias Klaes and Esther-Mirjam Sent construct a conceptual trajectory of first time occurrences of a family of expressions of limited, approximate, incomplete, and bounded rationality.

[59] Herbert A. Simon, "A behavioral model of rational choice," *The Quarterly Journal of Economics* 69, no. 1 (1955): 99.

[60] Herbert A. Simon, *Models of Man: Social and Rational; Mathematical Essays on Rational Human Behavior in Society Setting* (New York: Wiley, 1957): 204. Simon used the Scottish/Northumbrian term of "satisfice" meaning "satisfy." In his Nobel Prize lecture in Stockholm on December 8, 1978, Simon reflected on the conceptual development of bounded rationality by describing the Carnegie team's quadratic cost approximation to illustrate "how model building in normative economics is shaped by computational considerations." Herbert A. Simon, "Rational Decision Making in Business Organizations". *The American Economic Review* 69 (1979): 498.

uncertainty about outcomes of decisions, incomplete information about alternatives, and complexity that defied computation. Such constraints on the information-processing capacity forced economic actors and operations researchers to focus on the decision process by, for example, taking into account the costs of searching and computing information or replacing optimizing approaches with heuristic approaches that complemented a satisficing approach.[61] Simon was not assuming that decision makers were irrational; rather he argued that the limits on their capacity for collecting and processing the information needed to make the best decisions to meet their goals forced a new focus on the process of reasoning and problem solving.

At a talk at Groningen University in September 1973 and in revisions circulated in 1974 and published in 1976, Simon clarified his emphasis on the problem solving process by making the distinction between what he called "substantive" and "procedural" rationality. Substantive rationality was the achievement of the best outcome given an optimizing goal; the rational consumer achieving maximum utility or the rational producer achieving maximum profits. In contrast to the economist's emphasis on the choice *outcome* that a rational economic man made, the psychologist focused on the *process* of how decisions are made. Procedural rationality dealt with reasonable deliberation.[62] Simon illustrated the difference between the two with examples from

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[61] Herbert A. Simon, "Theories of Bounded Rationality," *Decision and Organization,* ed. C. B. McGuire and Roy Radner, (Amsterdam: North-Holland, 1972): 161-176.

[62] Herbert A. Simon, "From Substantive to Procedural Rationality" lecture at Groningen University September 24, 1973, box 81, folder 6519, Herbert A. Simon Collection, Carnegie Mellon University; "From substantive to procedural rationality," *Method and Appraisal in Economics*, ed. S. J. Latsis, (New York, 1976), 120-48. In many of Simon's notes and publications, starting with his dissertation in 1943, the contrasting adjectives of "substantial" and "procedural" appear in the same paragraph. Over the decades Simon paired the following nouns with the two adjectives: "matters", "conformity", "decision premises", "flexibility", "problems", and "alternatives". In his 1964 essay on "Rationality" [*Dictionary of the Social*

linear programming. The solution to Stigler's diet problem was substantively rational. Thanks to the linear programming model, the simplex solution algorithm, and contemporary computing equipment, an optimal least cost solution meeting the nutritional goals had been achieved. The "traveling salesman problem" of finding the city-to-city route that would minimize traveling costs was one of Simon's examples of procedural rationality. Computable optimal solutions were only possible for trivial set-ups of the problem. For the more complex traveling salesman problems, operations researchers searched for computationally efficient algorithms that would achieve good, but not necessarily optimal, solutions.[63] Bounded rationality in the form of limited information processing capacity led to procedural rationality. As Simon spelled out in other essays, the search process for the best procedures to make do might itself involve optimization, e.g. determining an optimal stopping point for the search process or minimizing the costs of the search process, even when the original optimization was precluded by limited computational resources.

Simon perceived "simplification of the model to make computation of an 'optimum' feasible" (as in approximating costs with a quadratic equation) and "searching for satisfactory, rather than optimal choices" (as in programming with a triangular input-output matrix) as examples of satisficing, rather than optimizing, behavior. The aim to

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Sciences, edited by J. Gould and W.L. Kolb (Glencoe, IL: The Free Press, 1964), 574], Simon contrasted two types of rationality, the economist's "attribute of an action selected by a choice process" and the psychologist's "processes of choice that employ the intellectual faculty" It was apparently not until 1973, however, that Simon coined the phrases "substantial rationality" and "procedural rationality". Once he did so he used the currency liberally in several key publications: See, for example, Herbert A. Simon, "On How to Decide What to Do," *The Bell Journal of Economics* 9 (1978): 494-507, "Rationality as Process and as Product of Thought," *The American Economic Review* 68 (1978): 1-16, and "Rational Decision Making in Business Organizations," *The American Economic Review* 69 (1979): 493-513.

[63] That search is ongoing, see William J. Cook, *The Pursuit of the Traveling Salesman: Mathematics at the Limits of Computation,* (Princeton: Princeton University Press, 2012)

both approaches was to construct “practicable computation procedures for making reasonable choices.”[64] Simon acknowledged that a search for the most efficient method of approximating sometimes made it difficult to draw a formal distinction between optimizing and satisficing. He argued, however, that there was often a major practical difference in emphasis, and that the aspirational approach of searching for satisfactory choices could lead to better results than the first-approximate-then-optimize approach.[65]

The thrust of Simon’s argument in many of his essays contrasting substantive and procedural rationality addressed positive economics that purported to describe actual behavior. Simon perceived consumers and producers as organisms with limited computational capacity. Therefore economists, Simon asserted, should learn from psychologists, as well as from their own discipline’s experience with normative operations research, and focus more on the process of how decisions are made. As is evident in a symposium on economics and operations research in the May 1958 issue of *The Review of Economics and Statistics,* Simon was not alone in drawing this conclusion.[66] Several of the authors, including Simon’s colleague William Cooper as well as Charles Hitch, Thomas Schelling, and Daniel Ellsberg from the RAND Corporation, spoke not only to how economists could contribute to improvements in operations research, but also to how their own operations research experience with approximation and good, alternative, non-optimizing rules should be incorporated into microeconomic

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[64] Idem, “From substantive to procedural rationality,” 140.

[65] Herbert A. Simon, “Theories of Bounded Rationality,” 167.

[66] “Economics and Operations Research: A Symposium” *The Review of Economics and Statistics* 40, no. 3 (1958): 195-229.

theory. It was Simon, however, who provided clarity with the naming of “bounded” and “procedural” rationality.

2.7 Programming after Project SCOOP

Significant Department of Defense budget cuts accompanied the new policies of Dwight Eisenhower, inaugurated as US President in January 1953, and the end of armed Korean conflict in July of that year. With a staff of 50 and major research operating expenses, Project SCOOP was vulnerable to such cuts. Also *planning*, particularly planning the entire US economy as was Project SCOOP’s ambition in its inter-industry modeling for their peacetime program, was taboo under the new Secretary of Defense, Charles E. Wilson. In the fall of 1953 the Air Force, disbanded Project SCOOP, formally acknowledging an end to the early development stage of mathematical programming and a commitment to a new stage of implementation, albeit now confined to modeling only Air Force activities. The Air Staff also changed the name of the “Planning Research Division” to the “Computation Division.”[67]

Mathematical programming, however, continued to thrive both at the Comptroller’s office at the Pentagon and at the RAND Corporation, to where George Dantzig and Murray Geisler had migrated. Even after the arrival of the UNIVAC, the Air Force had to rely heavily on the triangular model for programming operations with

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[67] Wilson’s anathema to planning and its effect on the disbandment of Project SCOOP is discussed in Lyle R. Johnson, “Coming to Grips with Univac,” 42 and by Edward Dunaway in his 1980 Oral History Interview, 5. In his *Personal History of Logistics*, Murray Geisler remarked that, “We learned how fragile a research group can be....A large bureaucracy does not value such groups adequately; they are doomed to have a limited life. ”(p. 11)

thousands of activities. Former SCOOP members, including Walter Jacobs and Saul Gass, worked at the Pentagon to design models and code algorithms that could be solved with existing computers and be operationally friendly to those having to formulate myriad Air Force routines. In 1956 they replaced the triangular model with the Trim model (also square and non- or sub-optimizing) that they had designed "as a production system" that disciplined and mechanized the data reporting process from various Air Force departments.[68] The Trim model was used to construct budgets and to determine for any specific war plan the monthly requirements for bombs, ammunition, fuel, personnel, etc. In cases of smaller military operations, linear programming on the UNIVAC with rectangular optimizing models was possible by the mid-1950s.[69]

So far in this chapter we have neglected the other superpower engaged in the Cold War. If necessity is the mother of invention, why didn't Soviet requirements for planning the entire national economy spur an early development of linear programming there? There was a major, albeit neglected, development in the linear technology for optimum resource allocation in 1939. In his capacity as a consultant to a plywood enterprise Leonid Kantorovich, Professor of Mathematics at Leningrad State University, was confronted with the economic problem of allocating raw materials in order to maximize equipment production subject to constraints. He formulated a linear programming model and suggested an iterative solution process similar to, but not identical to, the simplex method that held out the prospect for calculating "resolving multipliers" (the "efficiency

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[68] Walter Jacobs, "Air Force Progress in Logistics Planning," *Management Science* 3 (1957): 213-224.

[69] Gass described a typical aircraft deployment linear programming problem that he worked on in the mid-1950s, "Given the initial availability of a combat-type aircraft and the additional monthly availabilities in the succeeding months, divide these availabilities between combat and training so as to maximize, in some sense, the combat activity." Saul I. Gass, "Model World," 131.

prices” or “shadow prices” of Dantzig’s model). In May 1939, Kantorovich made two presentations of his new mathematical approach to the Institute of Mathematics and Mechanics of the Leningrad State University and to the Leningrad Institute for Engineers of Industrial Construction. That same year the Leningrad University Press printed his booklet on *The Mathematical Method of Production Planning and Organization*. A lack of computational capacity in the early 1940s, a distrust of a mathematical approach to planning allocation of resources, and the preoccupation of war with Germany led to the neglect of Kantorovich’s contribution to scientific management in the USSR. In the late 1950s, planners and academics in the USSR began to acknowledge the usefulness of Kantorovich’s protocol and its excellent fit with the growing Soviet interest in cybernetics.[70] In 1975, the Swedish Nobel Committee awarded Kantorovich and Koopmans the Sveriges Riksbank Prize in Economic Sciences for their contribution to the theory of the optimum allocation of resources. To the consternation and anger of many, including Koopmans, Dantzig was not included in the honor.

In June 1952, Dantzig left Project SCOOP to continue his developmental work for the Air Force at the RAND Corporation. There Dantzig worked with William Orchard-Hays to improve the computational efficiency of the simplex algorithm, to adapt it to new computers, and to develop commercial-grade software for solving linear programs.

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[70] *Management Science* published an updated, expanded English translation of Kantorovich’s 1939 booklet in July 1960 ["Mathematical Methods of Organizing and Planning Production." *Management Science* 6, no. 4 (1960): 366-422.] In his forwarding, Tjalling Koopmans, “A Note about Kantorovich's Paper, ‘Mathematical Methods of Organizing and Planning Production’,” *Management Science* 6 no. 4 (1960): 364, described the study as “an early classic in the science of management under any economic system.” Johanna Bockman and Michael A. Bernstein discuss the correspondence and Cold War mediated relationship between Kantorovich and Koopmans in “Scientific Community in a Divided World: Economists, Planning, and Research Priority during the Cold War,” *Comparative Studies in Society and History* 50:3 (2008):581–613.

Looking back on that work with Dantzig, Orchard-Hays described their occupation, "An algorithm designer is an engineer who works with abstract concepts rather than physical materials. The designer's goals are efficiency and that the algorithm works; it should give correct results reliably for a class of problems." [71] The algorithm designers at RAND were constructing what Simon named *procedural rationality,* "the rationality of a person for whom computation is the scarce resource".[72]

2.8 The Rise of Procedural Rationality

In the 1958 symposium on Economics and Operations Research the economist Daniel Ellsberg described the conditions in the Cold War military sphere that made "problems of choice and allocation almost unbearably pressing."[73]

> The budget famine, the sudden military challenge, the unprecedented variety of alternative weapon systems with their long lead-times, rapid obsolescence, high cost, and excruciatingly technical claims: these basic pressures on the Secretary of Defense are dramatized by the inter-service rivalry with the public for funds and resources and with each other for allocations and control of weapons.[74]

That description applied equally well to the earlier decade in which the blockade of and airlift for the western sectors of Berlin increased the urgency of US Air Force attempts to compute optimum programs of action. Reminiscing on this task forty years later, George

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[71] William Orchard-Hays, "History of the Development of LP Solvers," *Interfaces* 20 (1990): 61-73, 62.

[72] Herbert A. Simon, "On How to Decide," 496.

[73] Ellsberg is most well-known for his 1971 leak of *The Pentagon Papers*, top-secret decision-making documents on US involvement in Vietnam. Before that he had served as a nuclear strategist at the RAND Corporation and under Secretary of Defense Robert McNamara. While at RAND, Ellsberg ["Risk, Ambiguity, and the Savage Axioms," *Quarterly Journal of Economics* 75, no. 4 (1961): 643–669], demonstrated through experiments a paradox in decision making that violated the assumptions of the expected utility hypothesis so critical to the game theoretic perspective we will encounter in **Chapter Five**. Additional experiments that called into question the strict assumptions of economic rationality will be explored in **Chapter Six**.

[74] Daniel Ellsberg, A Final Comment. *The Review of Economics and Statistics* 40, no. 3 (1958): 229.

Dantzig described the conditions for the development and rapid diffusion of a mathematical protocol that held out the novel prospect of prescribing a rational allocation of resources in a complex system: "The advent or rather *the promise* that the electronic computer would exist soon, the exposure of theoretical mathematicians and economists to real problems during the war, the interest in mechanizing the planning process, and last but not least the availability of money for such applied research all converged during the period 1947-1949. The time was ripe."[75]

Dantzig claimed that "*True optimization* is the revolutionary contribution of modern research to decision processes." With the linear programming model and the simplex solution algorithm, Dantzig and his Air Force colleagues, had initiated "a vast *tooling-up*" that would characterize management science for decades. He acknowledged, however, that "[c]omputation of truly *optimum* programs was of course beyond the original capabilities of SCOOP." [76] For Operation Vittles and most other Air Force operations planned in its five-year existence, Project SCOOP made do with satisficing rather than optimizing protocols.

By the early 1950's operations researchers had the linear programming tool for modeling the optimal allocation of resources across activities and the dynamic programming tool for modeling the optimal allocation of resources across time periods. The essential link of mathematical programming to coding for digital computers was

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[75] George Dantzig, "Linear Programming," ed. by Jan Lenstra, et.al.

[76] George B. Dantzig, "Management Science in the World of Today and Tomorrow," *Management Science* 13 (1967): C-109. Emphases are Dantzig's.

accompanied by the standardization of model formulation and algorithmic design, inductive and deductive time studies of computational procedures, and deskilling goals applied to the data input process as well as the rule-based decision output process. Cold War military specifications for operational numerical solutions to calculation-for-allocation problems forced researchers to confront the bounds of their intended rationality and to direct reasonable deliberation to procedures for achieving good-enough, if not the best, decision rules.

Simon wanted to take this lesson from the normative, prescriptive realm of management science and apply it to descriptive realm of positive economics. According to Simon, economists had made valuable contributions to social science with their explicit and formal assumption of rationality, but they had neglected to take into account the limitations on the computing capacity of the consumers and entrepreneurs that they modeled. For Simon, the economists' representation of rationality as an optimal *outcome* for a goal-oriented decision-maker was unrealistic and incomplete. Simon's emphasis on procedural rationality begged for a psychological focus on the *process* of problem solving. As we will see in the next chapter, psychologists channeled their analytical emphasis on the decision-making process to generating an understanding of the conditions for the de-escalation of tensions surrounding another Cold War blockade – Cuba 1962.

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