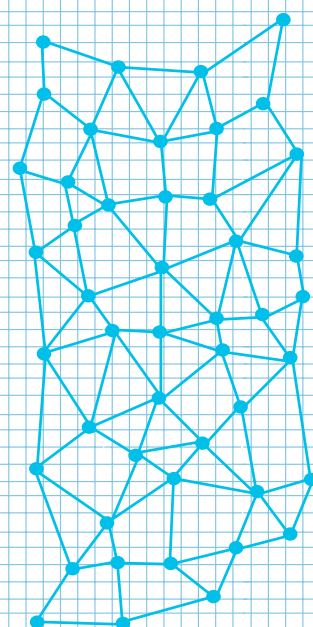
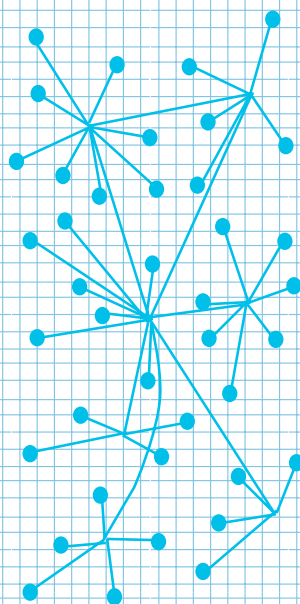
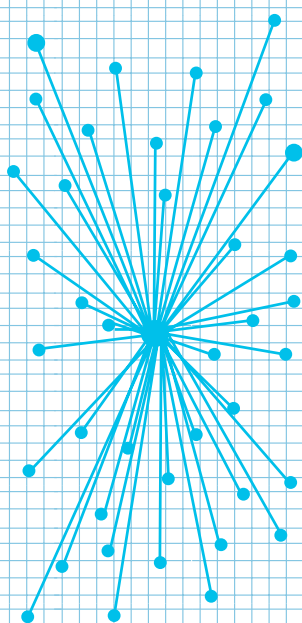


How **RAND** Invented the Postwar World

SATELLITES, SYSTEMS ANALYSIS, COMPUTING, THE INTERNET—ALMOST ALL THE DEFINING FEATURES OF THE INFORMATION AGE WERE SHAPED IN PART AT THE RAND CORPORATION **BY VIRGINIA CAMPBELL**



TO SOME FIRST-RATE ANALYTICAL MINDS, HAVING INTELLECTUAL elbow room in which to carry out advanced research can be a greater lure than money, power, or position. Academic institutions understand this, as do certain sectors of the corporate world. But military organizations, with their emphasis on hierarchy, discipline, and protocol, have traditionally been the least likely to provide the necessary freedom.

During World War II, however, the Commanding General of the U.S. Army Air Forces, H. H. (“Hap”) Arnold, saw creative engineers and scientists come up with key inventions such as radar, the proximity fuze, and, of course, the atomic bomb. He knew that research and development would be even more important in the battles of the future. So before the war ended, he began taking steps to ensure that the wartime spirit of innovation would continue after it was over—and made sure to put a premium on creating a flexible and innovative intellectual environment.

Centralized, decentralized, and distributed networks, from Paul Baran’s prescient 1964 book.

That was the genesis of the original “think tank,” Project RAND, the name being short for Research and Development. (The term *think tank* was coined in Britain during World War II and then imported to the United States to describe RAND’s mission.) The project officially got under way in December 1945, and in March 1946 RAND was launched as a freestanding division within the Douglas Aircraft Company of Santa Monica, California (whose founder, David Douglas, was a longtime close friend of Hap Arnold). A number of other aeronautical enterprises had sprung up or flourished in Southern California during the war, turning the region into a hotbed of aircraft, space, and missile development, so it was a natural location. Arnold made sure that RAND’s agreement with the Air Force gave it two remarkable freedoms: It could initiate its own research as well as respond to Air Force



Exemplifying RAND's mix of seriousness and informality, scientists in suits and ties sit on the floor discussing postnuclear strategy with Albert Wohlstetter (center foreground) at his home in 1958.

A MYSTIQUE HAS ALWAYS SURROUNDED RAND, WITH VIRTUALLY LIMITLESS

requests, and it could turn down Air Force proposals that it believed were inappropriate to the strengths of its 200 staff researchers.

Today the RAND Corporation, as it has been known since it became independent of Douglas in May 1948, is a nonprofit organization with more than 800 researchers. It performs research for many sponsors besides the Air Force, most of them nonmilitary. Throughout its history it has conducted innumerable studies, often with world-changing results, involving technologies both military and civilian. Some of its most exceptional work, though, has gone unsung, for a number of reasons. First, RAND's work consists of ideas and assessments, rather than inventions or manufactured goods. Second, a good part of its most technologically interesting research has been done under secret classification. And third, RAND's preferred public stance has always been one of understatement.

As a result, a certain mystique has always surrounded the RAND Corporation, with both supporters and detractors attributing to it virtually limitless influence and achievements. What is undeniable is that RAND has played a central role in the creation of critical technological developments since World War II, most prominently during the nail-biting era of the Cold War.

The extraordinary feature of RAND that emerged quickly after its creation was its interdisciplinary approach to identifying, evaluating, and applying technology. The organization was structured along conventional academic lines, with departments of mathematics, physics, engineering, economics, psychology, chemistry, and aerodynamics. But under the leadership of Frank Collbohm, a former Douglas test pilot and engineer, and exceptional division heads like John Williams of the mathematics department, RAND sought to cross those lines at every opportunity. Its mathematicians and physicists were urged to be conversant with the concepts its engineers and economists were pursuing, and vice versa.

As Arthur Raymond, the chief engineer of Douglas Aircraft, said in 1947, RAND studied “systems and ways of doing things, rather than particular devices, particular instrumentalities, particular weapons, and we are concerned not merely with the physical aspects of these systems but with the human behavior side as well.” The resulting intellectual crossbreeding bore epochal results. And the fact that all ideas were focused on concrete military challenges put a firmly pragmatic tug on RAND's creative intellectual freedom.

The organization's very first report, “Preliminary Design of an Experimental World-Circling Spaceship,” was issued in May of 1946, within months of RAND's creation. It set an immediate precedent, serving as a model of how orchestrated ideas could forcefully shape the development of technology in several different areas. The report was a detailed engineering feasibility study for a proposed satellite. It spelled out why such a vehicle should be developed: Space was the future; the Air Force should consider space its natural habitat; space offered tremendous advantages in reconnaissance, communications, and weather forecasting. It noted that technologies for launching into space, conducting activities in space, and de-orbiting were within reach.

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Franklin R. Collbohm, a former Douglas engineer and RAND's first president, in his office.



INFLUENCE ATTRIBUTED TO IT.

The report was solid in its engineering, recommending parallel studies on alcohol-liquid oxygen and liquid hydrogen-liquid oxygen as propellants, specifying a maximum desirable acceleration rate, and making a case for multiple-stage rockets. It was prophetic in other respects as well: It specifically defined areas of utility and speculated, for example, that in the future, satellites would be used to guide missiles to targets.

“Preliminary Design for a World-Circling Spaceship” was so direct and clear that it jump-started the minds of those within the Air Force who would, in the crucial years to come, push a host of space initiatives through the natural resistance that radical and expensive proposals engender. In a follow-up paper, the RAND analyst James Lipp remarked: “Since mastery of the elements is a reliable index of material progress, the nation which first makes significant achievements in space travel will be acknowledged as the world leader in both military and scientific techniques. To visualize the impact on the world, one can imagine the consternation and admiration that would be felt here if the United States were to discover suddenly that some other nation had already put up a successful satellite.” This is, of course, what happened a decade later, when the Soviet Union launched its Sputnik satellites. Fortunately, RAND’s first report had provoked the developments that let the United States respond quickly after the Soviet Union’s initial success in space.

RAND’S INTERDISCIPLINARY PHILOSOPHY WAS SO ESSENTIAL to its functioning that it became the driving concern in the architecture of the purpose-built facility RAND moved into in 1953. John Williams had planned the layout of the building to heighten the probability that researchers from different fields would come face-to-face in the course of their daily activities. From the outside, RAND’s headquarters had a functional, unremarkable mid-century look. Inside, however, the small, quiet offices in which analysts worked (there were no traditional laboratories, since RAND was devoted to pencil-and-paper research) were arranged in a two-floor grid around a set of square outdoor courtyards. It was impossible for any economist or psychologist to go far without encountering a physicist or engineer, which meant that theoretical constructs got steadily confronted with the shaping forces of economic reality, human behavior, and utilitarian concerns.

Meanwhile, the interdisciplinary approach was yielding concrete results. A researcher named Ed Paxson used the term *systems analysis* to describe the process of analyzing not just a military operation but the entire complex of activities in which

RAND’s Santa Monica headquarters, designed to promote interaction between disciplines.

the operation occurs. It’s widely taken for granted today, but until the concept of systems analysis was defined and repeatedly demonstrated, people didn’t think that way, especially people in military institutions. The mathematical logician who would become RAND’s most influential analyst, Albert Wohlstetter, put systems analysis to work in a study that realigned U.S. defense policy and determined the direction in which defense-driven technological inquiry would turn.

The Air Force had asked RAND to define the best possible basing scheme for the planes that would drop nuclear bombs on the Soviet Union in the event of war. In its request, the Air Force was assuming that its bombers would be striking preemptively in response to an extremely imminent threat. But suppose, said Wohlstetter, you start by looking at how you would survive a first strike from the Soviet Union and then see what that means for bombers, bases, and the long list of other factors that suddenly come into play. America’s overwhelming—but short-lived—nuclear superiority was probably part of the reason the Air Force had ignored the danger of a surprise attack so soon after Pearl Harbor. In any case, Wohlstetter (whose wife, Roberta, was a RAND researcher and historian working on what would be a classic early study of Pearl Harbor) wrote a report that provoked a huge change, affecting everything from specific mechanical procedures to the entire orientation of strategic policy.

On the simplest level, it established aerial refueling of the strategic bomber force as a routine practice. Wohlstetter’s study made clear that strategic bombers should be based securely within the continental United States and not in Europe, where they would be vulnerable to attack themselves. This made in-flight refueling a must. Wohlstetter’s work also gave high-profile urgency to technologies that enhanced the survivability of military assets, including communications.

In work that ran parallel to Wohlstetter’s, the RAND analyst Bruno Augenstein, who had come to Santa Monica in 1949 from Purdue University, established the technical foundation for the Air Force’s accelerated development of intercontinental ballistic missiles (ICBMs). Essentially, he joined the idea of the nuclear



THE JOHNNIAC WAS BUILT AFTER ANALYSTS DISCOVERED THAT THEY COULDN'T

blast to the idea of rocket propulsion. At that time nuclear bombs were heavy and unwieldy, and rockets were imprecise. But Augenstein realized that if you could achieve more precision in missile guidance, you would need a less powerful blast at the target, which meant a smaller warhead that could be carried by a smaller rocket needing a smaller amount of propulsion.

Augenstein and his team worked out the calculations covering precision guidance, rocket technology, high-yield weapons, re-entry techniques, and strategic reconnaissance to arrive at a set of feasibility alternatives and design tradeoffs. They then gave a four-hour briefing to a Department of Defense committee chaired by the mathematician John Von Neumann, which made recommendations based on RAND's results. Augenstein reported his work in a 1954 memorandum that is widely regarded as the most important document of the missile age. The Air Force's ballistic-missile program would never have received top priority as early as 1955 without it, and since this program helped develop the basic space-launch capability that is used to this day, America's space program would have proceeded more slowly as well.

Though systems analysis was the grand concept behind RAND's highest-profile work, the most important key to RAND's overall creativity was the sheer intellectual force of its mathematics department, with people like Williams, Von Neumann (who served as a consultant), and Willis Ware (who came to RAND in 1952 from Princeton University). At the Institute for Advanced Study, in Princeton, New Jersey, Von Neumann had pioneered the discipline of game theory, which formalizes the human decisions involved in games, negotiations, and so forth

in mathematical terms. Under his influence, RAND researchers added game theory to their arsenal of techniques, using it, for example, to predict the outcome of various scenarios involving nuclear confrontations.

While most of RAND's researchers shunned experimental work, it was the mathematicians, of all people, who got their hands dirty by building a computer, which they affectionately named the Johnniac in honor of Von Neumann. It was simple justice for the computer to be so named, because it was one of fewer than 10 "Princeton-type" parallel scientific computers built to the logic Von Neumann had developed at the Institute for Advanced Study.

THE MACHINE, WHICH BECAME OPERATIONAL IN 1953—four years after Williams and others had determined that they couldn't simply buy what they wanted—was custom-built at RAND with a slate of features that made it groundbreaking and ruggedly adaptable to the most practical concerns. It used punch-card input and output devices, and it was designed to allow easy access to all of its 80 vacuum tubes for ready maintenance. So thorough were the efforts to keep its moving parts cool and operational (most pioneer computers could run without interruption for only painfully short times) that researchers who were exposed to the closed-cycle air cooling system during maintenance began referring to the Johnniac as the Pneumoniac. The Johnniac was remarkably reliable for its time; the IBM 701 that RAND soon acquired never matched it in this respect.

Because RAND needed increasingly complex calculations to attack the problems it had defined through systems analysis, the Johnniac was continually being improved. When storage tubes made by RCA proved too troublesome, RAND had the International Telemeter Corporation develop the first commercially produced magnetic-core memory. The Johnniac also served as a test bed for advances that were later adopted by commercial computer makers, such as the first 140-column-wide, high-speed impact printer and a swapping drum to support multiple users of one of the first online time-sharing systems.

For a think tank like RAND, which deals in analysis, the production of an actual concrete object is a collateral, if not accidental, occurrence. It is for good reason that RAND's researchers as well as the users of its output have long joked that RAND stands for Research and No Development. The Johnniac was one major exception to this rule. Another was the 1955 volume A

Left: The Johnniac's console. Right: Analysts play a war game, with bomb bursts and planes.



COLD WAR CONSIDERATIONS PLAYED DIRECTLY INTO RAND'S ROLE IN DEVEL

Million Random Digits With 100,000 Normal Deviates. (According to RAND legend, the latter half of the title caused the book to be catalogued under Psychology by the New York Public Library.)

RAND developed its collection of random numbers by first building a machine, basically an electronic roulette wheel, to generate them and then subjecting the results to rerandomization and severe testing to weed out any unintentional patterns. RAND needed the numbers for the vast assortment of probability procedures that its research called for. The rest of the world needed them too, for everything from polling to sociological surveys. In a slightly more esoteric application, there is the story of the submarine commander who kept *A Million Random Digits* next to him when his sub was on patrol duty for use in setting his evasion courses. The book went through three printings by 1971, stood the test of time as a standardized text, and was reprinted anew in 2001. Within RAND, the joke about this surprise classic is that it is perhaps the only case in which a random misprint would not be considered an error.

RAND's work on reconnaissance, which began in its earliest years and continued for decades, resulted in some of its most impressive accomplishments. The organization's studies in infrared detection in the early 1950s led directly to the space-based early-warning system against Soviet attack. RAND researchers verified by calculation that sensors could detect the exhaust plume of a rocket sitting on a launch pad.

Only since the mid-1990s, with the declassification of work from the 1950s, has RAND's most interesting work in space reconnaissance been put in perspective. Back in 1946 RAND was avidly touting the importance of space vehicles when the rest of the world looked upon such notions as mere fodder for Hollywood. In the early 1950s the RAND researcher James Lipp led Project Feed Back, which made a passionate case for the feasibility of a reconnaissance system in which orbiting television cameras would transmit back to earth electronic data, giving the Air Force real-time images of enemy assets.

The technologies involved in bringing this off—including rocket propulsion, television cameras, and electronic transmission—were in various stages of development, some sufficiently short of maturity to give the Air Force pause. In general the Pentagon put far greater trust in spy planes, but the Air Force allowed RAND to continue its work on space reconnaissance.

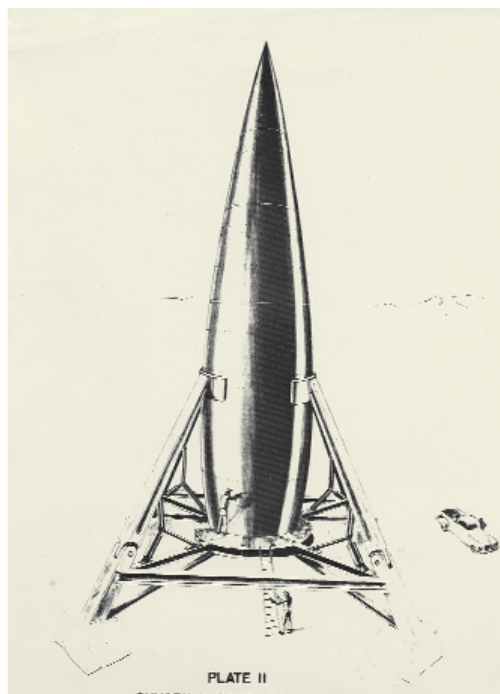
ONE IMPORTANT ELEMENT THAT PROJECT FEED BACK envisioned was the use of magnetic-tape storage to hold video images until the satellite flew over a point where they could be transmitted back to earth. As part of the study, RAND contracted with a small California company called Ampex Corporation that was doing groundbreaking work on video recording and magnetic tape. RAND's support spurred on Ampex's efforts, which proved crucial to the development of the commercial video-recording industry we have today.

The RAND researchers Amrom Katz and Merton Davies tirelessly briefed decision makers on Project Feed Back, continuing to argue in favor of space as a reconnaissance arena for the Air Force. RAND's 1954 Project Feed Back report became the blueprint for the development of an Air Force space reconnaissance vehicle,

and the contract for the vehicle, identified as WS-117L, went to Lockheed in 1956.

Back at RAND, Katz and Davies watched as electronic transmission difficulties began to bog down progress on WS-117L. But their colleague Richard Raymond had suggested a design that did not use a video camera and hence did not require video storage or transmission. It used conventional photography and depended on a re-entry vehicle that would be deorbited to bring film back for midair retrieval. As outlandish as the idea sounded, it required only technologies that were already developed. Re-entry technology—basically the search for an adequate heat shield—had progressed quickly under the impetus of ICBM research. And the midair film-retrieval procedure had already been shown to work in the

An illustration from RAND's first report, on a "world-circling spaceship," in 1946.



OPING THE CONCEPT BEHIND WHAT WE NOW KNOW AS THE INTERNET.

upper atmosphere with weather and reconnaissance balloons.

The Air Force objected to Raymond's idea, mostly because it wanted real-time reconnaissance and judged his approach far too slow. Then the Soviet Union launched its Sputniks in 1957, sending a shock wave through the Pentagon. Suddenly the midair retrieval system, which yielded pictures at least as quickly as reconnaissance planes, began to look very good as an interim strategy.

Spurred by new urgency, WS-117L was redefined and became highly classified under CIA management. The public, which had become aware of WS-117L from press coverage, was told that the project had been canceled. Even Katz and Davies, whose advocacy had helped bring about what was now taking place, were never told the truth. The reasoning was that Katz was such a talker that he would raise suspicion if he abruptly dropped his favorite subject, as he would have to do. Space reconnaissance throughout the 1960s was done very much as Katz and Davies had urged. The system was crucial to the nation's defense, because not until the 1970s were the problems associated with electronic transmission of high-resolution video images back to earth finally worked out.

Cold War considerations also played directly into RAND's role in developing the concept behind what we now know as the Internet. In 1959 RAND's reputation for intellectual freedom induced a young engineer named Paul Baran to leave Hughes Aircraft and pursue his interests at RAND, a few miles away. Baran was intensely interested in improving the reliability of the military "command and control" system—the means of communicating crucial information and orders from one level of command to another. This system could come under severe strain when it was most needed, in the event of an enemy attack.

Even before arriving at RAND, Baran had been thinking about the concepts of redundancy and rerouting that were put forth in the neurobiologist Warren McCulloch's work on "neural nets." When he heard that the Air Force had asked

RAND to look into the survivability of command-and-control structures in a nuclear war, he joined the project with the idea that McCulloch's work with human brains might provide a fruitful analogy, even a model.

The question Baran first confronted was this: How, in the event of a strike against the United States that might take out critical points of the command-and-control hierarchy, could the "go" or "no go" command for a counterstrike be communicated? This was a chilling, unanswered question in 1960, when tensions between America and the Soviet Union were fierce and unstable. Baran had heard RAND's president, Frank Collbohm, express reservations about the Air Force's dependence on high-

frequency communication and suggest using AM radio stations for survivability. So Baran, using RAND's Johnniac, plotted AM radio stations across the country and outlined a redundant network for communicating a simple, crucial "go" or "no go" message.

On the basis of Baran's work, the Air Force built the first emergency broadcast system by "hijacking" the AM network and sending a signal that couldn't be heard on radio but could be transmitted from node to node. However, once Baran had talked with people at Air Force bases

around the country, he knew that communicating a "go" or "no go" message was a very bare minimum requirement and that unlimited communication was what was ultimately needed. To have that in a robust, redundant system, digital technology was called for.

That's where Baran's key idea came in. He envisioned breaking each message into standardized blocks of data, with each block containing information about its recipient, its origin, the length of time it had been in the network, and its position within the message of which it was a part. A series of blocks would go out into the network and make their way through it in any sequence they could—each one sending back a confirmation from the new node to the previous node—until all the blocks arrived at their destination. If a certain node was not available, a block that was sent to it would bounce back



Roger Johnson of RAND shows a model of an experimental airplane.

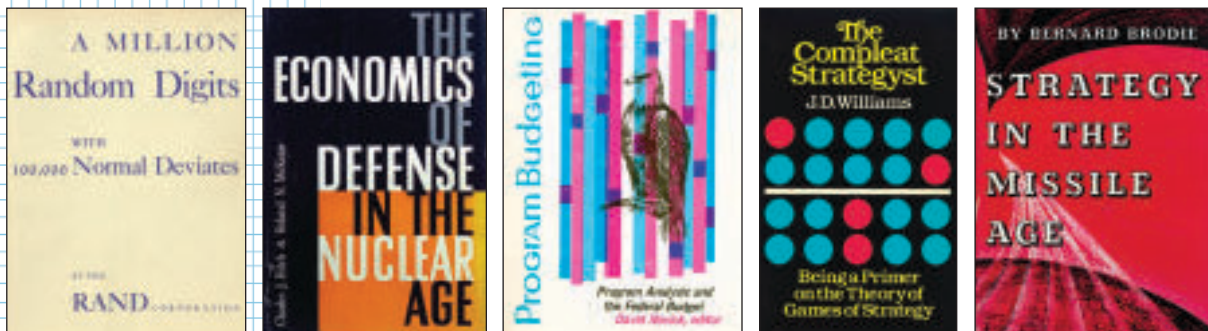
FROM A STRICTLY TECHNOLOGICAL STANDPOINT, THE RAND CORPORATION'S

and tell the node it had just come from to avoid sending any further blocks that way. When all the blocks reached their destination, they were reconstituted into a message.

Baran's idea was a brilliant inspiration to those who understood the concept of digital technology. But 40-odd years ago the digital universe was little more than fantasy to a world immersed in analogue reality. The people in charge of the nation's largest, farthest-reaching communication system, the telephone monopoly of AT&T, were analogue folk. AT&T even refused to listen to its own innovative research division, Bell Labs, and turned down the Air Force's request for a study of digital network possibilities. Prodded by RAND, the Air Force decided to do the work itself. Then the Department of Defense intervened to decree that work of this type belonged exclusively

on ARPA projects in 1969, and over the following decades it gradually shed its military orientation to become the Internet we know today.

Just as consequential as RAND's contributions to the Internet were its accomplishments in computer software, particularly the software it developed for linear programming. Linear programming (with *programming* used in the sense of planning or allocation, not as a reference to computing) basically involves finding the optimum value for a multivariable function governed by a system of linear equations. One classic problem involves designing a diet that will contain specified minimum levels of certain nutrients. Given an assortment of possible foods, along with their prices and a list of what nutrients they contain, what is the cheapest way to satisfy the constraint?



under the purview of the Defense Communications Agency, not the Air Force. But the DCA wasn't interested in digital technology, so nothing happened.

The instigation for the Internet ultimately came in 1966, when Robert Taylor, director of the Information Processing Techniques Office of the Defense Department's Advanced Research Projects Agency (ARPA, now known as DARPA), was looking for a way to exchange computer files among researchers around the country. Although Baran had briefed ARPA many times on his network concept, the architecture that researchers settled on for the ARPANET was that proposed by the British physicist Donald Davies, who in 1965 had independently reinvented the same technology.

Davies had coined the term *packet switching* for his network concept and had presented briefings in the United States in 1967. This turned out to be the right time for his ideas to get a hearing; Baran had come up with his own version of a network before the communications world was ready to think in digital terms. ARPANET began linking scientists at work

RAND has published many books over the years, aimed at widely varying groups of readers.

Many problems of this type come up in management. The inputs may be raw materials, personnel, or mechanical parts, for example, and the constraints may involve cost, time,

weight, or some other limiting factor.

Linear-programming problems can be expressed using matrices and vectors and handled with the techniques of linear algebra, but since they are usually underdetermined (that is, there are fewer constraints than variables), the standard methods of solving exact systems of equations do not apply. In the late 1940s George Dantzig of RAND developed the simplex method for solving linear-programming problems. In essence, it involves expressing the set of all allowable solutions as a polyhedron and going from one vertex to another until the optimum solution appears.

The simplex method was indeed simple, and it was brilliant. Industrial processes, management planning, and many other complex situations that could be formulated as linear-program-

GLORY DAYS CAN BE SAID TO HAVE ENDED SOMETIME IN THE LATE 1960S.

ming problems could suddenly be solved in a hurry with the aid of a computer. In a 1963 RAND report, Dantzig described the simplex method in action: "To solve [the problem earlier described] by brute force . . . would require solar systems full of nano-second electronic computers running from the time of the big bang until the time the Universe grows cold to scan all the permutations in order to be certain which is best. Yet it takes only a second using an IBM-370-168 and standard simplex method software."

PRECISION AND ACCURACY ARE DIFFERENT THINGS, OF course, and any analytical solution, no matter how clever, is only as good as the model used to derive it. In the excitement that attended RAND's advances, some enthusiasts got carried away and forgot this important truth. In an echo of Jeremy Bentham's "felicific calculus" of the eighteenth century, ambitious social scientists tried to express a host of amorphously defined social benefits and costs with mathematical equations and use them to make "scientific" policy decisions on economic, budgetary, and natural-resource issues. Robert McNamara, who had been an enthusiast of RAND-style analysis as a high-ranking executive at the Ford Motor Company, tried to run the Vietnam War with models and computers, learning too late that unanticipated factors without a variable in the equation can greatly alter the outcome.

From a strictly technological standpoint, RAND's glory days ended sometime in the late 1960s. By then the Air Force had drawn significant benefits from RAND's emphasis on free inquiry, cross-fertilization, and systems analysis, and its own research activities had incorporated these techniques. Other organizations and businesses saw that RAND's research could be useful to them, and they began offering subsidies for projects that had nothing to do with the military. As the 1970s wore on, RAND shifted more and more from actively creating the frontiers of technology to concentrating on policy analysis, military and nonmilitary. These studies have ranged far afield. One mid-1970s report, for example, suggested that some recovering alcoholics could safely drink in moderation instead of abstaining completely. Another set of studies evaluated cost, safety, and environmental impact for a proposed set of storm barriers along the Netherlands' northern coast. More recent publications have run the gamut from the arts to counter-terrorism.

RAND's policy-centered work has been impressive and influential, but most of it has not occurred at the

active frontier of technological advance. Both Willis Ware and Bruno Augenstein have suggested that the time and place (post-World War II Southern California) in which RAND was created had a great deal to do with the intellectual leaps it came up with. RAND's early reconnaissance research not only prompted technological innovations in the military but also spurred private-sector developments like video recording. That work was declassified only in the mid-1990s, and the next decades may well reveal other consequential research that can only be hinted at now. In the meantime, the advances that can be discussed, such as the work that Paul Baran did leading to the Internet, make a persuasive case that an organization whose sole job is to generate ideas can promote the advance of technologies with the power to change the life of an entire culture. ★

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An Air Force officer peers out from a room used by umpires in RAND's war games.