tual isolation of many oceanographic institutions needs to be corrected. Attempts should be made to associate oceanographic institutions with groups of universities to permit easy access by scientists throughout the country for work in ocean activities."

Other interesting qualities of the report are its conservatism, candor, and political sophistication. The general style of a disciplinary brief is to go for broke, to list all possibilities and predict national misfortune if they are not pursued. But the panel says that no more ocean survey ships are needed, that current technology does not warrant serious consideration of "deep-ocean airplanes" in the next decade, and that there is no need for accelerating research on deep-sea mining of minerals. It points out, "The mining and petroleum industries have shown a considerable willingness to invest in the development of ocean or any other resources wherever commercial prospects appear reasonably good. . . . Thus development of ocean raw materials is now subject to a market test that seems to be yielding reasonably sensible answers."

The panel stresses the military value of oceanography, and provides an interesting insight into a rarely discussed dimension of the arms race: concern over the possibility that the Soviets might develop techniques for continuous tracking of Polaris submarines. But on nonmilitary matters, it does not try to scare up support by warning what the Russians are doing, which is something of a landmark in scientific salesmanship. Whereas the Academy's Committee on Oceanography predicted great gains for U.S. fisheries from oceanographic research, the PSAC panel notes that "present performance suggests that foreign fleets would be quicker than U.S. industry to adopt new techniques." A rationale might be found, it adds, in the U.S. policy of seeking to improve the nutrition of the underdeveloped countries. But, in that case, it points out, the justification should be sought in foreign policy considerations and not in a direct economic return that is not likely to materialize.

Where the report does look for political support is in terms of the goals of the Great Society and the relative utility of oceanography versus space research. Noting "the ready and widespread Congressional acceptance of Great Society programs" aimed at eliminating environmental pollution, it says that oceanographic research and programs dovetail with this goal and can therefore be expected to attract support. The report states that "in any competition for funds with the space program, the case for oceanography would be very good." But it adds, "In making this statement we recognize many intangibles which are often used to justify programs."

MacDonald, chairman of the PSAC panel that produced the report, is a member of a new generation that is coming into the upper councils of science and government. At age 37, he is one of the few persons in these echelons who is not an alumnus of the World War II research effort. He has been a member of the Academy and of PSAC for several years, and in September will start a 2-year leave from U.C.L.A. to serve as vice president of the Institute of Defense Analysis, a Washington-based think-factory that serves the Defense Department. With his broad scientific background—he is widely considered to be one of the most versatile and creative geophysicists—and seasoning in the complex mix of military technology and strategy, politics, and science policy, MacDonald is extremely well regarded by the elders of science and government.—D. S. Greenberg

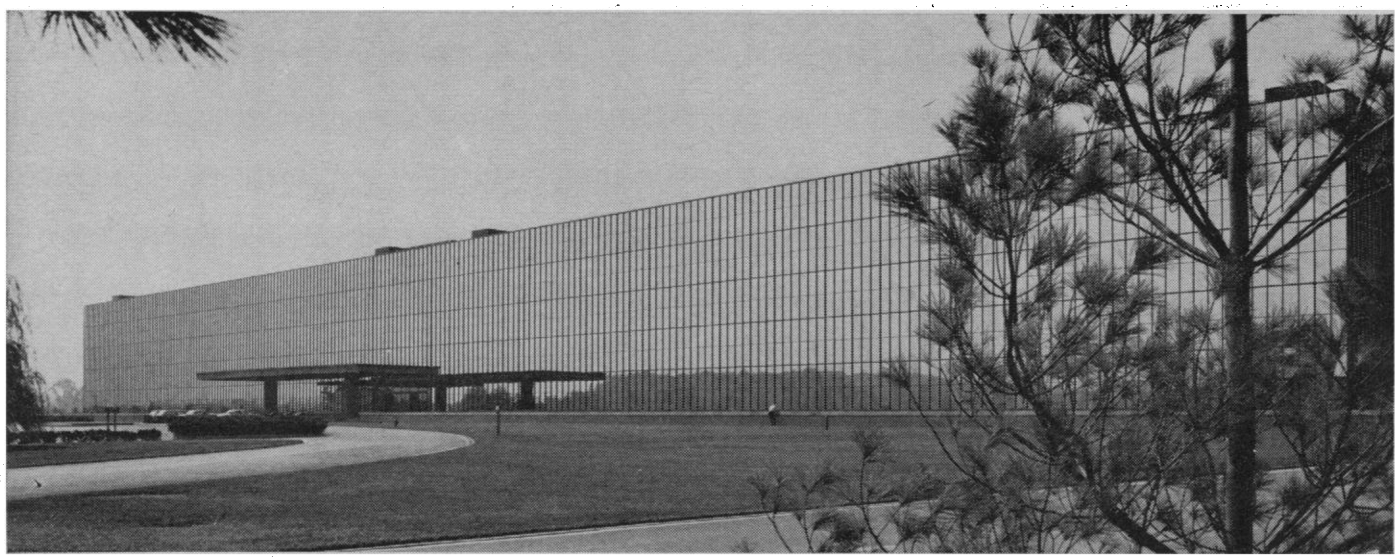
Bell Labs: A Systems Approach to Innovation Is the Main Thing

In a country setting about 30 miles south of New York City and off the Garden State Parkway you encounter the rectilinear bulk of the Bell Telephone Laboratories new Holmdel building, its one-way glass reflecting the landscape and sky of the Jersey littoral. The big building, now in the final stages of completion, is one of the posthumous works of the late Eero Saarinen, the pacesetter and chief prizewinner in monumental modern architecture in recent years. In the Holmdel building Saarinen seems to have been striving to create an outsize symbol of the organization which pioneered the integration of research, development, and manufacturing into a continuous process and which may still manage it best.

The Holmdel building, built at a cost put officially at $34,000,000, is really four buildings enclosed in a big glass box. Perimeter corridors on each floor of the four units are designed to carry traffic away from labs and offices on cross hallways. Inside corridors open on a huge, cruciform lobby and reception area, which, rising to the roof, reminds one of nothing so much as of the nave and transepts of a cathedral.

By ingenious design of office and lab areas Saarinen provided both flexibility in respect to space and islands of quiet. For some occupants the question now is when does privacy become isolation. Since the front half of the building was put into use in 1962, but the back half is only now being completed, the verdict on the building will not be in for some time. It is evident, however, that Holmdel represents an interesting experiment in the effect of novel facilities on research atmosphere.

Ultimately, some 4500 people will work at Holmdel, primarily on development and systems engineering problems. This roughly equals the present number at Bell Labs Murray Hill site, an hour's drive northwest. Murray Hill is where fundamental research for Bell Labs is centered, where administrative headquarters are located, and where general services will be transferred now that the old West Street Building in New York City, where the labs began, is being "phased out." A third major Bell Labs facility in North Jersey is at Whippany where military work for the government, principally on the Nike antimissile project, is running at the rate of more than $170 million a year. Another major laboratory site at In-



Bell Labs' Holmdel Building. The $34 million structure, designed by the late Eero Saarinen, will eventually house a staff of 4500.

dian Hill, outside Chicago, is under construction and will be devoted to development work on the new electronic switching systems. Small laboratories are attached to a dozen Western Electric plants.

In an era of big, federally financed, applied research and development in industry, Bell Labs, which draws more than half of its nearly $400 million annual budget from corporate sources, remains among the biggest of industrial R&D efforts. Bell Labs is the research arm of the Bell telecommunications system which is composed of the American Telephone and Telegraph Company, Western Electric Company, and the operating Bell telephone companies. A.T.&T. is a holding company which provides financing and general services for the system and operates its long lines. Western Electric is the system's manufacturing arm. A.T.&T. owns 90 percent of Western Electric, and both share ownership of Bell Labs. The working principle is that A.T.&T. shall pay for research and systems engineering work at the Labs and Western Electric for development work. This year's budget calls for contribution of $85 million by A.T.&T., $138 million by Western Electric.

From the beginning the Bell enterprise stressed organized innovation. As early as 1883 an "experimental shop" was established to simplify and improve apparatus and also to work on such problems as protecting the system from lightning and other strong electrical currents, developing long lines, and improving central office control. While theory and hardware have changed continuously, basic problems of transmission and switching still are major preoccupations.

The issue of autonomy for the labs was not, however, settled in the early days, and the nascent labs were vulnerable to demands from the operating companies and the manufacturing unit to do the kind of emergency problem solving that the Labs people still call "fire fighting."

The realization grew, however, that the best interests of the organization could be served by protecting the innovators from distractions and by adding, to what was essentially a development lab, a capacity to perform fundamental research. (The rationale then as now, as one executive puts it, was that "You'll be better off in 10 years if you understand the fundamentals now.") In 1911 the "engineering department," then lodged in Western Electric, was set up specifically to undertake fundamental research. This research section employed physicists recruited from among faculty and graduates of leading universities and established a pattern of recruiting and employment which still prevails. Bell Labs assumed its present form in 1925, when the Engineering Department and patent departments were combined and incorporated.

The Bell system is a public utility with a near-national monopoly involving not only service but the manufacture of equipment. The whole structure is currently under the official scrutiny of the Federal Communications Commission. Bell Labs is an integral part of the system, and Bell Labs policy makers give the impression of people who have had a lot of practice in walking an invisible tightrope. The peculiar situation, as a matter of fact, seems to have contributed to giving sharp definition to the mission of the labs and also to giving them a style.

In a broad sense, the mission of the Labs is achieving better communications, particularly telecommunications. What is also implied is that Bell Labs will not deploy its great resources in directions that will take it into areas where antitrust action might be invoked.

In practical terms, Bell Labs' function is to make possible the design of equipment which can be manufactured to improve the telephone system. At the same time, the labs contain a community of scientists and engineers aware of a more disinterested mission; as vice president for research W. O. Baker put it, "of linking the advance of science with great human problems." This dual concern—for profits and public service—seems to have provided a potent fuel.

Bell Labs is divided into three parts: research, systems engineering, and development and design. Of the 14,700 people employed by BTL in early 1966, some 4700 were scientists and engineers on the so-called technical staff. (Some 17 percent of the technical staff hold doctorates, 50 percent master's degrees and 28 percent bachelor's. The remaining 5 percent without degrees are mainly oldtimers.) Of these, 3400 were engaged in development and design work, 800 in systems engineering, and 530 on fundamental research. The remaining employees were divided between 5500 technical support workers and 4500 in administration and services.

For those engaged in fundamental research, the question of reconciling the interests of the individual investigator with the interests of the laboratories is of course a key one. In a chapter he contributed to a book on the organization of research establishments, Bell Labs president James B. Fisk had this to say.

"One of our thoughtful research administrators of recent years, Dr. Ralph Bown, in reflecting on the latitudes necessary to a productive research organization, saw two freedoms as requiring vigorous defence: the freedom to resist pressures from the development departments to work on their specific problems, and the freedom occasionally to carry ideas experimentally into the applicational stage to a point where merit can be demonstrated, when the researcher considers that this merit has not been recognized or has been overshadowed by development schedule pressures. The wise researchers will know that these freedoms have to be merited and that they impose obligations. The first freedom cannot ignore the occasional emergency where all available skill must be enlisted to solve a serious fundamental problem. The second cannot extend to stubborn clinging to a favourite scheme when wisdom would call for new approaches or a new activity."

It appears that a major influence in keeping an investigator from being carried too far off the track of relevant research is, as Baker put it, "the cultural influence of the community." Getting the glazed-eye treatment from colleagues is an effective way of keeping researchers from going too far afield.

Equality for Development

To flourish, Bell Labs believes it necessary to maintain a highly competent development organization to carry on the ideas of the researchers. The development staff members are accorded equal status with the researchers, are paid under the same salary schedule, and are treated in the same way as the research staff, with the signal exception that engineers and scientists doing development work are expected to meet deadlines with a fidelity not required of those who do what is locally known as "uninhibited research."

Development work accounts for more than two-thirds of the technical staff and a lion's share of the budget. As J. P. Molnar, executive vice president for development put it, "An invention needs working on before it is usable. Developing a component is one thing, developing a system is another. The cost of development is about ten times the cost of an invention."

Development work runs the gamut from "exploratory development," which is at the forefront of applied research, to final development chores usually performed at branch laboratories located at the factories, where a major task of development engineers is to expedite the application of advanced techniques.

A third major group in the laboratories, the systems engineers, have acquired a clearer identity of their own since the technological advances of World War II made the choice of new systems much more complex and created a need for their expertise. The systems engineers have to understand the implications of current research and be familiar with the needs of the operating companies. They are not simply middlemen, but have a major responsibility for systems planning. One of their chief tasks is to be sure that new components and systems will be compatible with the overall Bell system.

Systems engineers have to be concerned with questions of cost, quality, and reliability and essentially are faced with the same sorts of problems that confront Defense Department planners in choosing "technical paths" when new and prodigiously expensive weapons systems are under consideration. The decision on when a new device or system has developed sufficiently to be put into service economically is one which involves cost effectiveness–type analyses, the exercise of engineering judgment, and, always, something of a gamble.

The Bell system is now beginning the transition to an Electronic Switching System (ESS) which essentially means a jump to automated central offices with computer-like equipment doing most of the work. The stored-program aspects of the central equipment has kept causing trouble, at least until recently. More difficulties may crop up which haven't been evident in the lab or even in field tests. Manufacture and installation of ESS centrals are scheduled to begin soon, however, a move that involves a large commitment of funds, some risks.

Criticism to which Bell Labs people seem sensitive, since they often raise it, is that the labs are "conservative" or "stodgy." The example most often cited is the laying of the first transoceanic telephone cable in 1956. Not only did this seem to many a rather late date in view of the state of the art, but the use of vacuum tubes in the amplifiers or repeaters in the cable appeared to be an oddly cautious move since transistors by the middle 1950's looked to be sending the vacuum tube the way of the buggy whip. The reasoning of those responsible for laying the cable, however, was straightforward. The repeaters were to be designed for 20 years of trouble-free service, since single repairs of the cable would cost hundreds of thousands of dollars. Repeaters with vacuum tubes passed the test of reliability while those with transistors could not, so the decision was a simple one. The moral is that where so much money is involved conservatism is the only policy.

While awarding credit where credit is due in science is often a risky business, the Labs' half-century record of achievement in both fundamental research and applications is an imposing one.

Out of the Labs in the 1920's came the coaxial cable which made possible the transmission of multiple messages over a single cable. The 1940's saw the development of microwave radio relay systems capable of handling thousands of two-way telephone conversations or providing multiple television or data circuits. In addition to the flood of inventions which made possible the vast expansion of the telephone system, the Labs made crucial contributions in such neighboring areas as motion picture, high-fidelity, and stereophonic sound.

A Founding Father

In basic science, the Labs' accomplishments have also been substantial. A classic example occurred in the early 1930's when Karl J. Jansky, while using a rotating antenna to study interference in radiotelephone service, identified a persistent hissing sound as radio signals generated by the stars and galaxies. Jansky did not pursue his discovery since there did not seem to be much in it for the Bell system, but the science of radio astronomy developed from this by-product of his research.

Work done at the Labs has also figured in at least three Nobel Prizes. Clinton P. Davisson shared the 1937 physics prize for work on the wave nature of matter in which he had collaborated at Bell Labs. In 1956 Walter H. Brattain, William Shockley, and John Bardeen, all BTL technical staff members, shared an all-BTL prize in physics for invention of the transistor.

Charles Townes shared the 1964 Nobel Prize in physics for work in quantum mechanics that led to the development of lasers. Townes did his work in the early 1950's while a professor at Columbia and a consultant at Bell Labs.

For a laboratory concerned with telecommunications, research at BTL sometimes follows unlikely pathways. A small group in molecular biology, for example, operates at Murray Hill. While it may seem a slender threat, what the molecular biologists have to say about information storage as related to memory is relevant to the Labs' mission.

Equally surprising on the face of it, perhaps, has been Bell Labs contribution to the construction costs and operating expenses of a low-energy nuclear accelerator at Rutgers. Particle detectors proved useful in detecting radiation damage in the Telstar communications satellite and encouraged the Labs in the attitude that what low-energy physics reveals about nuclear structure may be very useful for communications.

The working rule at BTL seems to be that when efforts in fundamental research are on a modest scale it is not necessary to see exactly where they will lead in technology. The research department in part serves as a "sensory apparatus" for the Labs in keeping in touch with general developments in science, and this justifies having people around with a wide spectrum of talents and interests.

There are some disadvantages for Bell Labs researchers working in the more thinly represented branches of the physical sciences or in the life or behavioral sciences. The problem of finding people to talk shop to and limitations of the library in these fields seem to be the main ones.

In drawing up a balance sheet of advantages and disadvantages people at Bell Labs tend almost invariably to use the university as the object of comparison rather than other industrial laboratories. It seems to be an article of faith and policy that the Labs must offer conditions similar to the "freedom of the university" to attract the people it wants.

Emphasis is placed on individual effort and, while voluntary association of researchers, often from quite different disciplines, is encouraged, regimented "group" research is regarded as inconsistent with the Bell Labs zeitgeist.

The location of the three major BTL facilities on the fringes of North Jersey's megalopolitan suburbs seems to satisfy most of the technical staff. The public schools are generally good, housing is available at acceptable costs, New York is readily accessible, and so is the Jersey seashore. Abandonment of the West Street building seems to have been hastened by the reluctance of research men to endure the same commuting tribulations that afflict those who work on Madison Avenue, Wall Street, and in the garment district. Those engaged in basic research, however, do admit missing ready access to an academic research facility of the quality, say, of Columbia. Efforts now are being made to establish an "institute for science and technology in New Jersey" which would provide heavily industrialized North Jersey with something of what Harvard and M.I.T. on one coast and Berkeley and Stanford on the other offer their areas.

The Balance Sheet

For those who dislike teaching and university committee work the advantages of research at BTL are evident. Salaries are good, but, because of the delicacy of Bell's relationship with the public and the government, they are not lavish. A good academic scientist usually derives his earned income these days from a combination of academic-year salary, summer pay from his research grants, and fees for consulting. On the average, the pay of Bell Labs researchers equals the first two elements for a faculty member at a good university. There is, however, a "dual ladder" principle in informal operation at Bell Labs which makes it possible for the most productive researchers to earn salaries which equal and surpass those paid to top administrators.

Publication of research results is encouraged. All papers and talks are automatically subjected to an internal patent review and must also pass muster on grounds of quality of scholarship before they are released. Patents are taken out in the name of the inventor but assigned to Bell Labs, which is standard practice for industrial laboratories.

Opportunities to travel to professional meetings in this country and in Europe seem to be about the same for BTL researchers as they are for their university counterparts. Travel to meetings in other parts of the world may be more limited.

All members of the technical staff are now expected to attain at least master's degree level. The Labs will pay for a "year on campus" program which many new employees with bachelor's degrees opt for. An alternative is a work-study program which takes longer. Successful completion of the courses, which the Labs collaborate in developing, is a condition of continued employment. The extension of support to doctoral study is now being pondered, especially since the support programs have served as attractive bait in competing for the best graduates.

Stable financial support of the Labs seems to figure in their appeal. One candid researcher pointed out that if he were working in a university he would have to waste a lot of time promoting grants. Others suggested that universities these days are split over whether their mission is research or education, while at an industrial laboratory there is no confusion over identity.

There is of course no tenure at BTL and this is regarded as a good thing. All members of the technical staff up to the top administrators are rated under what is called the "octile" system (everyone is placed in one of eight categories according to age and merit and can figure out where he stands). While company regulations seem to cover just about everything, they do not mention an unwritten rule that a man in a technical post has 10 years to prove himself. If he falls short of BTL standards he will be encouraged to look for fairer fields. Many people, it is said, leave Bell to take better paying jobs. But one advantage of the organization is that there are multiple opportunities. A researcher, for example, may find a better outlet for his talents in applied work or administration at the Labs or perhaps in one of the associated companies.

Those who stay and prosper are not cast in any particular organization-man mold, except, perhaps in one respect. They do exude a common aura of confidence that seems generated by a record of corporate accomplishment and a conviction that they are part of an institution riding the crest of the wave of the future.

—JOHN WALSH

A second article will deal with the rapidly expanding use of computers at Bell Labs as both a research tool and an integral part of telecommunications equipment.