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Human Factors and Behavioral Science:

A Brief History of Applied Behavioral Science at Bell Laboratories

By B. L. HANSON*

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The history of applied behavioral sciences at Bell Laboratories follows two main paths. The first, the primarily customer-oriented "human factors" tradition, began in the late 1940s and has been characterized by an empirical approach, relying heavily on laboratory and field simulation. The second, the employee-oriented "human performance technology" tradition, had its roots in Bell Laboratories behavioral research organization formed in the late 1950s. It has been characterized by a more rule-oriented approach to the integration of human users and operators into large, computerized systems. This paper traces the evolution of these two applied traditions and the behavioral research organization and examines the people and the events that influenced their growth and success.

I. INTRODUCTION

From the earliest days of telephony when Alexander Graham Bell and Thomas Watson worked to perfect Bell's invention into a useful and convenient communication device, designing for users has been an important goal of the Bell System. As the number of Bell System

* American Bell.

employees has grown to more than a million, there has been an equal concern for using people efficiently in satisfying assignments. But it was not until the 1940s that specialists began to be hired to address customers' and employees' needs, and today Bell Laboratories employs hundreds of such specialists working in the behavioral sciences.

This article traces the major lines of evolution of applied behavioral science at Bell Laboratories and examines some of the forces that have shaped and continue to shape its growth, particularly the behavioral research organization. While there were some early applications elsewhere in the Bell System (the Western Electric Hawthorne studies conducted in the late 1920s and early 1930s, for example[1]), these are not treated here, except as they influenced events at Bell Laboratories.

II. SETTING THE STAGE

Human factors, human performance technology, and engineering psychology are a few of the many names used to describe the application of the behavioral sciences (psychology, sociology, anthropology, etc.) to the design of systems that involve people. While each of these names has its own connotations, human factors will be used here for simplicity to denote the entire discipline. Human factors traces back to World War II when American and British psychologists worked to match complex new weapons systems to the people who would employ them. Most human factors specialists, then and now, have been trained in psychology as specialists in learning, human performance, visual and auditory perception, motivation, social behavior, or decision making. Many have received training in systems analysis, industrial engineering or specifically in human factors engineering.

Human factors at Bell Laboratories has evolved along two paths which have only recently begun to come together. The first arose from the needs of telephone customers. The second arose in response to the needs and skills of employees, and led to a "pure" behavioral research organization as well as applied activities. This article describes the two applied paths and the path of behavioral research. To prevent getting lost in digressions, a chronological road map is provided in Fig. 1. References point to sources of additional information.

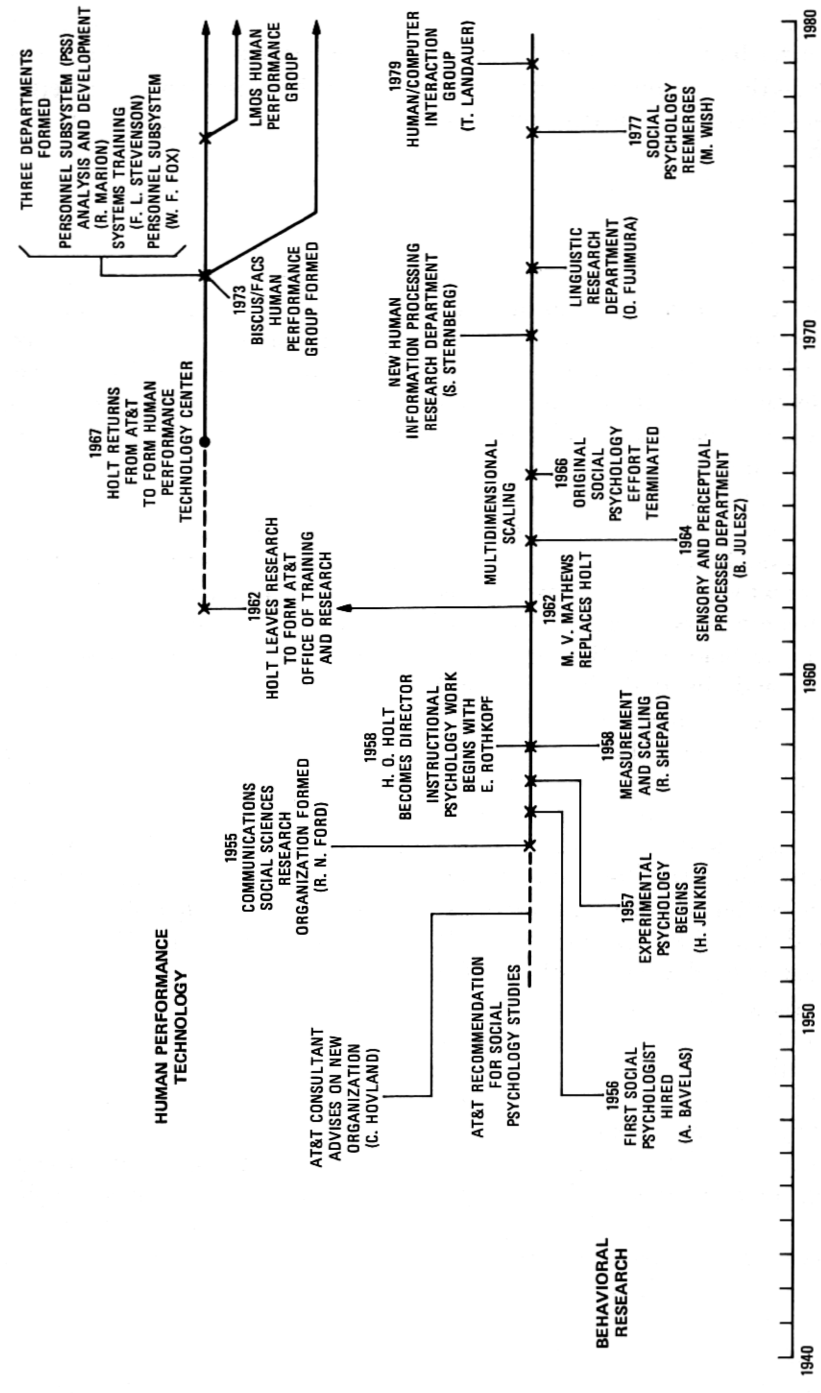
III. TELEPHONES AND CUSTOMERS

From the beginning of telephony, human factors decisions were being made about telephones. The first concern was to improve the quality and intelligibility of transmitted speech. Signalling was also important, especially as the number of users started to grow. Other, more subtle innovations also helped to make the telephone more useful and convenient. The invention of the switchhook meant users no longer had to remember to throw a switch after each call. More calls went through and many batteries were saved because when the receiver was "hung up" on the switchhook (it had to go somewhere), the job was done automatically. The one-piece telephone handset added portability and convenience, but only because designers calculated the dimensions of the heads of potential users to ensure that when the receiver was placed to the ear the microphone would be the right distance from the lips. At Bell Laboratories in the 1920s and 1930s, work was focused on designing better telephone sets by considering the physical dimensions of customers' heads and hands[2] and on understanding the properties of the human ear and voice so that electrical transducers and circuits could be improved.[3] It was in this second area, known as psychoacoustics, that behavioral science was formally instituted at Bell Laboratories.

The pioneering work in this field was conducted at Bell Laboratories under the leadership of Harvey Fletcher, Wilden A. Munson, and others,[4] but, by the 1940s, laboratories at other institutions were doing similar work for communications systems for the World War II effort. One such laboratory was managed by S. Smith Stevens, an experimental psychologist at Harvard. Fletcher was aware of the work in Stevens' lab and, in 1945, hired John E. Karlin from the list of notable psychologists who worked there.

Karlin worked only briefly in psychoacoustics before realizing that there were many other opportunities for valuable behavioral sciences work. On the basis of his observations, he made a proposal to his management for a broad program of customer studies. Shortly thereafter, the User Preference Research Department was formed, headed by Walter A. Shewhart (widely known for his work in quality control), and staffed by Karlin, Robert R. Riesz, and others. In 1951, Karlin succeeded Shewhart as head of the department.

Karlin's department continued to expand, performing a growing range of studies on user preference, telephone design, and network applications. Notable among these was a series of studies confirming people's inability to make reliable preference judgments about things they have never experienced. In one of these studies, customers were asked to judge their preference for handsets lighter than those already on their telephones. They all preferred the existing 18-ounce weight. But when they had the opportunity to handle handsets of various weights, they preferred ones that were much lighter. No one showed a preference for handsets as heavy as the standard one. Even 12-ounce handsets were heavier than people preferred. The customers could not predict their own preferences without having actual experience with the alternative choices. This rejection of armchair opinions set the


HUMAN PERFORMANCE TECHNOLOGY
BEHAVIORAL RESEARCH
1940
1950
1960
1970
1980
AT&T CONSULTANT ADVISES ON NEW ORGANIZATION (C. HOVLAND)
AT&T RECOMMENDATION FOR SOCIAL PSYCHOLOGY STUDIES
1956 FIRST SOCIAL PSYCHOLOGIST HIRED (A. BAVELAS)
1955 COMMUNICATIONS SOCIAL SCIENCES RESEARCH ORGANIZATION FORMED (R. N. FORD)
1957 EXPERIMENTAL PSYCHOLOGY BEGINS (H. JENKINS)
1958 H. O. HOLT BECOMES DIRECTOR
INSTRUCTIONAL PSYCHOLOGY WORK BEGINS WITH E. ROTHKOPF
1958 MEASUREMENT AND SCALING (R. SHEPARD)
1962 HOLT LEAVES RESEARCH TO FORM AT&T OFFICE OF TRAINING AND RESEARCH
1962 M. V. MATHEWS REPLACES HOLT
MULTIDIMENSIONAL SCALING
1964 SENSORY AND PERCEPTUAL PROCESSES DEPARTMENT (B. JULESZ)
1966 ORIGINAL SOCIAL PSYCHOLOGY EFFORT TERMINATED
1967 HOLT RETURNS FROM AT&T TO FORM HUMAN PERFORMANCE TECHNOLOGY CENTER
NEW HUMAN INFORMATION PROCESSING RESEARCH DEPARTMENT (S. STERNBERG)
1973 BISCUS/FACS HUMAN PERFORMANCE GROUP FORMED
THREE DEPARTMENTS FORMED
PERSONNEL SUBSYSTEM (PSS) ANALYSIS AND DEVELOPMENT (R. MARION)
SYSTEMS TRAINING (F. L. STEVENSON)
PERSONNEL SUBSYSTEM (W. F. FOX)
LINGUISTIC RESEARCH DEPARTMENT (O. FUJIMURA)
LMOS HUMAN PERFORMANCE GROUP
1977 SOCIAL PSYCHOLOGY REEMERGES (M. WISH)
1979 HUMAN/COMPUTER INTERACTION GROUP (T. LANDAUER)

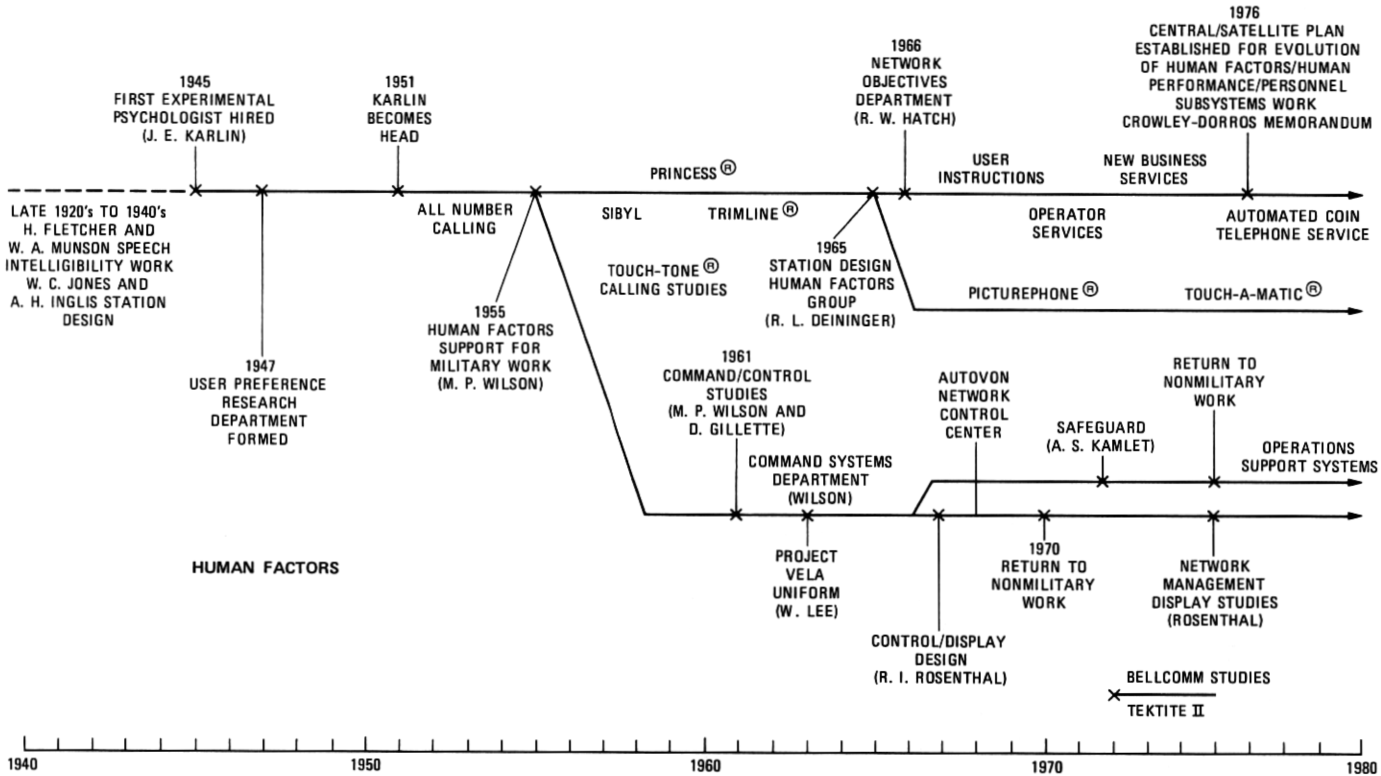


Fig. 1—Development of applied behavioral sciences organizations at Bell Laboratories.

tone for the activities in Karlin's department. The work was empirically based and it depended on providing people with product experience through laboratory simulation of alternatives.[5] At the root of this approach were the research methods and empirical orientation of experimental psychology.

The activities of Karlin's department in the early 1950s included studies comparing the use of seven-digit telephone numbers, termed "All Number Calling," with the two-letter, five-digit numbers in use at the time.[6] Both the telephone companies and customers were concerned that this change, designed to increase the number of available telephone numbers, would make dialing more of a problem. Laboratory studies showed that dialing performance was slightly faster with all digits, although long-term memory for numbers appeared to be slightly reduced. The small size of these effects led to the overall prediction, later confirmed, that All Number Calling would not impair customer dialing.[7] Other projects included design of dials for the 500-type telephone set (the little dots in the dial make dialing significantly faster, because they make it easier to see when the dial has stopped rotating from the previous number dialed). There were some futuristic studies demonstrating the feasibility, from the customers' viewpoint, of machine recognition of spoken digits (people with speech difficulties actually did better when they thought they were talking to a machine), and effects on customer perceptions of transmission quality of Time-Assigned Speech Interpolation (TASI)—a procedure for using the natural pauses in a telephone conversation to send bits of another conversation over the same line.

3.1 Military work

By the mid-1950s, word of the success of Karlin's enterprise had reached Bell Laboratories military development organization at Whippany, New Jersey, which was dealing with some complex control systems with significant human factors implications. At that organization's request, M. Paul Wilson was transferred from Karlin's department to organize a military human factors effort.

In complex systems, the division of responsibility between human operators and hardware called for some creative new analytic techniques. In a series of projects, each characterized by complex command-control systems—such as the XM3-H tactical radar: the Nike-Ajax, Nike-Hercules, and Nike Zeus missile systems; and the SAGE air defense system—Wilson and his colleagues developed this new approach to command/control systems. Two major characteristics were:

1. The emphasis on the human's role as decision maker in the system; and

2. The importance of information displays in conveying critical information required for correct and timely decisions.

Shortly thereafter, Wilson became head of the newly formed Command Systems Department, with a single human factors group supervised by W. L. Lee, another former Karlin employee. In the mid-1960s, this group was supervised by Robert I. Rosenthal, who extended the Wilson formulations to the design of control panels and display systems.

One of the interesting developments from this organization was the design of a network control center for the AUTOVON military communications system.[8] It was significant for two reasons. First, the human factors specialists conceived and designed the system rather than serving as consultants. Second, it introduced the concept of "exception reporting"—limiting displayed information to unusual or abnormal conditions that the system operator needs to know. As a result, system operators could focus on analyzing and solving problems, the most critical job and the one they could do best, while the computer's ability could be used to sort through large quantities of data to find abnormal conditions. This work exemplified the kinds of things the military human factors people could do for the Bell System. In fact, Rosenthal's group later designed the display system for the No. 4 Electronic Switching System (ESS) electronic toll switching machine using the principles established in military work.

Human factors studies had a significant part in notable government-sponsored projects that included the Safeguard Antiballistic Missile System and the Bellcomm company that was organized to provide technical support for NASA's Apollo project. Work on the antiballistic missile system began in 1967 with a human factors system evaluation at White-Sands, New Mexico, and continued with Arthur S. Kamlet's Command and Control Test Facility.[9] Human factors at Bellcomm was led by A. N. Kontaratos and focused on basic studies of problems of extended isolation and the dynamics of small technical groups. Some of this work, led by Nicolas Zill, used Tektite II, a small undersea laboratory where groups of scientists worked for extended periods. The Bellcomm effort was quite independent of other Bell System human factors activities.

By the mid-1970s most of the military work had been phased out at Bell Laboratories and the people had been reassigned to telecommunications projects, bringing with them the command/control system approach and experience in broader aspects of system design.

3.2 Sibyl, station equipment, and network applications

About the time Wilson left in the mid-1950s, the Karlin organization began development of a new, complex system for conducting simulation studies. This new system, called Sibyl, could be programmed to insert a wide range of network transmission and switching impairments into real telephone calls, record user-calling behavior, and record user-preference judgments.[10] Up to 100 Bell Laboratories volunteers could be connected to the system.

Sibyl's first use was in the evaluation of push-button vs. rotary dialing. It recorded dialing times, intervals between digits, and errors. In later applications, Sibyl varied factors such as dial tone delay, network blocking, or delay after dialing. Following each test call, Sibyl would call the user back to get a subjective evaluation. Users would dial one of several digits to express their opinions. Knowledge of customer opinions of various levels of service enabled designers to engineer the telephone network to satisfy customers without spending money on improvements that customers did not care about.

In 1966, Sibyl and other transmission quality activities were consolidated in a separate department under Richard W. Hatch. In 1970, psychologist Herman R. Silbiger was chosen to supervise a new human factors group in Hatch's department, specializing in subjective evaluation of network performance. Although it has undergone much modification Sibyl is still in use.[11]

Karlin's department also continued its work in customer instructions (design of flowchart dialing instructions for centrex users), transmission (defining the optimal parameters for trading off echo suppression with the listener's ability to interrupt, especially on long-delay satellite connections) and telephone set design. Particularly notable was Richard L. Deininger's work on the design of the *Touch-Tone** telephone. Most of the telephone set design work was carried out in cooperation with the Station Instrumentation Department (headed up by Alfred H. Inglis, and then Harris F. Hopkins), and the *Touch-Tone* telephone design was no exception. Deininger's responsibility was to determine the optimal parameters of the push-button dial, particularly the arrangement of the 10 buttons.

Deininger's studies led to the selection of the now ubiquitous *Touch-Tone* telephone dialing arrangement. His studies showed that it was strongly preferred over the now equally familiar calculator arrangement.[12]

Karlin's department also worked jointly with the Station Instrumentation people to design the *Trimline** telephone.[13] Early efforts to design a dial-in-handset telephone had been unsuccessful because the sets were uncomfortably bulky and unattractive. Invention of the space-saver dial by Charles F. Mattke enabled Lionel W. Mosing of Karlin's department to fashion a comfortable and attractive telephone

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* Trademark of AT&T.

of angular design, which he called the *Trimline* telephone. The final version of this set is now installed in millions of homes and appears on display in the design collection of New York's Museum of Modern Art. Much additional customer work was conducted primarily by engineers in the Station Instrumentation department. In 1964 this work was inherited by Leo Schenker's Telephone Station Studies Department, and Deininger was named to supervise the human factors work.

3.3 Station studies

For several years, Deininger's group was heavily involved in design and evaluation of the *Picturephone** visual telephone service, particularly aspects of image and quality and camera placement.[14] In 1970, after Deininger's untimely death, the group was managed by Gaber P. Torok, who worked to bring human factors work closer to the product-development activity, speeding up the development cycle by reducing the need for lengthy field testing and subsequent modifications.

In 1973, Murray J. Katz replaced Torok as supervisor of this group. Advancing technology, increasing customer demand for new products and the Bell System's entry into a more competitive environment all led to steadily increasing demand for the services of Katz's group. As a result of Katz's human factors evaluations, modifications were made to many new station products including the *Touch-a-matic*† repertory dialer (changes in labels, button characteristics, handset location), *Design Line*† decorator telephones (modifications to improve transmission characteristics, balance, and comfort), and *Dataphone*† II data communications terminal (design of maintenance panels and instructions). They also conducted extensive studies of the effects of mobile telephone usage on driving behavior[15] and worked jointly with Karlin's department on design of calling procedures for the Advanced Mobile Phone Service (AMPS).

Throughout the 1970s, station design work was changing from largely physical design ("knobs and dials" as it is sometimes called) to more procedural or feature-oriented work. Human factors specialists were addressing questions of how to implement new and complex features for residence and business customers. There was also a growing awareness of the role of human factors in identifying and satisfying customer needs. As a result, human factors was playing a larger role in the product design process. In the late 1970s, increasing demand for human factors support led to the formation of new groups in both station and business terminal development.

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* Registered service mark of AT&T.
† Trademark of AT&T.

3.4 Repositioning of human factors

In the mid-1960s, Karlin's department addressed a wide variety of customer issues such as the potentially disruptive effects of satellite delay on telephone conversations,[16] design of flowchart instructions, and diagnosis of network impairments. The problem with diagnosing network troubles was to correlate customer descriptions of problems with the problems, themselves. The solution was to create the same network impairments in the laboratory and ask test customers to describe the problems. Once the customer descriptions were tied to the difficulties, customer complaints could be used to pinpoint and repair the troubles.

Feasibility studies were also conducted to see whether business customers, if given computerized switching systems, could successfully program their own rearrangements and changes, e.g. reassignment of telephone numbers and features when employees moved offices. Such changes tend to occur frequently, and can be costly to both the customer and the telephone company if an installer must be dispatched to make them. It was found that, with the right user interface, customers could make their own changes with little difficulty, so long as they had a way to trace and correct their errors. An added benefit of this capability, which now exists in a number of Bell System customer switching systems, is that customers can make changes instantly, without having to wait for a telephone company employee to be dispatched.

The Human Factors Department had started in the research area and still viewed itself largely as an applied research department, but by 1970 it found itself in a development organization which was interested in increasing the direct, near-term payoff of human factors. Where the department had previously been organized around psychological topics (visual studies, interpersonal communication, etc.) it was asked to realign along Bell System lines (e.g., operator services, loop and outside plant). Along with this realignment, groups were given the responsibility for identifying and addressing existing human factors opportunities in their assigned areas and for contacting the appropriate organizations to discuss them.

During this same period there was a growing concern throughout Bell Laboratories about the impact of technology on customers and employees. While there is question as to cause and effect, the growing sensitivity to the impact of new products on customers and employees and the refocusing of human factors research were followed by remarkable growth in the human factors area. Within two years, Bell Laboratories "consumers" of human factors work were negotiating for long-term commitments of human factors support and were exploring the option of starting their own human factors efforts to guarantee adequate staffing of their work. By 1976, new human factors efforts had begun in both operator services and loop operations, and a director-level committee, conceived and led by Herbert M. Zydney, was assembled to plan an orderly expansion strategy.

The resultant plan, known as the Crowley-Dorros plan after the two executive directors who commissioned it—Thomas H. Crowley and Irwin Dorros—outlined a strategy for all human factors work at Bell Laboratories, including both customer and employee issues. The plan called for Karlin's department to focus on customer issues and to serve as a centralized resource to a growing number of satellite human factors groups that would be closely tied to specific development activities. The plan also viewed Karlin's department as a training ground for individuals to start such satellite groups.

As a case in point, an entire group, led by Edmund T. Klemmer, was transferred from Karlin's department to continue its work on business customer telephone systems. The group started with five people and an emphasis on procedures and instructions, and has since grown to two groups working on all aspects of business services, from customer needs studies to field introduction.[17]

In 1977, Karlin retired from Bell Laboratories after 32 years of service. (See Ref. 18 for Karlin's entertaining and insightful parting comments on the state of human factors at Bell Laboratories.) He was replaced by Charles B. Rubinstein, an electrical engineer from the Research Area who had done work in the psychophysics of color perception and visual thresholds. Shortly after Rubinstein arrived, Robert I. Rosenthal, who had supervised military control-display work under M. Paul Wilson and later worked on network management display systems, joined the department. In the late 1970s, the department's work included design of customer dialing procedures for AMPS,[19] and other new services that relied on recorded instructions to customers, such as the Voice Storage System,[20] the Automated Credit Card Service,[21] and Automated Coin Telephone Service (ACTS).[22] Each of these services depended on recorded instructions that could explain to customers what they were to do next. Computer-controlled voice recording and playback equipment enabled human factors people to conduct extensive laboratory simulations of these services, identifying deficiencies in procedures or instructions that led users to make mistakes. ACTS, for example, uses recorded messages to tell coin telephone customers how much money to deposit in the telephone. Laboratory and field studies were required to determine how long to wait for customers to deposit coins, and how often to prompt them for the remainder. Time limits had to be established to ensure that a human operator could come on the line to assist customers having difficulty. Customer satisfaction was also monitored to ensure that people would be comfortable with the less personal approach to coin service. As a result of the attention to human factors, ACTS has met with complete success. Customers have few difficulties with the service, and customer acceptance has been outstanding.

Recently a new focus has emerged. Bell Laboratories is developing new, complex products whose success will depend on the quality of the user interface. As a result, Rubinstein's department and other customer-oriented human factors groups are directing their efforts to human/computer interface issues.

IV. THE RESEARCH CONNECTION

4.1 Behavioral research beginnings

The second path in the evolution of applied behavioral sciences at Bell Laboratories began in the early 1950s at AT&T. The Personnel Relations department had been doing applied field work for some time, but had become frustrated by lack of knowledge of the social processes which influenced organizational success. Bolstered by a 1953 commitment by the AT&T Board of Directors to attracting and developing capable employees and first-rate leaders, Robert K. Greenleaf, Director of Personnel Research at AT&T, asked Bell Laboratories to start a new research group, the Communications Social Science Research Department.

The new department was led by Robert N. Ford who transferred from AT&T Personnel Relations, and its charter was to focus on problems of communication, organization, and leadership in small groups. The department was established at Bell Laboratories because BTL had experience in managing basic research and because of the stimulation other Bell Laboratories research activities could provide. Ford was to report directly to William O. Baker, then Vice President and Director of Research. To help get the effort under way, and to help recruit good research people, psychologist Carl I. Hovland was brought in from Yale as a consultant.[23]

The first person hired was Alex Bavelas, whose specialty was human motivation. Bavelas left after only a short time to join the Stanford faculty. Morton Deutsch, another social psychologist, was the second to arrive, and stayed for several years. Both Bavelas and Deutsch went on to establish major reputations in the academic world.

In addition to this venture in social psychology, efforts were begun in experimental and educational psychology. The experimental psychology activity began in 1957 with Herbert Jenkins (a disciple of Harvard behaviorist B. F. Skinner), who established a lab to study learning in pigeons. He was followed by Ernest Z. Rothkopf, an educational psychologist specializing in learning and instruction, and

Roger Shepard, another Harvard experimentalist recruited by Hovland and specializing in information processing.

In 1958, H. O. (Ollie) Holt, an educational psychologist who had been Deputy Director of George Washington University's Human Resources Research Office (HumRRO), took over operation of the center from Ford, who returned to AT&T to pursue his interest in job enrichment. Holt immediately began to develop a plan for entering the new field of programmed instruction. He worked primarily with consultants such as Hovland, Tom Gilbert from the University of Tennessee, and Skinner, himself. Given the massive sums of money spent by the Bell System in training its employees, the payoff from such work was potentially enormous.

This work showed such promise that Holt was transferred to AT&T in 1962 to head the Office of Training Research which had the job of implementing individualized instructional technology throughout the Bell System.[24] It is Holt who provides the ultimate connection to applied behavioral sciences, so the path of applied work follows him. But the Behavioral Research organization, with its worldwide reputation for excellence, deserves a short history of its own.

4.2 Basic research in psychology

Research on the social psychology of group interaction was the initial focus of the Behavioral Research Center. The problems ranged over issues of cooperation, influence, and social perception and the communicative behavior entailed. The amount of work in these areas gradually diminished, and the original social psychologists had all left by 1966. However, social psychology reemerged from 1978 to 1982 with a new central concern in interpersonal communications. The issues now involved the reasons why people choose one communication modality over another (e.g., voice-only versus face-to-face) and the consequences. This work was headed by Myron Wish, whose involvement in a study of the use of *Picturephone* visual telephone service sparked renewed interest in such matters.

There were other topics that, like group psychology, were pursued only for limited periods. Most notable of these were efforts in auditory neurophysiology between 1964 and 1968, and the psycholinguistics of grammar from 1963 to 1971.

By contrast, the research in human learning and instructional technology, which was under way by 1958, has continued, expanded, and diversified up to the present. For example, Ernst Z. Rothkopf and Lawrence T. Frase conducted a large number of experiments on the effect of adjunct questions on learning from text. These not only showed practical means for greatly improving instruction, but also deepened understanding of the active role of learners in studying.

Pioneering studies of the role of organization (e.g., the placement of repetitions of information) and surface structure (e.g., word choice) in learning from written prose led, among other things, to the development of computer methods for determining text difficulty (see Ref. 25). The fundamental work on instructional materials contributed to the development of widely used editorial aids such as the *UNIX** Writer's Workbench software (see Refs. 26, 27, and 28), and AT&T's Training Development Standards, a guide used in course development throughout the Bell System.

Two other areas that have continued since their establishment in the 1950s are human information processing and psychological measurement. Human information processing research at Bell Laboratories goes at least as far back as the work of John R. Pierce and John Karlin on estimating human channel capacities[29]; but as a continuous institutional activity, it can be dated from George Sperling's discovery and description of a visual memory that stores, for about a second, considerably more information than can be read out intact.[30] Saul Sternberg's elegant work on rapid scanning of active symbolic memories followed shortly.[31] He and his collaborators also made important advances in the study of temporal order judgments, and most recently, the control of rapid action sequences in speech and typing.

The Human Information-Processing Research Department, headed by Sternberg since 1970, has also been the home of pioneering work and major contributions in many other parts of cognitive psychology: verbal learning, picture memory, semantic memory, word recognition, visual perception, motor control (see article by Rosenbaum,[32] this issue) and adaptation, attention, and reasoning. In 1979 a new group was formed under Tom K. Landauer's leadership to explore cognitive problems in human use of computers. Its work has centered on issues in interactive language design and the proper representation of human knowledge to assure mutual understanding of the messages passed between machines and users (see article by Furnas et al., this issue).[33]

Measurement and scaling were among Roger Shepard's many interests when he first joined the Labs in 1958. Along with Joseph B. Kruskal, he developed the first effective methods for nonmetric multidimensional scaling of human similarity judgments.[34] There has been an almost continuous development of new theory, computational methods, and applications ever since. For example, in recent years J. Douglas Carroll and his collaborators have developed the method of individual differences multidimensional scaling, a method that identifies psychological dimensions by their orderly variations in perceptual importance as reflected in judgments of object similarity by

* Trademark of Bell Laboratories.

different people. These methods have found extensive use in such diverse areas as marketing research and telephone tone-ringer design.[35]

Over the last 20 years, the Research division has also sponsored a variety of other efforts with behavioral science content. There has been much noteworthy work in vision, color vision, and visual perception under the leadership of Bela Julesz. One example is his own invention and use of random-dot stereograms to demonstrate the independence of depth perception from object recognition and his explorations of fundamental mechanisms of perceptual processing. (See Ref. 36.) Speech analysis and evaluation research was conducted in a department headed by Peter B. Denes, and elsewhere. Linguistic research has been under way since 1971 in a department led by Osamu Fujimura, who himself has studied the production of motor action sequences, an interest shared recently by several other investigators. Finally, mention should be made of the important fundamental analyses of speech acoustics and perception carried out by James F. Flanagan's Acoustics Research Department and Manfred R. Schroeder's Hearing and Speech Synthesis Research Department.

Over the years there has been fairly regular communication between the behavioral research groups and the applied behavioral scientists. There have been many seminar series attended by both, frequent consultations and visits, and since 1977 a Bell Laboratories-wide convention of all behavioral scientists every 18 months. There are occasional cross-assignments of months or a year's duration, and a steady trickle—averaging perhaps one per year—of people moving from one kind of work to the other; most movement has been from the smaller population of research to the larger applied areas. There has been a great deal of useful stimulation in both directions.

5. HUMAN PERFORMANCE TECHNOLOGY

5.1 Human performance and employee systems

The Bell operating telephone companies, with their huge billing and accounting systems, were among the first businesses to make widespread use of computers in their operations. During the late 1950s and early 1960s, computers became an integral part of their accounting operations. While the development of computerized systems had resulted in substantial savings and better service, there had also been some difficulties, largely because of a mismatch between such systems and the employees who worked with them. The initial solution to these problems was thought to be in better training, so Ollie Holt and Harry A. Shoemaker of AT&T's Office of Training Research were asked to get involved.

At about the same time, it became clear that centralized planning and development of such systems would be more efficient and would ensure system-wide standards. Finally, in 1967, largely through the efforts of AT&T Assistant Vice President Bruce Warner, the Business Information Systems Programs (BISP) organization was created from parts of the AT&T Planning Department. Holt was asked to join the new organization as Director of the Human Performance Technology Center. After several months Holt moved, along with the whole BISP organization, to Bell Laboratories.

Holt brought with him several of his former staff members including Fred L. Stevenson, a training specialist originally with Pacific Telephone. The group's early experience showed that training was not going to be a universal cure for design deficiencies, so they set about to develop an organization that could influence system design.

One of the first additions to Holt's staff was Bill F. Fox, a psychologist with human factors training and experience. Fox had worked with HumRRo and Lockheed Aircraft. Fox's assignments were to adapt military experience with large hardware systems to the development of large software systems and to build a team of psychologists to do the work.

Holt also recruited Ralph Marion, a psychologist and personnel specialist from Southern Bell. Marion's assignment was to develop documentation that would enable system designers to do as much of the job as possible, themselves. Together, they continued to recruit both operations people from the Telephone Companies and behavioral scientists. By the end of 1970 they numbered over 40.

They called their work personnel subsystems (PSS), a phrase with military roots, rather than human factors roots, a term which they felt referred narrowly to control-display design rather than systems concerns. In later years, the name was changed to human performance engineering to more clearly characterize the major objective. In 1970 the Human Performance Center was organized into three departments. Fox's Personnel Subsystems Department provided direct consultation and support to projects and worked to develop PSS technology; Marion's Personnel Subsystem Analysis and Development Department refined the technology and documented it; and Stevenson's Systems Training Department trained others in the use of the technology.[37] This organization worked well, and the technology, documentation, and training it developed are in use in information systems organizations throughout the Bell System.[38]

In many ways Fox's department was the BISP homologue of John Karlin's Human Factors Department. Both were staffed primarily by behavioral science professionals who provided consultation to system designers and developers, and both experienced significant successes in the 1970s. The primary difference between them was in their way of approaching the job. The Karlin approach was to solve each design problem empirically; the Fox approach was to assist the project in utilizing the PSS technology to solve its own problems. In each case, the approach was appropriate to the problem—Karlin dealt with a number of specific problems, each with significant implications for many telephone users, while Fox was faced with vast needs for job requirements, training, etc., which could not have been efficiently done by behavioral scientists alone.

Typically, Fox's people would be assigned to projects as technical advisors to the project people who had design responsibility. For the most part, these project people were telephone company people on rotational assignment who had no prior experience with PSS. These people used the documentation produced by Marion's department and were trained in Stevenson's. The success of this work and the desire of the project organizations to have complete responsibility and guaranteed support led to the spin-off of separate PSS groups. In 1973, George A. Schweickert and Mort H. Kahn left Holt's center to form groups in Business Information System Customer Service Facilities Assignment and Control System (BISCUS/FACS).[39] Shortly after, the organization involved in the Trunks Integrated Record Keeping System (TIRKS) formed its own group under Roy J. Porterfield.[40] Barry K. Schwartz also left to work on systems engineering for network administration systems and later formed a group to work on the Total Network Data System (TNDS). By 1976, most of the projects which had started as part of BISP had their own groups of specialists, and few of Fox's people were assigned to specific BISP projects. Instead, many of them were working on user aspects of Operations Support Systems (OSSs) developed elsewhere in Bell Laboratories to aid in the operation and maintenance of various aspects of the Bell System network. The first of these to come to Fox's attention was the Loop Maintenance Operations System (LMOS).[41] By 1976, one of Fox's groups, led by Grace H. Leonard, had transferred to the LMOS organization.

In late 1976, the Crowley-Dorros plan—which had called for Karlin's department to serve as a centralized customer human factors resource—named Fox's department as the resource for employee human performance activities, serving as both consultants and the source of trained people to start satellite groups. Since that time, a number of new groups have been created in LMOS and other OSS projects, employing the methods and procedures developed in the late 1960s by Holt and Fox and their colleagues.

The growth of groups and activities has continued unabated through the late 1970s and early 1980s. Again the increasing complexity resulting from new technology has placed new burdens on employees and provided new opportunities and challenges for behavioral scientists.

VI. SUCCESSES. . .AND CHALLENGES

Measured by its impact and its growth, human factors has had notable success at Bell Laboratories, particularly since the early 1970s. Both the empirical orientation of Karlin and the technological approach of Holt and Fox have had significant impact. Why has human factors been a success at Bell Laboratories when external efforts in both industry and the military have fared less well? There are several possible explanations.

First, the philosophy and structure of the Bell System have been important. Its strong tradition of good customer service implies a need to give explicit consideration in the design process to the customers. The vertical integration of the system encouraged Bell Laboratories to design products and systems which are not only attractive at time of purchase, but which also continue to perform cost-effectively. In such an environment, design goals such as minimizing customer errors or increasing employee efficiency and decreasing turnover become more important. The numbers of employees and customers potentially affected by new designs also multiply the benefits that result from human factors.

The growing complexity of technology has also played a significant role. While technological advances have provided many new products and services, these products and services have become more complicated for the customers who use them and the employees who install and maintain them. Computerization of internal operations has led to substantial complications in some aspects of employee jobs. Human factors specialists have the responsibility to minimize the problems imposed by this complexity and to make new products and services "friendlier," more useful, and more attractive.

In addition to the technical challenges of the information age, the major challenge to human factors in the 1980s is to continue to expand its role in the design/development process. This implies both applying existing human factors skills in new areas and developing new skills which complement existing ones. For example, extension of human factors methods to the definition of customer needs for new products will lead to earlier and more influential involvement in product design. Development of systems engineering skills will result in improved communication with engineers and greater influence over design decisions. Specialized knowledge in electrical engineering and computer science will enable evaluation of the trade-offs that must often be made between human factors and hardware and software constraints. With a broader view of its responsibilities, human factors should continue to grow and contribute at Bell Laboratories.

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AUTHOR

Bruce L. Hanson, B.A. (Psychology), Johns Hopkins University; M.S., Ph.D. (Psychology), Pennsylvania State University; Bell Laboratories, 1972–1982; American Bell, 1983—. After joining Bell Laboratories in 1972, Mr. Hanson worked on the human factors aspects of central office craft jobs. He also has helped evaluate hardware, instructions, and procedures for outside plant craftspeople, engineers, and managers, and he has studied human factors in new services such as the Advanced Mobile Phone Service. In 1977, he became Supervisor of the Network Systems group, designing user interfaces for voice storage services. Before he assumed his present position, he also supervised studies of customer aspects of billing, PhoneCenter® and Business Office service. Mr. Hanson is currently Supervisor of the Customer Interfaces Group in the Product Family Services Planning Department and ABI. This group is engaged in the design and planning of user-computer interfaces for ABI products. Member, Human Factors Society, the American Psychologicpl Association, and Sigma Xi.