

REMEDIES FOR TELECOM RECOVERY

BASIC RESEARCH IN TELECOMMUNICATIONS

**Report of the Advisory Committee
On
Basic Research in Telecommunications**

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Report

Workshop on Basic Research in Telecommunication

May 23, 2003

Sponsored by:

Annenberg School for Communication at the University of Southern California
Columbia Institute for Tele-Information at Columbia University
Galileo Marconi International Fellowship Foundation at Columbia University.

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Report of Workshop on Basic Research in Telecommunication

“Leave the beaten track occasionally and dive into the woods.
You will be certain to find something that you have never seen before.”
Alexander Graham Bell (1847-1947)

SUMMARY

This report summarizes the deliberations of a workshop to discuss the current state of basic research related to telecommunication. A group of distinguished leaders of telecommunication research, most of whom have led or performed work at Bell Labs or one of its offspring, were invited to participate in the workshop, which was held on the afternoon of May 23, 2003 on the campus of Columbia University.

The overall consensus was that there is a problem facing the future of basic research in telecommunication because of inadequate levels of support and increasing emphases on short term applications. These factors are largely a result of restructuring, the resulting competition, and the poor financial health of the telecommunication industry. The conclusion was that government support is warranted and required in the interest of innovation, economic growth, national security, balance of trade, and other national goals. While recommendations were made and potential models explored, the specifics of the mechanism for such support were unclear, as were the ways to assure relevance and connection between basic research and the practical problems of the telecommunication industry.

The workshop raised more questions than it put to rest. That, in fact, was its purpose—to help open the dialogue and catalyze a response, ultimately with a broader set of interested parties who are increasingly vocal in their concerns about basic research in the United States today. In capturing the workshop deliberations, this report therefore does not represent new or detailed research into the problem, but instead highlights the general views of the participants.

BACKGROUND

The fate of fundamental telecommunication research conducted at industrial laboratories seems to be at risk. Since the Bell breakup of 1984, this basic research previously performed exclusively at Bell Labs has become increasingly fragmented. Today the remaining research units are at AT&T, Telecordia, Lucent Technologies, Avaya Systems, and Agere Systems. Cutbacks and changing missions afflict these entities, thereby threatening the environment for basic research. The computer industry's labs are not filling the void—they have only limited overlap in mission and face many of the same market constraints as the telecommunication industry. Academic research has not focused that strongly on telecommunication basic research and traditionally is challenged by the issues of mission and proximity to real problems. Yet, as it has in the past, the long-term future of telecommunication in the United States will continue to be shaped by advances in basic fundamental research.

The decline in basic telecom research is the subject of increasing concern. On the very day the workshop took place, the front page of the Wall Street Journal heralded the stakes. Days before, the Bush Administration reconstituted the President's Information Technology Advisory Committee. In parallel, the National Research Council is leading an exploration into the subject. This fall, CITI will be holding an event to report on its policy recommendations for the recovery of the

telecommunication industry. Despite concerns at these levels, however, the feeling among the general public is that there is a glut of technology—90 percent, or more, of the potential capacity of U.S. fiber optic networks is currently said to go unused, and yet new high-tech advances in capacity continue to appear on the scene.

WHY IS BASIC RESEARCH IMPORTANT?

Usually, it takes from 10 to 20 years for the application of basic research to evolve into practical results. This long-term horizon has become difficult for industry to justify in today's competitive world with its emphasis on short-term profitability and incremental developments.

Basic research is the unfettered exploration of new knowledge, resulting in discoveries and innovation. The conduct of the research is defined by the researchers themselves, rather than by concerns for improvements in current products and services. Knowledge and illuminating the way for the future are the goals of basic research.

The history of the science and technology of telecommunication shows a steady stream of important discoveries and advances flowing from basic research, such as the transistor, the laser, microwave radio, and communication satellites, to mention just a few. This kind of innovation has contributed to affordable telecommunication for all people around the world and specifically to a telecommunication industry that generate nearly 3% of the gross national product of the United States.

The new knowledge and discoveries that result from basic research create the foundation for surprises in the future of communication. The same knowledge also helps prevent unanticipated surprises. For example, electronic, computer-controlled switching changed telephone switching. Yet the basic concepts of electronic switching were discovered decades before its implementation in actual switching machines. There is a need for scouting by competent researchers of where technology is going, since this helps illuminate the future.

Yet innovation appears to be on the decline in the United States. It is debatable whether this is unique to the United States or a worldwide trend. If unique, then the United States risks being left behind other countries in the discovery of new knowledge and its application to goods and services.

Basic research is important to global competitiveness in another way. Developing nations seem able to manufacture anything more cheaply than anyone else. Thus with such globalism, the only way to stay ahead is to innovate. Those doing the basic research have clear "first mover" advantages.

There is a need for the real innovations that come from basic research in telecommunication. The future of telecommunication was determined very much by such research in the past. Today's world of telecommunication would be very sparse without these past innovations. These past discoveries and innovations indicate that research will result in future innovation, equally impressive and significant.

National security is of much concern, along with issues of network reliability and vulnerability. A broader view of networks is required to supplement and even replace the disjointed views of individual carriers.

IS THERE A PROBLEM?

The overall majority of the participants believed strongly that there is a problem with the current state of telecommunication basic research. Some felt that the problems were specific only to certain areas. In comparing today's Bell legacy with Bell Labs before divestiture, it appears that the number of researchers has not changed. However, the numbers conceal what is really going on, namely, an emphasis on short-term practical applications rather than researcher-driven investigations. It was observed that "horizons are getting shorter."

Today there are small numbers of self-directed people still doing basic research, but the numbers thus engaged are not sufficient for today's problems and for assuring the future. Also, much of today's research emphasizes incremental progress rather than the risky work that can produce real breakthroughs. What appears broken is the level of funding for basic research to create new ideas that emphasize longer-term horizons.

Some of the participants felt that venture money was available for research. However, the long-term horizons of research with uncertain payoffs would most certainly not appeal to today's venture capitalists. The researchers are there and the real problems are there. The missing link in the chain is the lack of investment in supporting the research.

DEFINING THE NEED FOR BASIC RESEARCH

In the past, much research resulted in innovations in products that were ultimately manufactured and provided. Today's broader context is in services. The future challenge is no longer the physical layer that so stimulated much of the research of the past.

Some research topic areas that were mentioned include: operations, networking, security and resiliency, database algorithms, provisioning, management of networks, worry-free networks, and network stability and interoperability. Most of these topics are service oriented in terms of their application.

Transmission and switching enable connectivity. But today the provisioning of connectivity has become a commodity. Differentiation and value are created in the provisioning of services delivered over connectivity. This is a fundamental change in telecommunication with implications for research.

A critical mass of researchers is needed. A few scattered researchers at different companies is not an effective way to perform the basic research that is needed for telecommunications.

To justify the support of and the investment in basic research, a vision of the accomplishments and rationale for basic research in telecommunication needs to be articulated and promulgated. This vision must capture the imagination and demonstrate a national significance.

SUPPORT MECHANISMS

Businesses that are real or virtual monopolies (such as the old Bell System, IBM of the past, and today's Microsoft) are able to support their own basic research laboratories, since the expense can be subsidized by monopoly profits. Businesses in competitive industries are less able to do so, because the long-term horizons and broader relevance of such basic research are inconsistent with the near-term financial imperatives of competitive markets. Thus, government—the ultimate monopoly—is really the only source of support for basic research to benefit competitive industrial sectors. Telecommunication today is much more competitive than in the days of the old Bell monopoly, and thus government support of basic research in telecommunication is now needed.

Such service providers as the Baby Bells are not supporting any basic research. It seems difficult for them to make a rationale for such support. Instead, they rely on the research performed by the manufacturers, such as Lucent's Bell Labs.

The Federal government should make the funds available for the support of basic research in telecommunication. This research should develop new ideas for the long-term future of telecommunication in the United States. The clear beneficiary of this research would be the country.

Various sources of funding were discussed, such as tax credits, reprioritizations of existing funds, the 3% excise tax on telecommunications, spectrum auctions, and the Universal Service Fund. Political factors could make access to some of these sources quite challenging. There is a risk that tax credits and some sources of research funds simply disappear into companies' general budgets and do not directly support research. With the large amount of R&D funding by the Federal government, a small reprioritization could result in substantially increased funds for telecommunication basic research, which has been under funded historically, possibly because of the past extensive commitment by the old Bell System.

Some form of endowment should be created over time to create financial security and independence. One possible source for such an endowment would be from the value of intellectual property.

The old Bell Labs performed the function of a national laboratory in telecommunication basic research, producing a long list of discoveries and innovations with broad benefits to the United States and communications. Competitive pressures mitigate against industry support of such benevolence today. Thus government support of telecommunication basic research is warranted and needed to assure the long-term future of telecommunication and the role of the United States in guaranteeing innovation.

There are many different venues for such basic research, including universities, university/industry partnerships, consortia, industry laboratories, and government laboratories. Each has their own advantages and disadvantages in terms of effectiveness, relevance, and excellence.

U.S. government-funded research, in the past, has seeded such crucial developments as the Internet, and has advanced fiber optics (Multiwavelength Optical Network, or MONET). Both were sponsored by the Defense Advanced Research Projects Agency (DARPA). The National Science Foundation has provided important fellowships and funded research in the field. Priorities and processes within either of these organizations could be studied and recast, as necessary, to handle a larger portfolio of basic research in telecommunication.

Some form of national telecommunication laboratory might be warranted. Such a national telecommunication laboratory should be a separate not-for-profit corporation—not a government

laboratory. Some of the factors essential for success of such a facility include independence, competent management, links to relevant problems, a national rationale, and continuity of financial support. At its peak, before the divestiture of 1984, Bell Labs supported research at a level of about \$300 million (1,200 researchers). Consideration should be given to achieving similar levels today through a combination of government and industry funding. Such funding should be considered within the context of the telecom industry's nearly 3% contribution to national GNP.

Research needs freedom, but also exposure to real problems. Basic research must somehow be connected to the business models in the market. Lucent, to its credit, has attempted this, as expressed in its branding of "Bell Labs Innovations."

The transfer of technology from research to application is essential. One possible way of transferring technology and assuring relevance is through the transfer and sharing of people. Industry people could come to the lab and visa versa. But it was observed that when this mechanism has been used usually junior people who are not essential are the ones sent, which loses any real impact.

A consortium model for linkages to practical problems and technology transfer has been tried repeatedly but mostly with poor results. Bellcore is an example of a failed consortium to support telecommunication research. The management of the Argonne and Brookhaven laboratories could be possible models for a national telecommunication laboratory. So too could the Sandia Laboratory, which was managed for years by Western Electric, with close ties to practical problems.

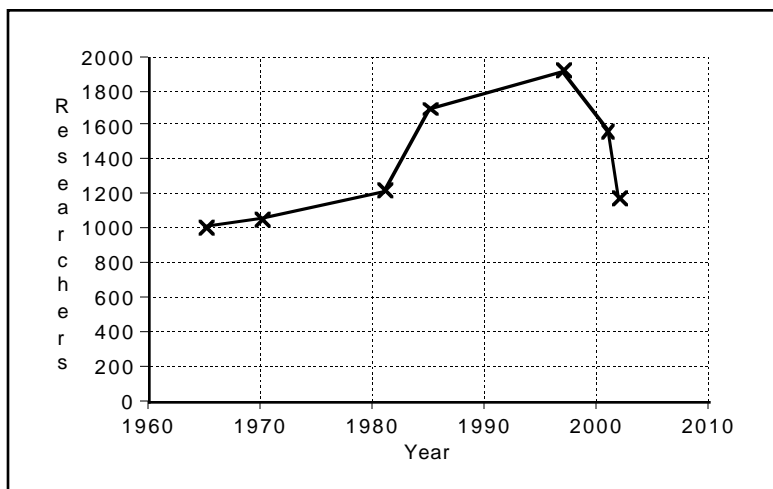
Fellowships, administered through the National Science Foundation, are an appropriate and successful mechanism to attract and support young researchers in telecommunication-related fields and topics.

Appendix A. Wall Charts

Terminology

- Basic Research
- Applied Research
- Systems Engineering
- Exploratory Development
- Development

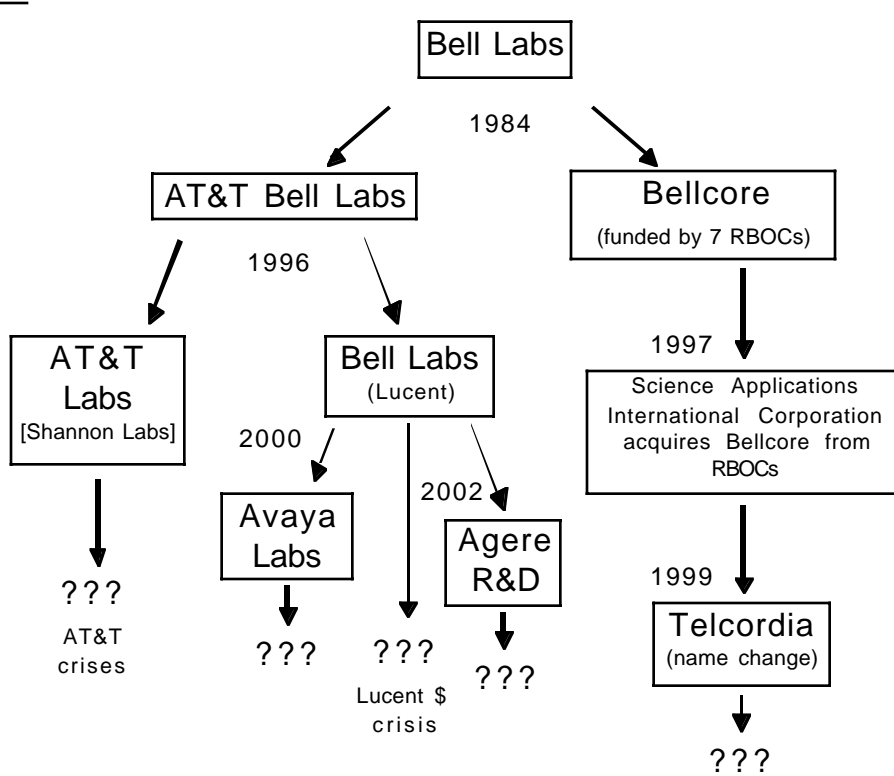
Number of Bell Family Researchers vs. Time



Conditions for Research

- secure, stable, long-term funding
- sense of purpose & clear mission
- freedom to fail
- ties to real-world problems

Research Fragmentation



Discoveries & Innovations

(representative list)

RADIO ASTRONOMY
HI-FI
NEGATIVE FEEDBACK
COMMUNICATION THEORY
TRANSISTOR
UNIX OPERATING SYSTEM
CELLULAR WIRELESS
LASER
VOCODER
ADAPTIVE ECHO CANCELLER
COMPUTER ART & MUSIC
SOLID-STATE PHYSICS
PULSE CODE MODULATION
FAST FOURIER TRANSFORM
ELECTRET MICROPHONE
PHOTOVOLTAIC SOLAR CELL
ERBIUM-DOPED FIBER AMPLIFIER
CCD IMAGER
COMMUNICATION SATELLITES

Appendix B. Participant Comments

The participants in the workshop were given an opportunity to comment on a draft of this report and to express their own thoughts. This section presents those comments.

Rob Calderbank

When there was one Bell System, there was vertical integration of service infrastructure, network / service / customer management, and network infrastructure within a telecommunications monopoly. The business model of guaranteed return on investment made it possible to use service revenue to fund basic research across a broad spectrum of research disciplines. In fact this model encouraged unfettered exploration, since the greater the investment, the greater was the return.

Vertical integration is no more, and today, the telecommunications industry is fragmented into different horizontal layers. Service infrastructure supports the business solutions practice that is of primary importance to IBM and others, network / service/ customer management is the core competence of multiple carriers as well as an emerging service industry, and Lucent is one of very many network infrastructure providers. These different layers have very different economics. Today connectivity is a commodity business, and success is tied to sales to the enterprise, and to sales at the edge of the network rather than the core. The higher margins are associated with value added services, for example, running distributed applications across wide area networks. What IP networking does is reinforce this separation of service value from network connectivity.

It may be that connectivity became a commodity business through the madness of over investment in telecommunications, and that margins may return over time, but commodity businesses can not be expected to sustain significant long term investment in basic research. Today, all network infrastructure players are embracing network and service management as a new growth business, and are reorienting basic research to support the shift. There is not a strong tradition of support for basic research within telecommunications carriers, and where there are long term investments they are tightly coupled to improving operational efficiency, so that even where there is basic research, it is a means rather than an end. On the other hand, there is a long tradition of support for basic research within IBM and HP, and a shorter history at Microsoft. Within IBM, I think it would be instructive to look at total numbers over time, but particularly at the distribution between IT infrastructure and services.

This analysis is consistent with the observation of declining support for basic research within the Bell family of companies and increasing emphasis on custom network solutions. There is in fact reason to consider the near term value of innovation to carriers and network infrastructure providers that are encumbered by significant legacy businesses. For example, advancing the practicability of VoIP cannibalizes legacy voice revenue, and direct wireless connection to an IP network substitutes for legacy cellular connection. There has been more innovation at the network edge and this is consistent with there being less friction associated with introducing innovation in services.

Federal support for a national telecommunications laboratory can only be justified by importance to the nation. Even if we were to find that the Bell family of companies has fallen short in its support for fundamental research, it would be necessary to identify consequences in terms of global competitiveness, or national security that are sufficiently compelling to justify federal funding. Certainly there is reason to be concerned about access to broadband, the stability of IP networks, and the security of IP services.

A. Michael Noll

In order to justify the support of and the investment in basic research, a vision of the accomplishments and rationale for basic research in telecommunication needs to be articulated and promulgated. This vision must capture the imagination and demonstrate a national significance. Of basic research in telecommunication.

This might imply a need for public illumination and education of the role of telecommunication basic research. Some form of telecommunication museum (perhaps at the Smithsonian or at some location in New Jersey where so much of the research was performed) might make sense to help achieve this goal. Another mechanism would be a focused media campaign, using appropriate researchers to humanize the message and also to attract young people to this field. Clearly attention should be given to these and other media relations and public relations aspects of telecommunication basic research.

What seems required is a spokesperson who can clearly articulate the need and mission of telecommunication basic research, drawing on the relevance of past accomplishments and expressing excitement for the future. In the past, John R. Pierce and William O. Baker of Bell Labs very much had that role. The computer industry has quite a few very visible advocates, telecommunication research needs equivalent spokespersons and advocates.

A "national telecommunication laboratory" might seem warranted, managed in a corporate style but funded by the government. A number of smaller laboratories, located in a variety of venues, but linked together might also function as such a national resource in a manner loosely similar to the old ARPA community. The key conclusions, though, seem to be that basic research in telecommunication has suffered as a result of the fragmentation of the telecommunication industry, that such research will continue to be essential to the future of telecommunication, and that some broader form of support is required.

The precipitous drop in the number of researchers seems to be a trend that will continue. But numbers alone do not tell the story. There has been a radical change in the nature of the work that is classified as "research," with the majority of it today being much more of an exploratory and applied nature. While in the past of a few decades ago, over 90% of the work classified as research was fundamental basic research, today the feeling is that only 10% (or even less) is basic research. Most of "research" today is incremental in nature or in support of existing products and services.

Appendix C. List of Workshop Participants:

Industry, Government, Academic Representatives:

Robert Calderbank – AT&T Labs
David Farber – University of Pennsylvania
A. G. (Sandy) Fraser – Fraser Labs
Jeffrey Jaffe – Bell Labs Research
John C. B. LeGates – Harvard University
Robert W. Lucky – Retired, Telcordia
Andrew M. Odlyzko – University of Minnesota
Mark Pinto – Agere Systems
Lawrence R. Rabiner – Rutgers University
Casimir Skrzypczak – Retired, NYNEX
Edmond J. Thomas – Federal Communications Commission

Sponsor Representatives:

Robert C. Atkinson – Columbia Institute for Tele-Information
Darcy Gerbarg – Marconi Fellowship Foundation
John Jay Iselin – Marconi Fellowship Foundation
Eli Noam – Columbia Institute for Tele-Information

Chair:

Karen Lynch – Markle Foundation

Organizer & Rapporteur:

A. Michael Noll – Annenberg School at USC

Sponsors:

The workshop was sponsored jointly by:

- the Annenberg School for Communication at the University of Southern California;
- the Columbia Institute for Tele-Information at Columbia University; and
- the Galileo Marconi International Fellowship Foundation at Columbia University.

Planning and arrangements were performed by the Marconi Fellowship Foundation, and the Annenberg School provided financial support. The workshop was coordinated with a panel of the National Research Council that is studying research in telecommunication and was held with the cooperation of the Markle Foundation.

Appendix D. Readings:

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Telecommunication Basic Research: An Uncertain Future for the Bell Legacy¹

A. MICHAEL NOLL

ABSTRACT *The Bell Labs of decades ago was well recognized as a national treasure for its pioneering innovations and its creation of new knowledge. However, the breakup of the Bell System that occurred in 1984 resulted in considerable change for research and development in telecommunication. This paper reviews that history and, in anticipation of continuing uncertainty and a possible impending crisis, examines possible options for the future to assure leadership by the United States in basic research in telecommunication.*

Keywords: research, Bell Labs, AT&T Labs, R&D, basic research, telecommunication research.

Research Legacy

A hundred years ago, the radio spectrum and telecommunication was developed by a number of pioneering inventors and businesses. Some of these pioneers were: Thomas Alva Edison, David Sarnoff, Nikola Tesla, Guglielmo Marconi, Samuel Finley Breese Morse, Lee de Forest (triode vacuum tube), Claude E. Shannon (information theory), Alexander Graham Bell, Allen DuMont, Philo T. Farnsworth (TV camera), Vladimir Kosma Zworykin (electronic television), Michael Pupin (loading coil), and Edwin Howard Armstrong (FM radio).

Many of the businesses founded by these pioneers created their own corporate research laboratories to continue the tradition of invention. Some of these laboratories still exist today as Bell Labs (Lucent Technologies), AT&T Labs, Sarnoff Laboratories (formerly RCA Labs), and Telcordia (formerly Bellcore). In addition, the IBM Labs and the Xerox Palo Alto Research Center have contributed greatly to innovations in computers and information processing, fields closely related to telecommunications.

Basic research benefits society as a whole and has such a long-term horizon that commercial exploitation might not be initially possible by the supporter. For example, Apple adapted the friendly computer interface invented at the Xerox Palo Alto Research Center (PARC)—not Xerox. In fact, ‘... Xerox, having

invented the technology underlying present-day personal computing, committed the monumental blunder of letting it slip through its fingers'.² The transistor was invented by Bell Labs, but was first used in transistor radios manufactured by Sony. It is the fundamental nature of basic research that its results cannot be owned by anyone. The results leak out and become shared with industry and society as a whole.

There are many reasons a company supports its own basic research laboratory. The prestige of the basic research laboratory facilitates the recruitment of the very best engineers and technicians for development and other applied research work. Nobel prizes, research awards, patents, and published papers enhance the image and public awareness of the sponsoring company. The basic researchers as noted experts in their respective fields are available as in-house consultants to other divisions of the company.

Bell Labs of the past was a great research institution. When the Bell breakup of 1984 occurred, Bell Labs was split by the creation of Bellcore to perform research for the local telephone companies (the Baby Bells). The AT&T divestiture of 1996 then resulted in a further splitting of research with Bell Labs serving Lucent Technologies and AT&T Labs serving AT&T. The Baby Bells ceased their direct support of Bellcore, which renamed itself Telcordia Technologies and was acquired by Science Applications International Corporation in 1997. Each of the Baby Bells created and had their own research facilities for a few years, but the emphasis was clearly on applied work in the form of exploratory development and not in basic research. Basic research in the old Bell tradition clearly is at risk.

The basic research sponsored at Bell Labs was something of an anomaly in the communication industry. The only other communication-related firm to sponsor basic research at its own laboratory over the years on such a large scale has been IBM. Perhaps the old AT&T of the former monopoly era actually believed in a corporate responsibility to create knowledge for the storehouse of basic research.

The Research Dilemma

The shared nature of basic research makes it increasingly difficult for individual companies to justify continued support. Such firms as AT&T, Xerox, and Lucent Technologies are experiencing financial problems. It will become increasingly difficult for these companies to justify funding for basic research at their own laboratories. The long-term viability of basic research at these facilities thus is at risk. Yet longer-term research has been—and most likely will continue to be—essential for the future of telecommunication. A former science advisor to the President observed 'industry must show its willingness to invest in more venturesome and longer-range R&D'.³

The United States has moved from the monopolistic provision of telecommunication services to competition. In the former monopolistic situation, the need for basic research was well recognized and allowed by regulators. In today's competitive situation, the emphasis on short-term profits and markets make it increasingly difficult for a few companies to continue to fund longer-term basic research in telecommunication. The United States is thus about to face a crisis in basic research in telecommunication.

Telecommunication research over the last two decades clearly has been subjected to many risks arising from changes in corporate ownership, twists in

mission, and funding uncertainties. This is not the best environment for research. Years ago, John R. Pierce (an early Bell Labs pioneer of communication satellites) stated that the best environment for research consisted of: (1) secure and stable long-term funding; (2) a clear mission and purpose; and (3) the freedom to fail.

Research and Development

The term ‘research’ can describe almost any form of intellectual, investigative activity. Companies conduct market research to measure the response of consumers to new products; students perform library research to obtain references for term papers; and consumers perform research to compare prices for some particular product. This paper is concerned with research meaning the creation of new fundamental knowledge, mostly with ultimate application to the area of telecommunication.

Research and development—commonly known collectively as ‘R&D’—form a continuum of efforts, ranging from development to basic research. Exploratory development, systems engineering, and applied research fall in-between the two extremes. Industrial research is a term that has been used to define the entire R&D continuum.⁴

- Basic Research
- Applied Research
- Systems Engineering
- Exploratory Development
- Development

Development includes the engineering and design work necessary to manufacture and provide specific products and services. Exploratory development is somewhat less specific in terms of an actual product or service offering, and as its name implies, is ‘exploring’ the possibilities for near-term future products and services. Systems engineering is concerned with the design and engineering of overall systems, taking a broader perspective than the specific engineering design of a single product or service.

Basic research is usually discipline motivated and creates new knowledge, usually with very long-term implications and with no specific application to any near-term products or services.⁵ Applied research is the creation of new knowledge that is more immediately applicable to specific products or services.

The actual boundaries, distinctions, and semantics between these different efforts are blurry and depend on such factors as:

- the time-frame of the applicability of the results of the effort;
- the discipline orientation of the work; and
- the motivation and stimulation of the effort.

A key factor of basic research is that it is usually stimulated and directed by the individual researcher. The philosophy used at Bell Labs, and some other industrial research facilities, was to hire the people with the best minds, expose them to practical problems that can stimulate research into new solutions, and then give them the freedom to invent and innovate novel and creative solutions to problems of interest. Bell Labs combined ‘. . . an atmosphere of freedom of integrity with a sense of purpose’.⁶

The conditions that seem optimum for basic research are:⁷

- secure, stable, long-term funding;
- a sense of purpose and clearly articulated mission;
- the freedom to fail; and
- ties and proximity to real-world problems.

Basic research should not be performed in isolation with no consideration given to the transfer of its applicability to practice. There is a need to ‘farm’ the basic research facility to facilitate the transfer of technology from research to practice. The researchers themselves are notoriously poor at the identification of practicality and the transfer of technology.

The transfer of technology from basic research needs to be a formalized process, yet not so bureaucratic as to be useless. In the early 1980s, I suggested to AT&T that one way of doing this was to create a ‘skunk works’ at the Bell Labs research facility, staffed jointly by researchers and marketing people.

Pre-divestiture Bell Labs

The Bell System was vertically integrated from the provision of service to research. Telephone subscribers were provided basic service and access by the local Bell telephone companies, which were known as the Bell operating companies (BOCs). Manufacturing, from basic telephones to switching and transmission equipment, was provided by the Western Electric Company. Engineering design, development, systems integration, and research was done at Bell Labs. The stock of these operating entities was all owned by the American Telephone and Telegraph Company (AT&T), which provided central leadership, direction, and coordination. The Long Lines division of AT&T provided long-distance service to the BOCs for their customers.

The essential role of research and development was long recognized as essential for the long-term future of telecommunication. Alexander Graham Bell was a teacher of the deaf, in addition to being an inventor. The development of improved telephone transmitters was a key ingredient in the early progress of telephone technology.

Loading coils, invented in 1899 by Professor Michael Pupin, clearly demonstrated the importance of mathematical analysis of transmission lines and also of early patent application after the Bell System lost its claims. Almon B. Strowger in the 1890s invented automated electromechanical switching, again a non-Bell invention. These major advances by non-Bell people spurred AT&T to make a stronger commitment to basic research. In 1925, Bell Telephone Laboratories, Inc., jointly and equally owned by AT&T and Western Electric Company, was formed as the centralized R&D facility for the Bell System.⁸ The Bell Labs of 1925 had 3,560 employees, including 598 research employees.⁹ By 1983, Bell Labs had grown to over 22,000 employees, with 1,480 employed in research.¹⁰

Just a few of the innovations that resulted from basic research conducted at Bell Labs and the responsible researchers are listed in Table 1.

In addition to these technology related areas, researchers at Bell Labs also made significant contributions and discoveries in a number of other areas, to name just a few examples, such as, economics, computer art, computer music, computer animation, psychology, human vision, and psychoacoustics.

Table 1. Bell Labs innovations

Researchers	Innovation
George Ashley Campbell:	electric-wave filter & frequency-division multiplexing
Harold S. Black:	negative-feedback amplifier
Walter H. Brattain, John Bardeen & William Shockley:	junction transistor
Claude E. Shannon:	mathematical theory of information & communication
Edward C. Molina:	probability theory applied to blocking in switching
Harvey Fletcher:	high-fidelity sound reproduction
Arno A. Penzias & Robert W. Wilson:	cosmic microwave background radiation
Philip Anderson:	solid state physics
Karl Guthe Jansky:	radio noise from galaxy, leading to radio astronomy
John L. Kelly Jr, Benjamin Logan & M. Mohan Sondhi:	adaptive echo cancellers
Bishnu S. Atal:	linear predictive coding for speech compression
Charles H. Townes:	laser

The vast majority of the work at Bell Labs was involved with the research and development of specific products and telecommunication services. The products would then be manufactured by the Western Electric Company for use in the Bell System, and the services would be provided by the local telephone companies (the BOCs) and the Long Lines division of AT&T. In addition to the centralized R&D performed at Bell Labs, individual operating units of the Bell System also had their own engineering units involved with the day-to-day operation of the businesses. The centralized R&D performed at Bell Labs was involved with the future, whether a few months hence in terms of tomorrow’s new products, services, and technologies or decades hence in terms of basic research in disciplines deemed essential for the long-term future.

John R. Pierce, an executive director of communication research at Bell Labs, observed that the research at Bell Labs ‘was suited, not to a manufacturing company whose revenues fluctuate wildly with the economic cycle, but to the future needs and opportunities of a national resource that was there yesterday, was there today, and was expected to be there tomorrow and tomorrow. Research accordingly was supported largely by a fee levied by AT&T on the operating companies’.¹¹ ‘With divestiture and competition, the communication industry has become fragmented, but the communication network and system must remain universal . . . research is even more important today to assure the future of telecommunication in the United States’.¹²

The basic research and systems engineering supported by AT&T was for the benefit of the Bell System as a whole. As such, license contract fees charged to the

BOCs and to the Long Lines division of AT&T funded it. Although the license contract fee was capped at 2.5% of revenues, it actually usually was only about 1% of revenues. The rationale for the license contract fees was that the BOCs operated under patents held by AT&T and also received coordination services from AT&T.

Bell Labs was a separately owned facility within the Bell System and was managed as a business. The researchers were exposed to real-world problems, and it was expected that such exposure would guide the research to seek innovative solutions and new knowledge applicable to the problems for longer-term solutions.

Many of the inventions and patents issued to the basic research division were not related to the core businesses of the Bell System. Nevertheless, these non-core patents were valuable in terms of access through cross licensing to the patents held by other companies.

Indeed, much of the basic research conducted at Bell Labs was developed commercially outside the Bell System. The transistor, mentioned earlier, was invented at Bell Labs but first used in transistor radios manufactured by Japanese companies. The transistor later found use within the Bell System. The linear predictive coding (LPC) method of speech compression, invented at Bell Labs, was first used in a toy manufactured by Texas Instruments. LPC later found use within the Bell System. Adaptive echo cancellers, invented at Bell Labs, were first used by Comsat, and were only later adopted for use by the Bell System. The electret microphone, invented at Bell Labs, was first used in consumer electronics, and only later was adopted for use in telephones for the Bell System. In all these cases the initial benefactors of the research conducted at Bell Labs was outside the Bell System, but all these innovations later were very important for uses within the Bell System. The path, however, was initially outside and then a return to the Bell System.

Aftermath of the Bell Breakup

On 1 January 1984, AT&T divested the local telephone companies from the Bell System and organized them into seven regional holding companies (RHCs)—also known as the Baby Bells. In return for this divestiture, AT&T was allowed to enter the computer and any other businesses. AT&T retained ownership of Bell Labs but was required to rename the organization AT&T Bell Labs. Bell Communications Research (later called Bellcore) was created to serve the R&D needs of the seven RHCs and was owned jointly by the seven Baby Bells.

Each of the RHCs created their own R&D facilities, in addition to the central one they supported at Bellcore. For example, NYNEX Science and Technology, Inc. was owned by NYNEX and performed applied research, exploratory development, and funded development for NYNEX. About 400 people worked at the NYNEX facility. Today this facility performs mostly development work for Verizon, the successor of NYNEX.

The author examined the immediate effects of the Bell breakup of 1984 on R&D and concluded that ‘. . . no major changes have occurred as a result of divestiture’. The examination included a variety of factors, such as the number of employees, budgets, patents, and publications.¹³ His analysis combined post-divestiture AT&T Bell Labs with Bellcore and compared the combined effort with the pre-divestiture Bell Labs. However, he cautioned ‘There are reasons for

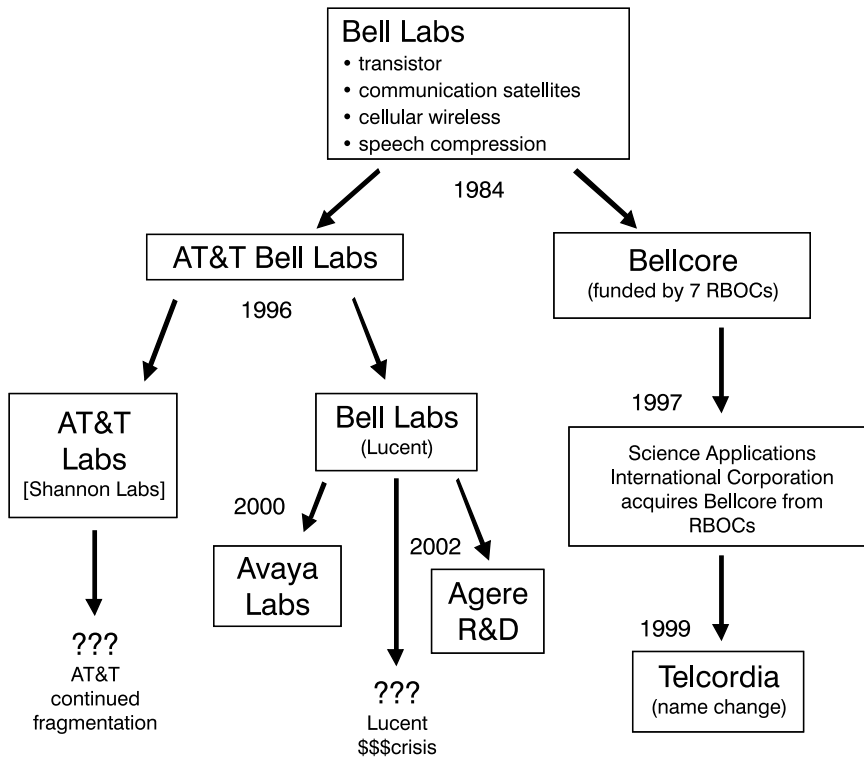


Figure 1. Bell family R&D.

concern about the future'.¹⁴ This concern was because it was reported that research at AT&T Bell Labs since the Bell breakup of 1984 was forced to emphasize products rather than longer-term discipline-oriented research.¹⁵ Indeed, product development was being emphasized, although clearly the market pressures facing AT&T perhaps justified such a change in direction.¹⁶ Such emphasis was not new, and decades ago, Dr William O. Baker—then Chairman of the Board of Bell Labs—testified that 'A characteristic failing of modern R&D is over compression of the span between discovery and use, so that the basic scientist is expected to become a design engineer and the whole system crumbles from internal pressures and implosion'.¹⁷

The Stage Unfolds: Post-divestiture

After years of failing to achieve any success with its own computer business, in 1991 AT&T acquired NCR. This failed to develop the computer business for AT&T, and accordingly in 1996 AT&T divested NCR and the entire manufacturing business of Western Electric, in what is known as the trivestiture. The divested Western Electric was renamed Lucent Technologies. The vast bulk of AT&T Bell Labs was transferred to Lucent, and the R&D facility reverted to the former simpler name of Bell Labs. Lucent quickly advertised its connection to Bell Labs with the corporate slogan 'Bell Labs Innovations'. Some of the basic research at Bell Labs is focused on the physical sciences, in addition to other areas.

Table 2. Bell family research support

Year	Facility	Total R&D employees	Research employees	R&D budget
1981	Bell Labs	24,100	1,200	\$1.6 billion
1985	AT&T R&D	24,500	1,200	\$2.37 billion
	+ Bellcore	<u>7,700</u>	<u>500</u>	<u>\$0.86 billion</u>
	TOTAL	32,200	1,700	\$3.2 billion
1997	Bell Labs (Lucent)	25,000	1,200	\$3.0 billion
	+ AT&T Labs	2,000	400	\$0.3 billion
	+ Bellcore	<u>5,300</u>	<u>320</u>	<u>\$1.1 billion</u>
	TOTAL	32,300	1,920	\$4.4 billion
2001	Bell Labs (Lucent)	16,000	550	\$2.4 billion
	+ AT&T	10,000	450	\$1.3 billion
	+ Telcordia	5,350	230	\$1.0 billion
	+ Agere	2,888	275	\$0.8 billion
	+ Avaya Labs	<u>2,860</u>	<u>65</u>	<u>\$0.5 billion</u>
	TOTAL	37,098	1,570	\$6.0 billion

Source: Company representatives and annual reports.

AT&T created its own corporate R&D facility named AT&T Labs. The research component of AT&T Labs was named the Shannon Labs in honor of Claude E. Shannon, the founder of information theory. Much of the research at the Shannon Labs is systems research concentrating on information sciences and mathematics. Figure 1 gives an overview of the restructuring of R&D within the Bell family.

The RHCs viewed themselves as competitors and in the early 1990s became concerned about the possible antitrust implications of supporting and sharing common work at Bellcore. Some of them also had become somewhat disenchanted with Bellcore. Clearly, the situation was awkward since the RHCs were both competitors and the customers of Bellcore. These issues created an uncertain future for Bellcore, which was finally resolved in 1997 when the RHCs sold Bellcore to Science Applications International Corporation (SAIC). In 1999 Bellcore changed its name to Telcordia. Telcordia has become a contract systems house for hire to work on specific projects, frequently for the RHCs.

Data (shown in Table 2) about the total number of R&D employees, research employees, and R&D budget from 1981 to 2001 are informative in terms of overall trends over time.¹⁸ The budget numbers are not adjusted for inflation. The general conclusion from this data is that the R&D situation has been very stable from the Bell breakup of 1984 until 1997, but with decreases starting in 2001 in the number of research employees. The increase in the number of R&D employees that occurred in 2001 was due mostly to a change in how AT&T defined R&D employees and hence is not significant.

NYNEX created its own company, called NYNEX Science and Technology, Inc., to perform applied research and exploratory development, at a level of a total of about 400 people. This facility mostly today is a development laboratory for Verizon. US West had its own advanced technology laboratory, which was later disbanded.

Frequently, the pay-offs and direct applications of basic research at Bell Labs were to other companies and industries than the AT&T that directly paid for it. For

Table 3. Bell family R&D for 2002

Facility	Total R&D employees	Research employees
Bell Labs (Lucent)	10,000	500
+ AT&T	6,500	250
+ Telcordia	4,090	230
+ Avaya	2,500	90
+ Agere	<u>2,100</u>	<u>100</u>
TOTAL	25,190	1,170

Source: Company representatives. The Agere data for total R&D employees was estimated by reducing the 2001 data by the reported decrease in R&D expenditures.

example, as observed earlier, the transistor invented at Bell Labs was first used in portable radios. Furthermore, the Consent Decree of 1956 required AT&T to license all its patents for reasonable fees to everyone. Yet AT&T continued its support of basic research through the divestiture of 1984 and even today supports basic research at its Shannon Laboratory.

Current Situation

Lucent, created in 1996, inherited the responsibility for the financial support of basic research in telecommunication at Bell Labs. As long as Lucent was doing very well financially, during its initial years, this support was not a burden. But when financial doom gripped Lucent in 2000, with problems worsening through 2002, such benevolence becomes challenging to justify in terms of the bottom line.

The problems at Lucent could have been anticipated, and in 1996 the author had predicted that '[Lucent] most certainly will not be able to afford basic research, the research that could create innovations that could help secure the United States' place in the global market a decade or two hence'.¹⁹ Given its serious financial problems, in 2001 Lucent began selling entire business units and also initiated downsizing of its remaining employees, including those at Bell Labs. Nevertheless, Lucent has mostly maintained its commitment to basic research, with only a small decrease in the number of researchers at the end of 2002 from the year before.

As a response to financial difficulties, Lucent was active in divesting and selling its various business units. Avaya Communication, responsible for manufacturing PBXs and other business communication systems, was created from the business systems division of Lucent in 2000. Avaya then formed Avaya Labs Research as a small, internal, centralized research facility, mostly concentrated on applied research and exploratory development in support of Avaya business units.

Agere Systems, which used to be the microelectronics division of Lucent responsible for the manufacture of integrated circuits (chips) and communication components, was completely divested from Lucent toward the end of 2002. The various R&D people have been merged into Agere business units, and no centralized research facility exists.

AT&T encountered financial problems in early 2000 as a result of its costly acquisitions of cable television companies. This resulted in the divestiture of its

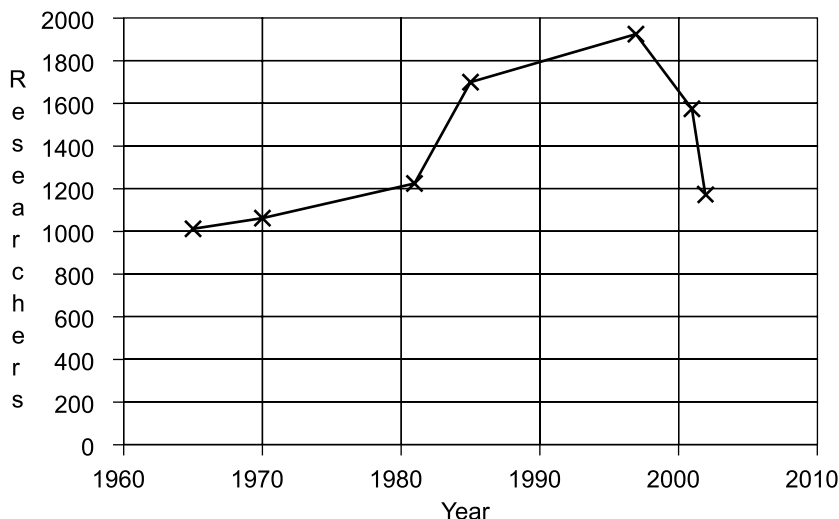


Figure 2. Graph of researcher employees of reconstituted Bell family.

wireless business in 2001 and the divestiture of its cable broadband business at the end of 2002. In early 2002, AT&T reorganized and refocused its Shannon Laboratory to be more relevant to the business of AT&T, resulting in a fairly significant reduction in the number of research employees.

Table 3 documents the R&D picture for 2002. Compared to 1997, the reassembled Bell family (consisting of Bell Labs, AT&T, Telcordia, Avaya, and Agere) is spending about as much on R&D, but the number of researchers has decreased by nearly one-third over the five years. The downward trend is shown clearly in Figure 2 which plots the total number of researchers for the reconstituted Bell family. Such measures as the number of patents and publications have a long time constant and thus might not show a looming crisis for a number of years.

The telecommunication landscape in the United States is very different today than it was before the Bell divestiture of 1984. A number of competing firms manufacture telecommunication equipment, including not only Lucent Technologies (the reincarnation of the old Western Electric) and Nortel (formerly Northern Telecom) but such others as Cisco and Corning. Hence, the potential for support of basic research has expanded greatly, although many of these firms do not support their own research laboratories.

The telecommunication service landscape is likewise quite different than before the Bell divestiture when telecommunication was synonymous with AT&T and the Bell System. Today, such major carriers as AT&T, MCI/Worldcom, Sprint and Global Crossings provide long distance service, with a host of smaller firms that sometimes own their own facilities but more frequently package and resell service provided over facilities owned by the major carriers. Local telephone service is still provided primarily by the divested Baby Bells, but the provision of wireless service is provided by a number of highly competitive firms. Internet access is provided by a large number of firms, although dominated by a small few, such as AOL and Earthlink. With the exception of AT&T, the service providers do not support their own research facilities.

Table 4. R&D support benchmarks, 2000

Company	Net sales	R&D budget	Percent of sales
Lucent	\$33.813 billion	\$5.023 billion	14.8%
Avaya Systems	\$7.680 billion	\$0.468 billion	6.1%
Agere Systems	\$4.708 billion	\$1.273 billion	27.0%
IBM	\$88.396 billion	\$5.151 billion	5.8%
Hewlett Packard	\$48.782 billion	\$2.646 billion	5.4%
Intel	\$33.726 billion	\$4.006 billion	11.9%
Nortel Networks	\$30.275 billion	\$5.496 billion	18.1%
Texas Instruments	\$11.875 billion	\$1.747 billion	14.7%

Benchmarks for R&D

The determination of an adequate level of support of R&D is a difficult issue. Table 4 gives the R&D budget for Lucent Technologies, Avaya Systems, and Agere Systems for 2000. Data for IBM, Hewlett Packard, Intel, and Texas Instruments are also shown as benchmarks for comparison.

As a normalized metric, the R&D budget as a percentage of net sales is shown in Table 4. Agere Systems appears to be spending proportionately more on R&D compared to such comparable firms as Intel and Texas Instruments. Avaya seems in line with such comparable firms as IBM and Hewlett Packard. Lucent spends less than Nortel but both spend considerably more than IBM and Hewlett Packard as a percentage of sales for 2000.

The Conduct of Basic Research

There are many mechanisms for the support and conduct of basic research. Each mechanism needs to be evaluated by the four conditions, listed in an earlier section of this paper, that seem to facilitate the best environment for basic research.

One mechanism is support by an industry consortium formed from many companies. This mechanism is close to real world problems because of the strong ties to industry. But since all the members of the consortium share the results, issues over proprietary ownership can occur, leading to the situation where the supporters all lose interest in the research. Also, too many cooks all attempting to oversee the direction of the research can lead to chaos.

Much basic research is performed at universities, frequently supported by the Federal government. Clearly the decentralization of research in many universities as opposed to a few national laboratories was a wise decision.²⁰ But the process for seeking support is lengthy. Proposals must be written and then evaluated by peer review. Considerable effort is expended in this process, sometimes more effort than will be spent on the research if it ultimately receives support. University research is far from the real world with few ties to industry, although much thought has been given on how to improve these ties. In reality, the ties occur when doctoral students leave the university and go to work for industry. But rarely do industry people return to the university, and if they do, their more academic colleagues who have spent their entire careers in academe view them with suspicion. The need to renew support creates insecure long-term funding. Furthermore, the main mission of the university should be education—not some national goal for the future of

Table 5. Support mechanisms

	Funding	Mission	Freedom	Real-world
Consortium	Perhaps	Diffuse	Yes	Yes
University	Variable	No	Yes	No
Government	Yes	Diffuse	Somewhat	No
Company	Yes	Yes	Yes	Yes

telecommunication. But universities do protect academic freedom and understand the role of individual researchers in guiding their own research.

The Federal government supports its own various research laboratories. This makes good sense when the mission of the laboratory is the same as that of the agency supporting it. Government laboratories have secure, long-term funding, and yearly proposals are not needed. But when it comes to the needs of industry, government laboratories are far distant.

Basic research can occur at a laboratory supported by a specific company. The company needs to value basic research and accept that the payoffs might be far in the future and might arrive back at the company after a circuitous route outside the company.

Table 5 evaluates, in my opinion, each of these support mechanisms by the optimum conditions for basic research. The company-supported basic-research laboratory seems to be the best mechanism. But that mechanism seems to be slipping away as concerns over short-term profits capture most companies. This leads to thoughts about other approaches.

The RHCs purchase their equipment from a number of suppliers, such as Lucent and Nortel. To the extent that Lucent has been sponsoring basic research at its Bell Labs, the RHCs thus indirectly help fund that research through their purchase of equipment from Lucent. However, in a competitive environment, basic research is a very costly luxury with long-term applicability and pay-offs. Thus, one would expect the support for such basic research at industrial laboratories to shrink in a competitive environment where business decisions must be made based on short-term profitability and payoffs. This then strengthens the rationale for federal government support of basic research, usually at universities.

The author suggested ‘the creation of a national telecommunications research institute funded by a tax on the gross revenue of all service providers’.²¹ The implementation would be as a formal organized consortium of existing research laboratories, with an emphasis on basic research. Assured long-term funding through a tax on industry revenues would eliminate the need for yearly research proposals and would introduce the model used for decades to support basic research at industrial research laboratories. The telecommunication industry would be asked to contribute current buildings, or the equivalent to create this facility. In return, the industry would no longer need to support such basic research internally, which would allow the use of these funds for other purposes. An advisory board could be created to assure the relevance of the research and also to facilitate the transfer of the results of the research into practice.

Bell Labs is not the only facility responsible for basic research in telecommunication. Various universities also conduct basic research in various aspects

of telecommunication, usually funded by government agencies but also by industry. But the prime mission of universities is education—research comes second. However, some universities were able to create separate research institutions staffed by full-time researchers, for example, the Lincoln Laboratories by MIT and the Stanford Research Institute by Stanford University. Academic faculty members do most university-based research. This academic research creates the opportunity for doctoral students to be exposed to research and to work as junior members of research teams. This helps to prepare these students for future careers as academics themselves. Of course, this is a different world than the company-sponsored research laboratory, since university research is far removed from the practical considerations and mission of industry.

Some universities have been successful in an administrative role in managing a somewhat independent research facility, such as Cal Tech's administration of the Jet Propulsion Laboratory and the University of California's administration of the Lawrence Livermore Laboratory. This suggests yet another model for the support of basic research in telecommunication, namely a facility supported financially by industry yet affiliated with and administered by a university. The financial support could be in the form of contributions either to the yearly operating expenses or to the creation of an endowment. An endowment would assure continuity and also strengthen research freedom.

The Bell Legacy

Telecommunication and its infrastructure are essential enablers for the growth of the economy, particularly in a global environment. Without long-term basic research, the future of telecommunication is at risk. The founders of the Bell System realized the importance of such research over a century ago.

In many ways, the RHCs—the so-called Baby Bells—inherited the Bell legacy and commitment to basic research in telecommunication. They today represent and are responsible for the future of telecommunication in the United States, much more so than AT&T or Lucent. As service companies, with near monopolies for local access, the Baby Bells have inherited the responsibility to the public of the old Bell System. They are all very profitable with after-tax profit margins over 15% for the year 2000. All this means that they should be supporting basic research in telecommunication at their own research facilities—a responsibility they have been ignoring, after their past negative experience with Bellcore.

Basic research is believed to be most relevant to products, and thus the Baby Bells probably believe that primarily the manufacturers of these products should fund such research. Telecommunication service providers, with the exception of AT&T, therefore do not support basic research at their own facilities. Service providers, such as the Baby Bells, believe that their support of basic research occurs indirectly with their purchase of equipment from manufacturers. But very few manufacturers are supporting research on the scale and level needed to assure the long-term future of telecommunication in the United States.

Any basic research supported by telecommunication manufacturers (such as Lucent) is subjected to the short-term variations in profits, changing corporate missions, and a short horizon that forces the research to be product specific. Telecommunication service providers, particularly the Baby Bells, have secure long-term profits, a clear sense of mission, and a broad definition of service. They thus

would seem to be the most appropriate source of support of long-term basic research in telecommunication.

The provision of telecommunication service is the prime mission of the Bell RHCs. Other companies, such as Lucent and Nortel in North America, manufacture the technology component of the provision of that service. Thus, there is some rationale in the position that these manufacturers should support basic research relevant to telecommunication technology. But there is also basic research that is relevant to the provision of services. That research focuses on human behavior in the use of telecommunication. Decades ago, the futurist Alvin Toffler studied the Bell System and one of his many conclusions was the identification of the need for what he called a 'Bell Behavioral Laboratories'.²² This facility would focus on social science research to increase 'socio-behavioral know-how'.

Each of the three RHCs will most likely be allowed to provide long-distance service in a few years. An efficient way of doing this would be for each of the three RHCs to acquire each of the three major long-distance companies. This would result in three mini Bell Systems, each with yearly revenues in the order of \$100 billion and profits of over \$15 billion. A possible condition imposed by the government to allow such powerful consolidation, even though the three mini Bell Systems would compete with each other in many of their businesses, would be that each make a long-term commitment to the support of their own basic research facilities. This then could result in three 'Bell Labs'. This situation would be more exciting than the basic research situation of the past with only one Bell Labs because there would be strong competition between the three Labs for the best researchers, for the best published papers, and for patents and inventions.

To assure the long-term future of such basic research facilities, an endowment is needed for financial stability and independence. The Baby Bells could contribute to the creation of such an endowment, perhaps gradually over a decade to spread the financial commitment. But strong management with exposure to real-world problems must always be emphasized.

The Bell RHCs believe that they indirectly fund basic research through their purchase of equipment from the manufacturers who then directly have their own research laboratories. This flow of research through the products of manufacturers that are purchased by service providers has been the traditional model for telecommunication. But the intense competition in manufacturing with a strong emphasis on short-term profits has created a crisis for the support of research at industrial telecommunication laboratories. It is time to re-examine this model and consider alternatives, before the long-term harm from a crisis in research can no longer be remedied. Service industries must invest in their future through the direct support of basic research at laboratories close to their mission and with the characteristics that were so strongly responsible for the great contributions of Bell Labs of the past. These are challenges that must be discussed and addressed.

Discussion

Long-term consequences are difficult to predict, in general. Yet years before the Bell breakup of 1984, a number of well-respected people warned of the dire consequences for Bell Labs. Dr. William O. Baker (a past president of Bell Labs) stated 'Changing the structure of the Bell System would necessarily mean that Bell Labs could no longer survive as we know it'.²³ Dr. Edward E. David, Jr, past science

advisor to the President of the United States, warned that ‘. . . the fragmentation of the Bell System will mean emasculation of the Bell Telephone Laboratories . . .’.²⁴ Nobel laureate Dr Arno A. Penzias predicted that ‘It is possible to kill Bell Labs as we know it’.²⁵ Their and the warnings of other people were premature, but ultimately might be correct.

The crisis in telecommunication research in the Bell tradition is not unique and is occurring in other industries. The RCA Labs invented television and pioneered the NTSC compatible color system. General Electric then acquired RCA and the RCA Labs became the Sarnoff Labs, which then became a subsidiary of SRI International in 1987, all but halting basic research related to television. The Sarnoff Corporation is now about ‘to move . . . from its historical research-and-development mode . . . into a more client- and consumer-friendly entity’.²⁶ But such diffuse attempts at redirection have rarely been successful and usually are the death knell of any basic research.

A recent paper by Professor Roli Varma observes that corporate ‘has shifted to low-risk, mission-oriented, and short-term research’ and that ‘Basic research projects seem to be completely gone from centralized corporate research laboratories’.²⁷ Perhaps the large centralized R&D facility has outlived its role in today’s business world of individual business units each with their own bottom-line financial responsibility. The various business units in a company require direct control of all the elements needed to bring a product or service to market, including the R&D spectrum from applied research to product development. The decentralization of R&D results in much faster development and also much closer ties with the marketplace. However, basic research serves all business units and thus should remain in a centralized structure. The issue should be centralization of all R&D—not support of basic research.

However, the challenge in justifying support by industry of basic research is not new. A study supported by the National Science Foundation in the late 1970s stated ‘The justification for doing basic research in industry *before* a direct connection between the basic research and a need or opportunity is recognized is very difficult for many industrial managers’.²⁸

The future for basic research laboratories supported by industry is very uncertain today. For example, it has been observed that ‘the utopian ideal of a corporate laboratory whose scientists are free to roam through Idea-space draws only ridicule today’.²⁹ There are many who believe that ‘. . . the company-owned research lab, that proud 19th-century invention, has become obsolete’.³⁰ Indeed perhaps the times have changed substantially, and the basic research laboratory sponsored by a specific company has become obsolete. Yet, surprises can occur, sometimes with dramatic effect. For example, the attacks on the United States on 11 September 2001 could stimulate a return to basic values and national defense, with a renewed emphasis on basic research supported by industry. Also, bucking the accepted wisdom and recreating the centralized, company-supported basic-research laboratory could become innovative and the way to build for the future in today’s world of global competition.

After all has been studied and written, as a final conclusion to this paper, the thoughts of Dr John R. Pierce written in 1986 are wise and relevant:

Above all, a laboratory needs a clear purpose. It needs to be essential to some ongoing work or enterprise. The future of that work or enterprise must lie in its hands, or, the researchers must believe that it does.³¹

Notes and References

1. An initial version of this paper was presented at the Telecommunications Policy Research Conference in Alexandria, VA on 30 September 2002. Drafts of this paper were commented upon by Professor Eli Noam of Columbia University, Dr Lawrence Rabiner (formerly of AT&T Labs), Dr Robert W. Lucky (formerly of Telcordia), Dr Abe Zarem, Dr George H. Heilmeier (formerly of Telcordia), and others. Clearly, the opinions expressed in this paper are the sole responsibility of the author, but the wisdom of these commentators are much appreciated and helped to shape and improve the final paper.
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